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C-shaped canal configuration in mandibular second molars of a selected Uyghur adults in Xinjiang: prevalence, correlation, and differences of root canal configuration using cone-beam computed tomography

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Abstract

Objectives To determine the prevalence of C-shaped root canal system configurations and assess the correlation between C-shaped root canal prevalence and root morphology in mandibular second molars among adults in Xinjiang Uyghur population using cone-beam computed tomography (CBCT).

Materials and methods CBCT imaging data from patients treated at the First Affiliated Hospital of Xinjiang Medical University (Affiliated Stomatology Hospital) were retrospectively analyzed. The prevalence of C-shaped root canal configurations in mandibular second molars was determined based on Fan et al.'s classification. Axial sections of each tooth were evaluated in the coronal, middle, and apical thirds to identify canal configurations and analyze root morphology. The differences in C-shaped canal prevalence between genders and tooth positions were compared. Statistical analysis was performed using the chi-square test ($p < 0.05$).

Results A total of 1748 patients were included, with 510 (29.17%) exhibiting C-shaped root canals. Females exhibited a higher prevalence (31.49%) than males (25.15%). C-shaped canals were more frequently observed on the lingual surface (76.8%) than the buccal surface (22.2%). Bilateral symmetry of C-shaped canals was observed in 64.7% of cases. A significant association was found between C-shaped canals and root morphology ($p < 0.001$). Among patients with C-shaped canals, 66.9% demonstrated symmetrical configurations. The most common configuration was C3 (present in all axial levels), followed by C1 and C2. Mandibular second molars with three roots or type 3/type 4 morphologies exhibited a high probability of C-shaped canals.

Conclusions C-shaped canals were more prevalent in females and lingually positioned in mandibular second molars. Bilateral C-shaped canals were frequently symmetrical and more common than unilateral cases. Mandibular second molars with three-root or type 3/type 4 morphologies may indicate a high likelihood of C-shaped canals. The

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most common configuration was C3, followed by C1 and C2, all present across all axial levels. Understanding these anatomical variations preoperatively can improve clinical management.

Keywords C-shaped canal, Mandibular second molar, Cone beam computed tomography

Background

The root canal system (RCS) often exhibits anatomical variations that complicate endodontic procedures, particularly during the initiation of root canal treatment (RCT). Understanding the most common configurations and potential variations is crucial for effective cleaning, shaping of the RCS, and improving treatment quality and long-term prognosis [1]. A common variation involves a fin or web connecting individual canals, forming a C-shape. In some cases, the thin lingual canal wall creates a "danger zone", increasing challenges during cleaning, shaping, and obturation. The C-shaped root canal system is a significant anatomical variant, most frequently observed in mandibular second molars.A major challenge in endodontic treatment is the prevalence of C-shaped root canal configurations, which are predominantly found in mandibular second molars, with reported rates ranging from 2.7 to 52.0% across different populations [2]. A major challenge in endodontic treatment is the prevalence of C-shaped root canal configurations, which are predominantly found in mandibular second molars, with reported rates ranging from 2.7 to 52.0% across different populations [3, 4]. Studies have identified leaking canals, isthmus-related issues, missed canals, overfilling, and iatrogenic complications as common causes of treatment failure in mandibular second molars with C-shaped canals [5]. Therefore, analyzing the morphology and incidence of C-shaped canals in diverse populations is vital for clinical decision-making.

Previous anatomical studies employed various techniques, including teeth clearing, histological analysis, and in vivo methods such as spiral-CT, cone-beam computed tomography (CBCT), and conventional radiography [1]. Among these modalities, CBCT has gained popularity in dentistry due to its superior accuracy in detecting pathologies, tooth types, and root morphological variations compared to two-dimensional radiographs [6].

