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C-shaped root canal systems in the bilateral mandibular first molars: a case report and literature review

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Abstract

Background Mandibular first molars typically exhibit complex root and canal anatomy. A thorough understanding of their morphological variations is crucial for endodontists to achieve successful root canal treatment. A C-shaped root canal system is a unique anatomical variation characterized by a C-shaped or semi-circular cross-sectional morphology, observed predominantly in mandibular second molars. The prevalence rate of the C-shaped root canal system is approximately 2.7–48.7% in the mandibular second molar, while the condition is rarely seen in mandibular first molars, particularly in bilateral cases.

Case presentation This report details an uncommon case of a C-shaped root canal system in bilateral mandibular first molars: the right molar exhibited a fused root with two separate mesial and two distal canals, while the left molar displayed a single oval mesial canal and a semicolon-shaped distal canal. To our knowledge, this is the first report of the presence of four separate canals within a fused C-shaped root in the mandibular first molar.

Conclusions While C-shaped root variations are detected in mandibular first molars, a thorough knowledge of normal root canal anatomy and associated variations presents a significant challenge for clinicians in terms of successful endodontic treatment.

Keywords Mandibular first molar, C-shaped root canal system, Root canal treatment, CBCT

Background

Mandibular first molars are the earliest permanent teeth that emerge, generally appearing at ages 6–7. These teeth are frequently affected by pulp or periapical diseases, often requiring root canal treatment. A thorough knowledge of the variability in root canal systems is essential for accurate endodontic diagnosis and treatment. Mandibular first molars exhibit highly complex root and canal morphologies, typically presenting with a well-defined mesial root exhibiting two canals as well as a well-defined distal root that has one or two canals [1]. Variations in the root canal system include configurations with five, six, or even seven canals, middle mesial canals, middle distal canals, four mesial root canals, or four distal root canals [2–4]. These anatomical variations are strongly associated with factors such as ethnicity, age, gender, and research strategies [5].

The C-shaped root canal system is a unique anatomical variation in root canal morphology, with the term "C-shaped" describing the cross-sectional appearance of the canal, resembling the letter "C". This configuration results from incomplete fusion of the root walls during

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tooth development and is characterized by a fin-like or web-like connection between the root canals, resulting in a continuous, groove-like structure varying in shape and complexity [6].The complex anatomy of C-shaped canals presents significant challenges for successful endodontic treatment. Their irregular shape makes thorough cleaning, shaping, and filling difficult, often leading to complications such as missed canals, inadequate disinfection, or incomplete obturation [7, 8]. Missed canals act as reservoirs for primary bacterial infections or locations for secondary infections within the canal systems; it has been found that teeth with at least one missed canal exhibited a 3.658 times greater probability of developing a periapical lesion [9]. C-shaped canal systems are also characterized by inherently thinner dentin walls, making them more prone to strip perforation and root fracture [10]. A thorough identification of variations in root canal structures and the complete elimination of infection within the root canal system are critically important to prevent the failure of root canal treatment.

C-shaped root canal systems are more commonly observed in mandibular second molars, with an incidence as high as 44.5%, with variations across different populations. In a Korean population, the prevalence was reported to be 40%, with a higher occurrence in females (47%) compared to males (32%) [6, 11]. Among mandibular second molars, C-shaped roots are sometimes considered a normal anatomical variation. However, the reported rates of C-shaped variations among mandibular first molars range markedly from 0.19 to 24.33% [12–16] (Table 1). Studies often describe lower incidence rates, including 0.39% in a Thai population, 1.7% in an Iranian population, and 2.39% in a Brazilian subpopulation [17–19]. Moreover, an in vivo cone-beam computed tomography (CBCT) analysis detected no C-shaped canals among 290 mandibular first molars in a Saudi population [20]. Dental practitioners often overlook this anatomical

Table 1 Prevalence of C-shaped Canal configuration in mandibular first molars

Investigators	No. of teeth	No. of C-shapes	Prevalence(%)	Gender differnce	Common type	Race	Type of study	Method of study
Martins et al. (2016) [31]	695	4	0.6	Not stated	Not stated	Portuguese	In vivo	CBCT
Shemesh et al. (2017) [41]	1229	2	0.16	Not stated	Not stated	Israel	In vivo	CBCT
Alfawaz et al. (2019) [12]	529	1	0.19	Not stated	Not stated	Saudi Arabian	In vivo	CBCT
Vaz de Azevedo et al. (2019) [34]	379	91	24.01	Female	C1 (89.01%)	Brazilian	In vivo	CBCT
Hiran et al. (2021) [18]	256	1	0.39	Not stated	Not stated	Thai	In vivo	CBCT
Nejaim et al. (2020) [19]	710	17	2.39	Female	C1	Brazilian	Invivo	CBCT
Kenawi et al. (2022) [15]	283	16	5.7	Not stated	C1 (87.5%)	Saudi Arabian	In vivo	CBCT
Feghali et al. (2022) [40]	296	3	1.01	Not stated	C1	Lebanese	In vivo	CBCT
Chen et al. (2022) [48]	2000	11	0.55	No difference	Not stated	Eastern Chinese	In vivo	CBCT
Mashyakhy et al. (2020) [20]	290	0	0	Not stated	Not stated	Saudi Arabian	In vivo	CBCT
Alnowailaty et al. (2022) [16]	600	146	24.33	No difference	C1(coronal) C2(middle) C3(apical)	Saudi Arabian	In vivo	CBCT
Nouroloyouni et al. (2023) [32]	248	11	4.4	Male	C2	Iranian	In vivo	CBCT
Shekarian et al. (2023) [17]	291	5	1.7	Not stated	Not stated	Iranian	In vivo	CBCT
Alazemi et al. (2023) [14]	651	43	6.6	Females	C3	Kuwaiti	In vivo	CBCT
Singh et al. (2024) [33]	99	3	6	Not stated	Not stated	Rohilkhand	In vitro	Dentascan
Armenta et al. (2024) [13]	1057	2	0.2	Female	C2	Mexico	In vivo	CBCT

variation, potentially leading to misdiagnosis and inappropriate treatment.

Fan et al. classified the C-shaped canal system into five types based on cross-sectional morphology [21]: (i) C1: An uninterrupted "C" without any separation or division; (ii) C2: A semicolon-shaped canal due to a discontinuity in the "C," where either angle of the canal cross-section is greater than 60°; (iii) C3: Two (C3c) or three (C3d) separate canals, with both angles of the canal cross-section being less than 60°; C4: A single round or ovoid canal cross-section; and C5: No evident canal lumen (typically only evident near the apex). Among those categories, C1 with one canal is the most common type, followed C2 with two canals and C4 with one canal. To the best of our knowledge, a mandibular first molar with four separate canals in a fused C-shaped root has not been previously reported. This case report discusses an instance of rare anatomical variations of the C-shaped root canal systems in the bilateral mandibular first molars. The right molar exhibited a unique configuration consisting of four separate canals within a single fused C-shaped root, as confirmed by CBCT imaging.

Case presentation

A 35-year-old male patient presented to the Department of Endodontics at Liaocheng People's Hospital (Liaocheng, Shandong, China) with spontaneous lower right posterior region pain. The patient reported intermittent pain in his right mandibular first molar for nearly two months, which had intensified over the past five days. A filling had been placed in the affected tooth five years earlier for the treatment of caries. Intraoral examination revealed an amalgam filling on the occlusal surface and deep secondary caries on the mesial side of the right mandibular first molar. The tooth exhibited an abnormal appearance, with a longer lingual marginal ridge and a shorter buccal ridge. It was tender to percussion, sensitive to thermal stimuli, and showed a delayed response to electric pulp testing. No periodontal lesions were detected. A preoperative periapical radiograph revealed mesial-occlusal radiolucency extending to the pulp space and a widened periodontal ligament (Fig. 1a). The patient was diagnosed with symptomatic irreversible pulpitis in the right mandibular first molar, and nonsurgical root canal therapy was planned. After explaining the treatment plan, informed consent was obtained from the patient. Local anesthesia was administered using 4% articaine (1:100,000 epinephrine). After caries excavation, the tooth was temporarily restored with intermediate restorative material (IRM; L. D. Caulk Co., DE, USA) to address the mesial defect. Rubber dam isolation was used to prepare an endodontic access cavity. The pulp chamber was localized, revealing a fused C-shaped canal (Fig. 1b). Under a dental operating microscope (Carl Zeiss, Oberkochen, Germany), four distinct canal orifices were identified: two mesial and two distal, with evidence of buccal merging (Fig. 1c). Given the curvature and narrowness of the canals, small-sized instruments (06#, 08#, and10# C-files) were used to negotiate the canals, to establish the glide path and ensure patency. The working length was determined using an electronic apex locator (Raypex 6, VDW, Munich, Germany). Chemomechanical preparation was performed using pre-bendable, controlled-memory NITI files (PLEX-V, Orodeka Srl, China), up to size 25, 0.06 taper, following copious irrigation using a 3% sodium hypochlorite solution and 17% EDTA. Sonic activation was used to enhance the disinfection to ensure thorough debridement of the intricate anatomy. A CBCT scan confirmed the unusual morphology: a fused mesial and a separate distal canal in the coronal third with canal cross-sectional angles less than 60° (C3c), two mesial and two distal canals in the middle third (C3?), and individual mesial and distal canals in the apical third (C3c) (Fig. 1d-g). The fused C-shaped root extended buccally to the apex, as corroborated by the three-dimensional (3D) reconstruction of the CBCT images (Fig. 2a, b). After one week of intracanal medication with calcium hydroxide, the patient was asymptomatic, and the canals were obturated using the single-cone technique with gutta-percha and iRoot SP, a premixed calcium silicate-based bioceramic sealer (Fig. 1h-j). The access cavity was restored with posterior composite resin. Postoperative radiographs showed well-obturated canals with four distinct root canals (Fig. 1k). At the 6-month follow-up, radiography revealed no radiolucent lesions, and the patient remained asymptomatic (Fig. 1l).