However, limited research exists on C-shaped canal prevalence and characteristics in Xinjiang uyghur population, particularly regarding correlations between C-shaped canals and external root shapes in two-dimensional imaging. This study aims to investigate the prevalence and configuration types of C-shaped root canals in mandibular second molars using CBCT. Additionally, we examine whether specific root and canal configurations observed in two-dimensional CBCT reconstructions correlate with C-shaped canal anatomy.

Materials and methods

Data collection

CBCT images from patients who underwent CBCT examinations for treatment at the First Affiliated Hospital of Xinjiang Medical University (Affiliated Stomatology Hospital) between January 2020 and June 2024 were collected. The study received approval from the Institutional Review Board of the First Affiliated Hospital of Xinjiang Medical University (K202403-38).

Inclusion and exclusion criteria

inclusion criteria: (1) high-quality CBCT images without artifacts, (2) Age ≥ 18 years, (3) Fully formed roots of the mandibular second molar with a closed apical foramen, (4)Absence of treatment history, pulp/periapical lesions, root canal calcification, or root resorption.

exclusion criteria: Images that do not meet the inclusion criteria will be excluded.

Indicators and classification

C-shaped root canal configuration was classified according to the classification of Fan et al. [7], which categorizes C-shaped canal systems into 5 categories (Fig. 1).

C-shaped root canal configuration

I. C1: Uninterrupted C with no separation or division.
II. C2: The canal shape represents a semicolon resulting from discontinuation of the C outline.
III. C3: Two or three separate canals.
IV. C4: Only one round or oval-shaped canal in the cross-section.
V. C5: No canal lumen could be observed (usually it is seen near the apex only).

Mandibular second molars on panoramic-like views of CBCT were then classified using the modified classification of Fan et al. [7, 8], as follows (Fig. 2):

Type 1: Presence of two separate, divergent or parallel roots with clear trabeculae between them.
Type 2: Presence of two separate converging roots with clear trabeculae between them.
Type 3: Presence of attached roots with mesial and distal canals merging near the apex.
Type 4: Presence of attached roots with two separate canals that do not meet at the apex.
Type 5: Presence of one root with one or two canals.

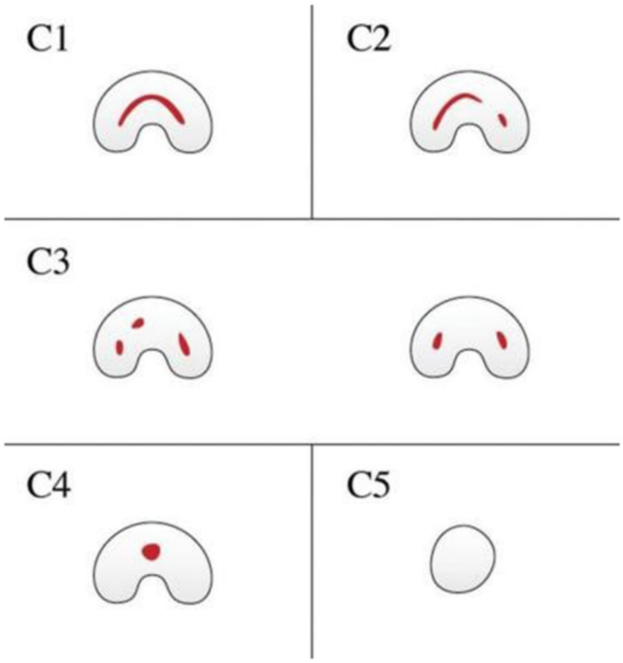

Fig. 1 Types of C-shaped canal morphology on the axial CBCT section

Radiographic evaluation

The CBCT protocol involved a medium-large field of view (16 cm × 13 cm), 120 kVp, 20.27 mAs, 14.7 s scan time, and 0.25 mm voxel size. Imaging was performed with patients in a natural head position. Sidexis software (Sirona Dental Systems, Inc., Long Island City, NY, USA) was used to analyze root and root canal morphology of mandibular second molars. Serial axial, coronal, and sagittal sections were acquired to evaluate external and internal morphology. All CBCT images were independently reviewed by two endodontists.