Interestingly, the preoperative X-ray examination had incidentally revealed an abnormal fused root with a well-circumscribed radiolucent lesion in the left mandibular first molar (Fig. 3a). During the intraoral examination, an amalgam filling and secondary caries were observed on the occlusal surface, while the tooth showed no significant percussion pain and no response to pulp vitality testing. CBCT examination confirmed the diagnosis of chronic apical periodontitis and C-shaped canal variation (Fig. 4a, b). Unlike the right molar, the left molar exhibited a semicolon-shaped cross-section, with an oval mesial canal and an elongated, narrow distal canal (cross-sectional angle approximately 80°), classified as type C2 (Fig. 3b-g). After a comprehensive explanation of the pathological status and the associated risks, the patient consented to proceed with root canal therapy. An informed consent form was signed and the same treatment procedure was conducted. With the assistance of a dental operating microscope, an access cavity was prepared and a C-shaped pulp chamber floor was presented with a separate mesiolingual orifice and fused mesiobuccal and distal orifices in a narrow slit-like configuration

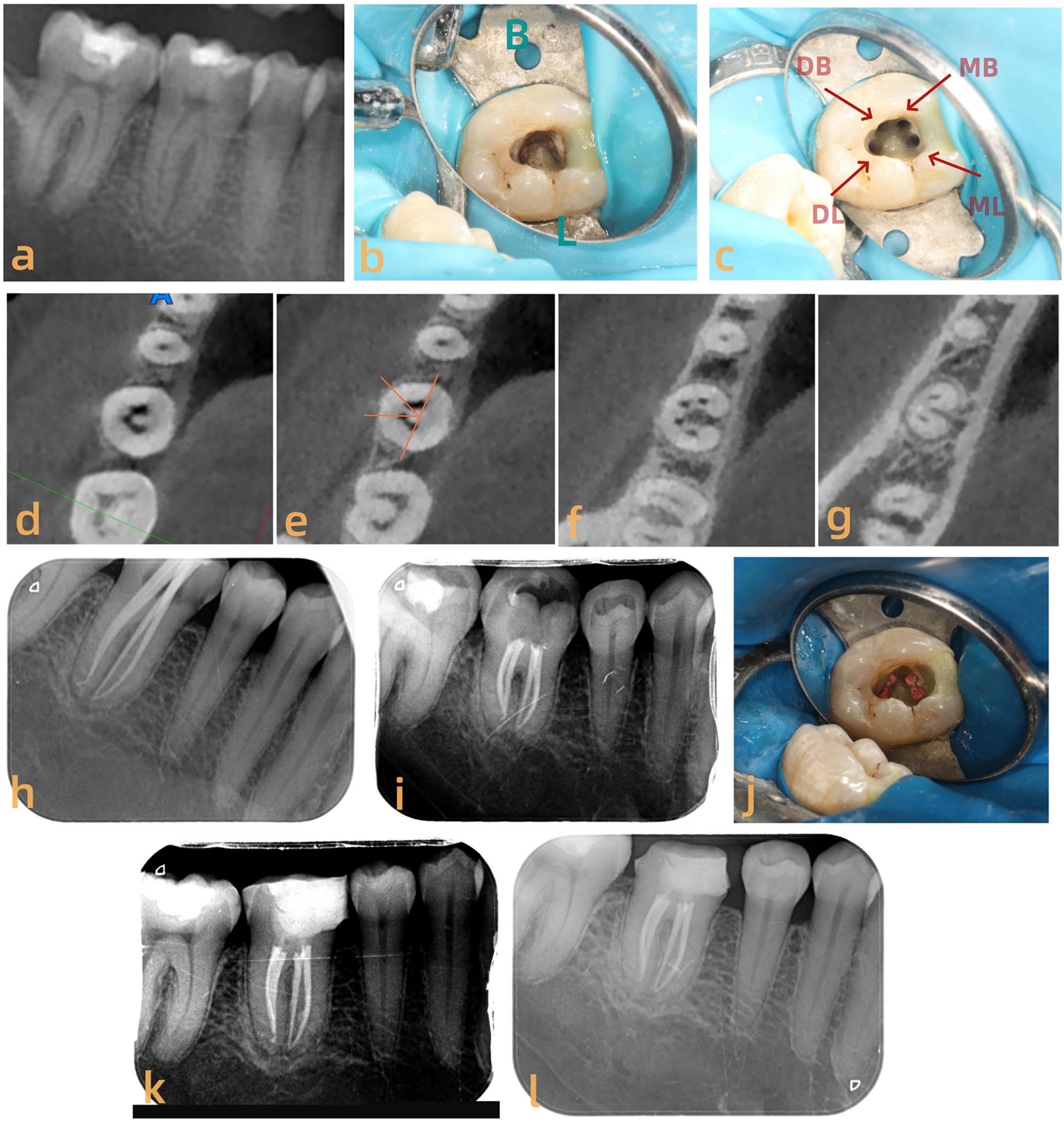

Fig. 1 Images of the right mandibular first molar. (**a**). Preoperative radiograph showed a mesio-occlusal radiolucency approaching the pulp space. (**b**). Clinical view of the C-shaped orifice on the pulp floor (**B**: buccal, L:lingual). (**c**). Clinical view of the access cavity preparation showing four distinct root canal orifices (red arrow; DM: mesiobuccal, ML: mesiolingual, DB: distobuccal, DL: distolingual). (**d**). Axial CBCT section from the pulp chamber: C-shaped orifice. (**e**). Axial CBCT section from the coronal third: two canals separately, either canal cross-sectional angles less than 60° (C3c). (**f**). Axial CBCT section from the middle third: four canals separately (C3?). (**g**). Axial CBCT section from the apical third: one fused mesial canal and one fused distal canal (C3c). (**h**). Periapical radiography for working length determination with gutta-percha (size 25, 06 taper) in four separate canals. (**i**). Postoperative radiograph for root obturation. (**j**). Intraoral photograph showing four separate canals after root obtruation. (**k**). Postoperative radiograph with resin composite restoration. (**l**). Six-month follow-up radiograph indicates the health periapical tissue

(Fig. 3b, c). During the root canal preparation, it was discovered that the mesial canal was calcified in the middle and apical thirds, and could not be effectively negotiated and sealed, with the axial CBCT view also revealing no visible pathway (Fig. 3e-g). Following routine root canal preparation and interappointment medication, the canals were obturated using gutta-percha and iRoot SP (Fig. 3h). Postoperative radiographs confirmed the root sealing(Fig. 3i). A 6-month follow-up revealed a reduced radiolucent lesion and evidence of bone healing on periapical radiography (Fig. 3j), the patient was asymptomatic. 3D reconstruction views also confirmed the presence of the fused C-shaped root (Fig. 2c, d).

Discussion and conclusion

A thorough grasp of normal root canal anatomy and associated variations presents a significant challenge for clinicians aiming to achieve effective root canal cleaning and shaping, which is essential for successful endodontic therapy [22]. The mandibular first molar is known for its complex anatomical variability. Typically, it has two separate roots: the mesial root generally contains two canals, while the distal root often features a round or elliptical canal. In some cases, three-rooted morphology with a distolingual root was also observed [23]. The number of root canals varies widely, with reports of both mesial and distal roots containing three canals each, or a total of 5–6 canals in the tooth. The presence of a middle mesial canal has been shown to be significantly associated with an additional distal canal [24]. Banode et al. reported a rare anatomical variation in a mandibular first molar with seven canals across three roots: three canals in the mesial root and four in the distal roots, with the distolingual and mid-distal canals sharing the same orifice [4].