Calibration and training

Observer calibration was performed between the two endodontists.One observer was trained and calibrated for reading CBCT images using a sample size of 100.The kappa value was 0.814 ($P < 0.05$).

In cases of disagreement, the two endodontists discussed the data until a consensus was reached. An oral radiologist provided guidance when necessary.

Parameters evaluated

- Differences in C-shaped canal prevalence and location between age groups and genders.
- Location of longitudinal grooves and differences between genders.
- Bilateral symmetry of C-shaped canals in the same patient.
- Prevalence of C-shaped canal configurations in mandibular second molars.
- Correlation between C-shaped configurations and two-dimensional reconstructions in mandibular second molars.

Statistical analysis

Data analysis was performed using SPSS (version 29; IBM Corp., Armonk, NY, USA). Findings were presented as n (%) and mean ± standard deviation. The chi-square test was used to compare enumeration data between groups, while the Student's t-test was applied for measurement data.

Results

Patient characteristics

A total of 510 patients with C-shaped canals in the mandibular second molars were identified among 1,748 adults, yielding an overall incidence of 29.17% (25.15% in males 161/640 and 31.49% in females 349/1,108). Females exhibited a significantly higher prevalence ($P < 0.05$). Statistically significant differences were observed between genders and canal locations (left vs. right vs. both sides; $P = 0.05$), as well as between left-side C-shaped canals and gender ($P < 0.05$) (Table 1).

Age group analysis

Patients ranged from 18 to 76 years (mean age: 32.31 ± 12.0 years). Significant differences were found between age groups and root numbers, panoramic

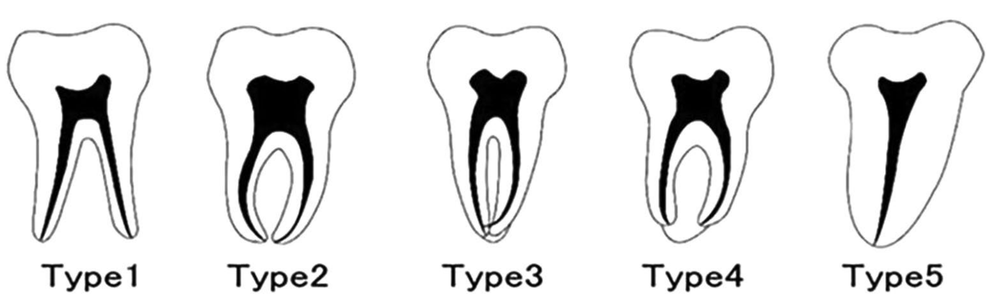

Fig. 2 Classification of mandibular second molar root morphology on panoramic-like images of CBCT

Table 1 Prevalence of C-shaped morphology in mandibular second molars: analysis by anatomic location and gender

		Male (%)	Female (%)	All (%)	*p* value
		161(31.5)	349(68.5)	510(100)	
#37					0.035*
	Absent	40(24.8)	59(16.9)	99(19.4)	
	Present	121(75.2)	290(83.1)	411(80.6)	
#47					0.091
	Absent	26(16.1)	55(15.8)	81(15.9)	
	Present	135(83.9)	294(84.2)	429(84.1)	
Locations					0.05*
	Left	26(16.1)	55 (15.8)	81(15.9)	
	Right	40(24.1)	59(16.9)	99(19.4)	
	Both side	95(59)	235(67.3)	330(64.7)	

Note: #37: left mandibular second molars; #47 right mandibular second molars

reconstruction views, and longitudinal groove locations ($P<0.05$). However, no significant association was observed between C-shaped configurations at three axial levels and age groups ($P>0.05$) (Table 2).