C-shaped root variations are most commonly detected in mandibular second molars, with a prevalence of 42.2% in a Thai population, 30.33% in a Saudi Arabian cohort, and 14.32% in a Brazilian subpopulation [17–19]. The incidence of C-shaped canals ranges from 2.7 to 48.7% for mandibular second molars, and this morphology is

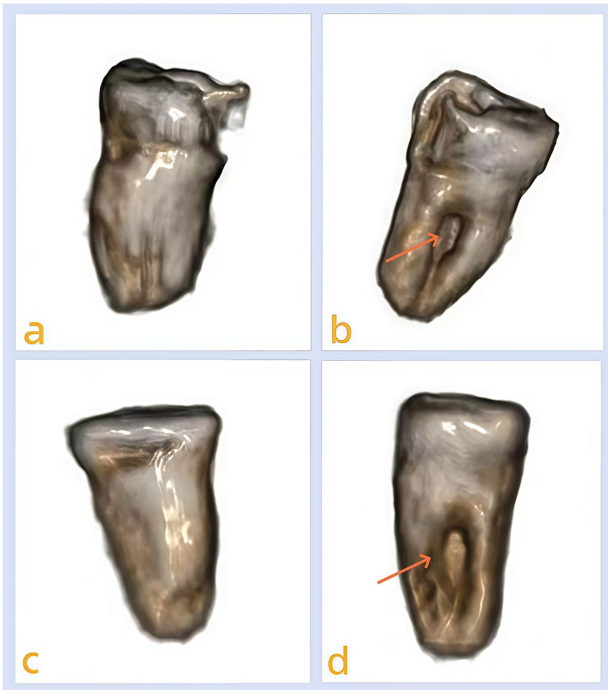

Fig. 2 3D reconstruction views. (**a**, **b**). 3D reconstruction for the right mandibular moral. (**a**). A fused root showed in the buccal side. (**b**). A longitudinal groove (orange arrow) showed in the lingual side. (**c**, **d**). 3D reconstruction for the left mandibular moral. (**a**). A fused root showed in the buccal side. (**d**). A longitudinal groove (orange arrow) showed in the lingual side

Fig. 3 Images of the left mandibular first molar. (**a**). Preoperative radiograph showed an fused root with a well-circumscribed radiolucent lesion. (**b**). Clinical view of the C-shaped orifice on the pulp floor (**B**: buccal, L:lingual). (**c**). An elongated narrow orifice (red arrow) form the distal canal. (**d**). Axial CBCT section from the pulp chamber: C-shaped orifice. (**e**). Axial CBCT section from the coronal third: an ovalshaped single canal in the mesial and an elongated narrow canal (angle of canal cross-section more than 60°) in the distal (C2). (**f**). Axial CBCT section from the middle third: an elongated narrow canal in the distal root (C2). (**g**). Axial CBCT section from the apical third: one canal in the mesial and one in the distal (C3c). (**h**). Intraoral photograph showing C-shaped canal after root obtruation. (**i**). Postoperative radiograph for root obturation. (**i**). Six month follow-up radiograph indicated the healed periapical tissue

Fig. 4 CBCT imaging for the mandibular molars. (**a**). Axial CBCT section from the coronal one-third. (**b**). Axial CBCT section from the middle one-third