Location of longitudinal grooves and bilateral symmetry

Longitudinal grooves were most frequently located on the lingual surface (75.9% on the left and 77.6% on the right mandibular second molars), with buccal grooves occurring less commonly (23.1% left, 21.4% right) and both sides in 1% of cases ($P<0.05$). Bilateral symmetry was defined as identical C-shaped configurations in both mandibular second molars, while asymmetry denoted unilateral presence. No significant difference was found in the frequency of symmetric (330 cases) versus asymmetric (180 cases) C-shaped canals ($P>0.05$). Notably, 66.9% of symmetric cases (221/330 pairs) exhibited bilateral symmetry (Table 3).

Table 3 Anatomic distribution of groove patterns in C-shaped mandibular second molars

	#37(%)	#47(%)	χ2	*p* value
Buccal	95(23.1)	92(21.4)	271.21	$p<0.001$
Lingual	312(75.9)	333(77.6)		
Buccal and Lingual	4(1)	4(1)		
Total	411	429		

Note: #37: left mandibular second molars; #47 right mandibular second molars

Symmetry and asymmetry analysis

Symmetry was defined as the presence of identical C-shaped canals in both mandibular second molars, while asymmetry denoted unilateral occurrence. Symmetry/

Table 2 Age-group specific prevalence of C-shaped mandibular second molars

		Age (*n*)						Total	χ2	*p*
		< 20	20~	30~	40~	50~	60~			
Root number	1 root	21	47	14	5	13	7	107	37.75	0.001
	2 roots	69	140	54	16	48	37	364		
	3 roots	95	206	100	55	34	56	546		
	4 roots	1	18	6	3	0	3	31		
Panoramic view	Type 1	23	54	16	19	12	10	134	37.424	0.001
	Type 2	67	178	73	25	34	47	424		
	Type 3	41	81	43	18	24	25	232		
	Type 4	39	50	18	11	10	7	135		
	Type 5	16	48	25	5	15	14	123		
Groove location	Buccal	50	63	29	17	27	14	200	24.174	0.007
	Lingual	118	285	111	47	56	66	683		
	Both	0	4	4	0	0	2	10		
Coronal third	C 1	62	124	45	16	22	25	294	7.637	0.937
	C 2	19	42	18	10	13	11	113		
	C 3	68	142	62	32	37	36	377		
	C 4	19	44	19	6	11	10	109		
Middle third	C 1	23	45	14	4	3	7	96	18.385	0.562
	C 2	27	60	23	10	12	11	143		
	C 3	111	230	99	47	59	59	605		
	C 4	6	16	8	3	9	5	47		
	C 5	1	1	0	0	0	0	2		
Apical third	C 1	19	29	10	3	5	4	70	19.978	0.459
	C 2	25	49	13	7	8	8	110		
	C 3	111	230	101	49	55	59	605		
	C 4	12	42	18	5	14	9	100		
	C 5	1	2	2	0	1	2	8		

Table 4 Gender-related incidence of symmetrical characteristics in mandibular second molars

		Male	Female	Total	χ2	*p* value
Symmetry					3.347	0.067
	Unilateral	66(41)	114(32.7)	180(35.3)		
	Bilateral	95(59)	235(67.3)	330(64.7)		
Symmetrical in same patient					0.840	0.359
	Symmetry	65(40.4)	96(59.6)	221(43.3)		
	Asymmetry	156(44.7)	193(55.3)	289(56.7)		
Total		161(31.6)	349(68.4)	510(100)		

Table 5 Prevalence of C-shape morphology and root canal configuration in mandibular second molars: a panoramic reconstruction study

		Type 1	Type 2	Type 3	Type 4	Type 5	χ2	*p* value
#37							114.78	0.001*
	Absent	39(57.4)	21(11.8)	4(4)	12(16.4)	0		
	Present	29(42.6)	157(88.2)	96(96)	61(83.6)	58(100)		
#47							118.19	0.001*
	Absent	33(55.9)	18(8.5)	4(3.5)	8(14.3)	0		
	Present	26(44.1)	195(91.5)	109(96.5)	48(85.7)	51(100)		
37Root							209.46	0.001*
	1	7(10.3)	17(9.6)	8(8)	0(0)	37(54.4)		
	2	21(30.9)	71(40.1)	25(25)	2(2.7)	31(45.6)		
	3	40(58.8)	86(48.6)	65(65)	61(836.)	0(0)		
	4	0(0)	3(1.7)	2(2)	10 (13.7)	0(0)		
47Root							152.68	0.001*
	1	1(1.7)	12(5.6)	5(4.4)	1(1.8)	22(39.3)		
	2	33(55.9)	93(43.7)	31(27.4)	3(5.4)	31(60.7)		
	3	25(42.4)	103(48.4)	73(64.6)	46(82.1)	0(0)		
	4	0(0)	5(2.3)	4(3.5)	6(10.7)	0(0)		
Total		127	391	213	129	109		

Note: #37: left mandibular second molars; #47 right mandibular second molars

asymmetry was evaluated in patients with identical root canal types on both sides. No significant difference was observed in the frequency of symmetric (330 cases) versus asymmetric (180 cases) C-shaped canals ($P > 0.05$). Notably, the frequency of bilateral C-shaped canals (330 cases) was higher than unilateral cases (180 cases; ratio 1:1.8), but this difference was not statistically significant ($P > 0.05$). Among the 330 bilateral patients, 66.9% (221/330 pairs) exhibited symmetrical C-shaped canals in both mandibular second molars (Table 4).

Prevalence of C-shaped canals configuration

As shown in Table 5, among all 127 cases with type 1 morphology on the panoramic reconstruction view, the most common root patterns on the axial view were two- or three-root configurations. Notably, no four-root patterns were observed in type 1, while only 8 cases exhibited single-root morphology. Specifically, 56.6% of these single-root cases demonstrated a C-shaped pattern, with the remaining cases presenting a single-root configuration. Statistically significant differences were observed between C-shaped canal prevalence and root morphology types on two-dimensional images.In 391 cases with type 2 morphology, the axial view also predominantly revealed two- or three-root patterns, although only 8 cases showed four-root morphology. Among these, 10% (39 cases) exhibited no C-shaped canals. For type 3 and 4 morphologies (213 and 129 cases respectively), the three-root pattern was most frequent. Finally, among 109 type 5 cases, single- and double-root patterns predominated on axial views, with no three- or four-root structures identified. All types demonstrated statistically significant differences in root numbers ($p < 0.001$). Typical mandibular second molar morphologies are illustrated in Fig. 3.

Axial level configuration analysis

C-shaped configuration types for each axial level in right and left mandibular second molars are presented in Table 6; The most dominant configuration type in p right and left mandibular second molars were C3 (coronal was31.6%, middle was 52%, apical was 51.8% in 37 and coronal was 36.9%, middle was 58.8% and apical was 58.2%in 47) which was found in all axial levels. followed by C1 and C2 were also found in all axial levels, C1 was most presented in coronal third (26.5% and 27.8%), C2 was most presented in middle third (13.7% and 12.7%),