often considered normal for these teeth [25, 26]. However, emerging evidence suggests that this anatomical configuration may occur in diverse tooth types. Recent systematic reviews have indicated that mandibular premolars exhibit a 2.1–6.3% prevalence of C-shaped roots [20, 27], with maxillary molars demonstrate 0.5–3.8% occurrence rates depending on ethnic background [28]. Particularly noteworthy is the recent multicenter study by Lin et al. [29], which analyzed 12,487 CBCT scans and identified C-shaped morphology in 0.9% of maxillary first molars and 1.7% of mandibular first premolars in Chinese populations. This highlights the importance of maintaining vigilance for C-shaped variations beyond the classical mandibular second molar presentation. Although less common, C-shaped root canal systems have also been reported in mandibular first molars (Table 1). In a study of 695 mandibular first molars in 792 Portuguese Caucasian patients, analyzed using both routine panoramic radiographs and presurgical CBCT exams, only 0.6% exhibited C-shaped configurations. Fused roots were significantly more likely to have C-shaped canals compared to non-fused roots [30]. Similarly, in a CBCT study, Sirawut reported the 0.39% prevalence of C-shaped canals among mandibular first molars in a Mongoloid population [18]. Higher prevalence rates of 2.39%, 4.4% and 6% have also been reported, particularly in radiographic fused root types, where the odds of C-shaped canals in fused roots are 17.2 times higher than in non-fused roots [19, 3132]. The highest incidences of C-shaped mandibular first molar canals were reported as 24.1% in Brazilian individuals and 24.33% in a Saudi Arabian population. Notably, the incidence is significantly higher in females and in the coronal portion of the roots [16, 33]. Variations in incidence may result from differences in evaluation methods, the use of CBCT, and sample size. CBCT provides more detailed anatomical information, enhances the accuracy of canal morphology assessment, and enables the evaluation of canal configurations

Table 2 Summary of case reports with C-shaped canals in mandibular first molars

Reference	Age	Gender	No. of canals	Pulp chamber anatomies	Location of the C-shaped canal	Type	Radiological Examination
Helvacioglu-Yigit (2015) [47]	20	Female	3	Continuous C-shaped	A mesial lingual canal; Fused mesiobuccal and distal C-shaped canal	C2	Panoramic radiograph Periapical radiograph
Wu et al. (2018) [48] Case1	28	Female	2	Continuous C-shaped	A mesial lingual canal; Fused mesiobuccal and distal C-shaped canal	C2	Periapical radiograph CBCT
Wu et al. (2018) [48] Case2	34	Male	2	Three orifices	Buccally deviated II-I C-shaped canal; A separate distolingual canal	Not stated	Periapical radiograph CBCT
Ravi et al. (2024) [37]	28	Male	4	Four distinct orifices	Fused mesiolingual, distolingual and distobuccal canals A separate mesiobuccal canal	Not stated	Panoramic radiograph Periapical radiograph CBCT
Our report	35	Male	4	Continuous C-shaped	Fused two orifices (cervial) Four separate canals (Middle) Fused Mesiolingual and mesiobuccal canals (apical)	C3	Periapical radiograph CBCT
			3	Continuous C-shaped	An oval mesial canal; An elongated, narrow distal canal	C2	Periapical radiograph CBCT

at different levels. Vaz de Azevedo et al. were the first to describe bilateral C-shaped canal prevalence, finding an incidence of 61.70% in mandibular first molars, which was significantly higher than the 38.29% observed in mandibular second molars [33]. In our report, we also observed bilateral mandibular first molars with C-shaped root canals: the right molar had a fused C-shaped root with four individual canals in the middle thirds, while the left molar exhibited a semicolon-shaped outline in the coronal and middle thirds.

The Fan et al. classification is a highly valuable and widely used system for categorizing C-shaped canals [21]. With appropriate modifications, it can also be applied to mandibular first molars, premolars, and even maxillary molars [20, 30, 34]. C1 is the most prevalent type among those five categories. A CBCT-based prevalence study found that C1 dominated 89.01% of cases (81/91), while C2 and C4 accounted for 8.79% (8/91) and 2.19% (2/91), respectively. Types C3 and C5 were not identified in any mandibular molars [33]. C-shaped configurations most frequently appear in the coronal third of the root (89%), and only one of the 91 mandibular first molars studied displayed a C-shaped configuration along the entire root length. Analysis of morphological changes in C-shaped canals along the full length of mandibular molars using 3D reconstruction technology revealed that the most common variation was C1-C2-C3d (18%), followed by C1-C3c-C3d (15.4%), C4-C3c-C3d (7.7%), and C3c-C3c-C3d (7.7%) [35]. In our case, the right mandibular molar displayed a C3c-C3?-C3c configuration, while the left molar exhibited a C2-C2-C3c pattern. Interestingly, for the right mandibular molar, four distinct canals were identified in the middle-third cross-section: mesiobuccal, mesiolingual, distobuccal, and distolingual. While there is extensive documentation of C-shaped canal configurations in mandibular first molars [13, 36], the present case demonstrates a rare anatomical variation characterized by a fused C-shaped root housing four distinct and fully separated canals.This pattern differs from those described in previous reports, which predominantly describe C-shaped systems with two or three canals. To date, only one case of mandibular molars with four canals in C-shaped roots has been reported [37], and none have demonstrated complete separation of all canals as observed in this case. To our knowledge, this is the first report of four separate canals in a fused C-shaped root, a configuration not previously described in the literature (Table 2). Whether this represents a new subtype of C3 requires further investigation with additional samples.