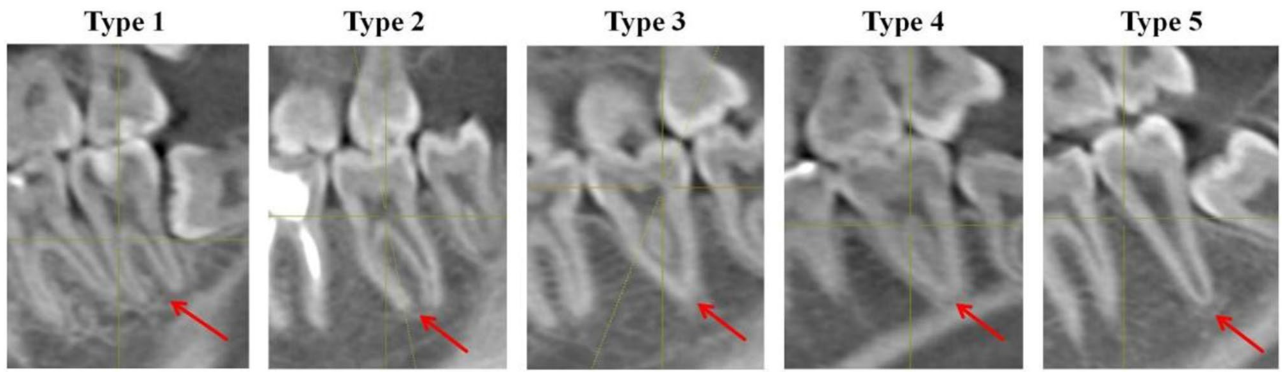

Fig. 3 Typical tooth morphology of mandibular second molar on panoramic-like images

Table 6 Distribution of C-Shape configuration variants at different radicular levels in mandibular second molars

	37			47			
	Coronal	Middle	Apical	Coronal	Middle	Apical	Total
C1	135(26.5)	52(10.2)	33(6.5)	142(27.8)	42(8.2)	36(7.1)	440
C2	56(11)	70(13.7)	55(10.8)	53(10.4)	65(12.7)	50(9.8)	354
C3	161(31.6)	265(52)	264(51.8)	188(36.9)	300(58.8)	297(58.2)	1466
C4	59(11.6)	22(4.3)	55(10.8)	46(9)	22(4.3)	42(8.2)	246
C5	0(0)	2(0.4)	4(0.8)	0(0)	0(0)	4(0.8)	10
Total	411(100)			429(100)			
$\chi 2 = 10.42$; $p < 0.001$							

Note: #37: left mandibular second molars; #47 right mandibular second molars

respectively. C5 was found two case (0.4%) in middle third on the left mandibular second molars and four case (0.4) in apical third level on both sides, therefore none C5 found on coronal third in any side of mandibular second molars.Typical C-shaped root canal morphologies are illustrated in Fig. 4.

Discussion

C-shaped root canal systems have been consistently documented as anatomically complex variations by dental professionals. Maintaining a comprehensive understanding of these intricate configurations is critical for clinicians, as C-shaped root canals significantly impact the success of endodontic treatment outcomes aimed at pain relief and infection elimination. Numerous studies report a prevalence of C-shaped root canals in mandibular second molars ranging from 2.7 to 44.5%, influenced by different population and study methodologies. For example, Chinese populations exhibit frequencies between 39% and 52% [9]. Numerous studies report a prevalence of C-shaped root canals in mandibular second molars ranging from 2.7 to 44.5%. For example, Chinese populations exhibit frequencies between 39% and 52% [9]. This investigation analyzed 1,748 patients, revealing 510 cases of C-shaped root canals in mandibular second molars (prevalence: 29.17%). Gender-specific analysis demonstrated a higher incidence in females (31.49%, 349/1,108) compared to males (25.15%, 161/640). While these findings align with global data (e.g., 13% in Australians [10] and 22% in Indians [11], respectively, they exceed rates reported in Chile (8.9%) [12] and Brazil (12%) [6, 13], Conversely, lower prevalence in mandibular first molars concurs with Pakistani [14] and Israel [15], and Iranian studies [16]. The significantly higher prevalence of C-shaped root canals noted in our study was also reported in previous studies from Korea [17], Portugal [18], and Saudi Arabia [19]. This finding is also supported by a worldwide assessment [9] and a recent systematic review [20]. On the other hand, similar to the findings of the present study, previous studies detected a significantly higher prevalence of C-shaped canals in females from a variety of population [6, 21]. In addition, in our study, the majority of the sample size belonged to females, which may contribute to the higher prevalence of C-shaped canals among females.

Due to the intricate anatomy of C-shaped root canals, root canal treatment can pose significant challenges. Clinicians should maintain heightened awareness of the prevalence and various types of C-shaped canals, along with their associated danger zones, to ensure successful endodontic outcomes. The use of dental operating microscopes proves instrumental in managing root canals with such anatomic variations, enabling more precise and effective treatment [22]. Accurately identifying the location of the longitudinal groove - where the thinner portion constitutes the danger zone - is critical for

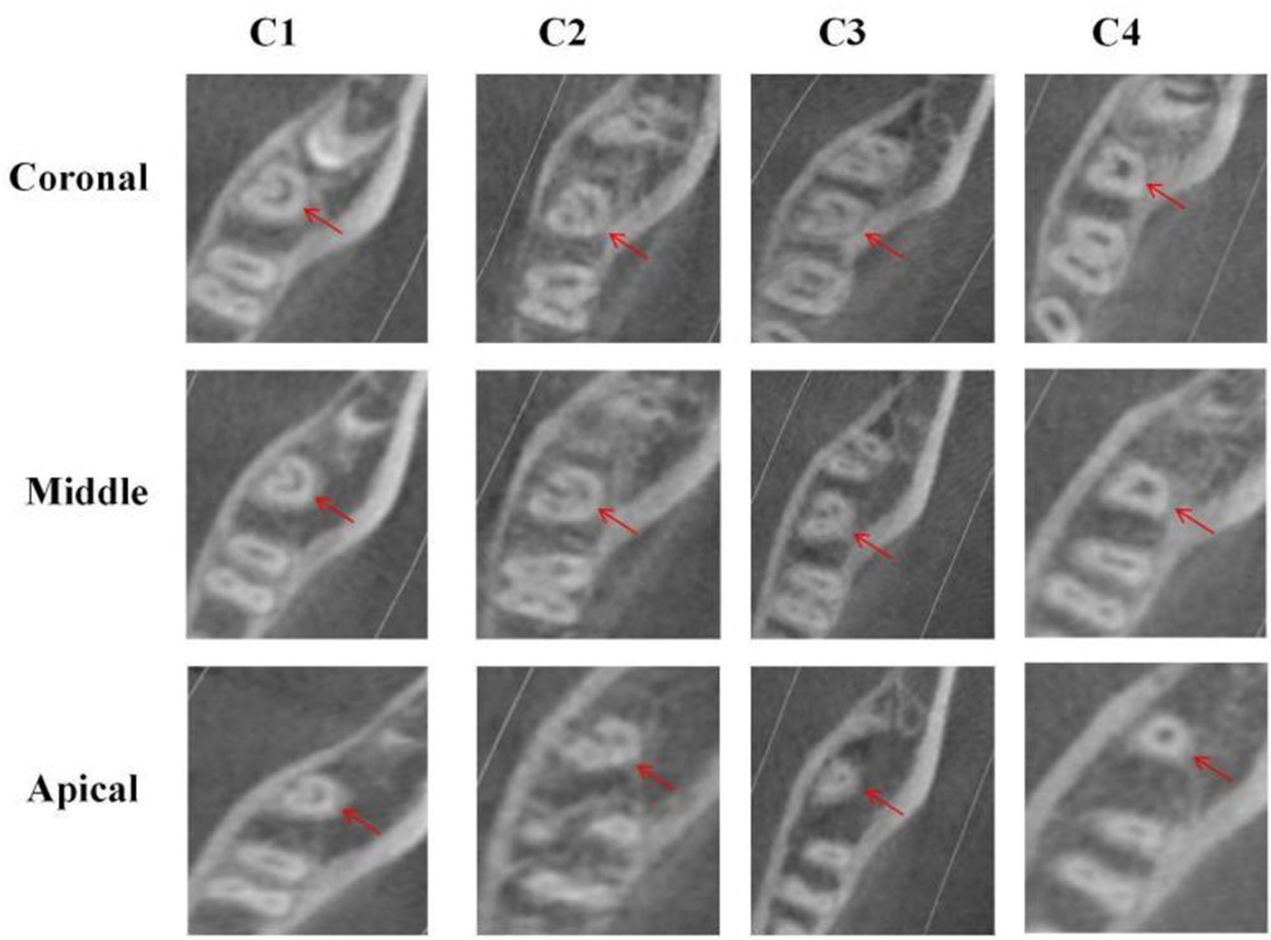

Fig. 4 Typical C-shped root canal morphology of mandibular second molar

preventing strip perforations during mechanical preparation. When prominent grooves are evident, dental practitioners are strongly advised to consider the exact positioning of danger zones, regions highly susceptible to perforation. This awareness is particularly vital when treating the lingual aspect of the root, where danger zones are most pronounced. Extensive literature confirms that nearly all molars with C-shaped canals consistently demonstrate lingual radicular grooves [1, 23]. In our study, mandibular second molars with C-shaped canals exhibited three groove configurations: 76.8% had lingual grooves, 22.2% buccal grooves, and only 1% presented both.

Previous studies in other countries reported bilateral symmetry of C-shaped canals in mandibular second molars; bilateral occurrence ranged between 38% and 85.9% [24, 25]. In our study, we observed a high incidence of bilateral symmetry (64.7%) among adults with mandibular second molars: 180 cases were unilateral, and 330 were bilateral (ratio, 1:1.8).Of these 330 bilateral cases, 66.9% (221/330) exhibited symmetrical C-shaped canal configurations in both the right and left mandibular second molars.Therefore, dentists should consider the possibility of contralateral C-shaped canals when a patient presents with this morphology in one mandibular second molar.

However, some of these studies noted that it was difficult to recognize anatomical variation when limited to 2D panoramic and periapical radiographs. Radiographs do not provide data about the cross-sectional morphology of the root canal system. Therefore, the diagnosis of C-shaped canals on two-dimensional radiographs is challenging. Cone Beam Computed Tomography (CBCT) is