Rates of C-shaped configurations in mandibular first molars vary significantly in diverse populations, with the highest incidences observed in South American and West Asian populations, particularly in Brazilian (24.01%) and Saudi Arabian (24.33%) individuals [16, 33] (Table 1). However, the association between gender and C-shaped variations remains controversial. While some studies have reported no correlation between C-shaped canals and gender or age [38, 39], others have found a significantly higher prevalence in females [13, 33]. Conversely, certain investigations have noted a predilection for males [16]. Anatomical variants associated with C-shaped configurations have also been discussed; for example, longitudinal grooves are more commonly observed on the lingual or buccal surfaces [40, 41]. A strong correlation with taurodontism has been revealed through CBCT scans, with 56.9% of molars presenting with C-shaped canal systems [42]. Interestingly, we noted a unique anatomical feature in the mandibular molars described in our case, characterized by a longer lingual marginal ridge and a shorter buccal ridge. Whether these features are associated with C-shaped canals warrants further investigation.

The complex anatomy of C-shaped canals poses significant clinical risks. As demonstrated in the present case, the continuous slit-like isthmus between the canals increases the likelihood of missing accessory canals and incomplete debridement, which are strongly associated with persistent apical periodontitis [9]. The fin or web connecting between root canals in the C-shaped canal system may harbor residual soft tissue or infected debris, which are often inaccessible to instruments and irrigants, and potentially prevent adequate sealing and disinfection of the root canal system [43]. Furthermore, the thin dentinal walls predispose to iatrogenic perforations during instrumentation or root fracture after treatment, particularly when using rotary files in the danger zone [44]. Comprehensive knowledge of radicular anatomy, particularly the thickness and spatial distribution of dentin, is essential for minimizing complications during root canal therapy. CBCT is frequently used to reveal morphological variations and supplementary canals in teeth through the generation of 3D images [20, 45]. Optimal diagnosis and meticulous planning of treatment can be conducted through a comprehensive and precise visualization of the dental root and pulp system. In the present case, preoperative radiography showed the presence of a fused root, with four separate canal orifices observed on the floor of the pulp chamber with the assistance of a dental operating microscope. Further CBCT was conducted to confirm the presence of root canal variations. The CBCT images at different levels revealed morphological variations in the axial section, with two canals in the coronal third, four canals in the middle third, and two fused canals in the apical third. Further 3D reconstruction views revealed a fused root with a deep lingual groove extending to the apex. Similar radiographic features were observed in the contralateral first molar. Through radiographic analysis and the use of a dental operating microscope, comprehensive and rational treatment was planned: with controlled-memory NiTi files used for instrumentation, with 3% sodium hypochlorite and 17% EDTA used for irrigation, followed by ultrasonic activation. The successful outcomes of these treatments verified the importance of recognizing anatomical variations and utilizing advanced imaging techniques during the treatment process.

In conclusion, while most studies on C-shaped canals have focused on mandibular second molars, increasing attention is being directed toward mandibular first molars. Advances in 3D imaging technology and larger sample sizes have enhanced our understanding of the details and complexity of anatomical morphology in mandibular first molars, particularly regarding C-shaped root systems. For clinicians managing similar cases, the use of CBCT and dental operating microscope for the identification of unique or atypical cases is crucial for accurate diagnosis and successful treatment. Further research is needed to explore these anatomical variations in greater depth and refine clinical protocols the effective management of C-shaped canals in mandibular first molars.

Abbreviations

CBCT Cone	beam computed tomography
3D Three	dimensional

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Author contributions
Rongjing Zhou: supervision, performed the operation, edited the manuscript. Lili Shen: reviewed the manuscript, validation and data curation. Chengshi Wei: participate in the treatment, sorted data and reviewed the manuscript. All the authors have read and approved the final manuscript.

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Data availability
The complete data and materials described in the case report are freely available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study did not involve human or animal subjects' experiment, and thus ethical review and approval were waived. Informed consent was obtained from the patient for the treatment and publication of this case, with permission to use clinical and radiographic images.

Consent for publication
Written informed consent for publication from patient has been taken.

Competing interests
The authors declare no competing interests.

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