a sophisticated three-dimensional imaging technique that significantly facilitates and enhances the understanding of complex morphological structures [15]. It is essential to emphasize that to avert patients from receiving excessive double X-ray radiation doses, we judiciously reconstructed a panoramic view from the CBCT images. This innovative process enables us to obtain two-dimensional imaging, thereby enabling us to discern the C-shaped morphology correlations of C-type root canals in two-dimensional images with precision [26].

For the purpose of this research study, we meticulously assessed the cross-sectional configuration at three distinct regions - the coronal, middle, and apical thirds - in canals exhibiting C-shaped morphology. In undertaking this analysis, we rigorously adhered to the classification methodology outlined by Fan et al. (as delineated in Reference [7]), a methodology widely utilized in prior studies. This approach, involving meticulous evaluation of canal cross-sectional configurations, has been adopted across diverse research endeavors, including but not limited to studies referenced in [6, 21, 23]. In our evaluation of 840 mandibular second molars with C-shaped canals, C1 and C3 emerged as the most prevalent configurations in the coronal third. In the middle third, C3 was most common, aligning with previous findings. Similarly, C3 dominated the apical third in our study, consistent with Fan et al.'s observations [7, 23] (see Table 6). Notably, Fan et al. emphasized that this configuration's narrow isthmus contributed to 23.8% of endodontic failures [17]. Our data revealed most configuration changes occurred at the apical level, which remains undetectable clinically even with magnification. This underscores the necessity of preoperative CBCT for comprehending such complex anatomy.While two-dimensional radiographs may inadequately diagnose C-shaped canals, CBCT's three-dimensional imaging capabilities enhance characterization of these structures. Although micro-CT or histological clearing techniques offer superior detail, CBCT's practicality aligns best with our study's objectives.

Conclusion

A limitation of this study, which should be noted, is its rather narrow focus on the prevalence of C-shaped canals and the nuanced anatomical differences inherent to these canals. Therefore, further clinical data are needed to investigate root canal morphology of mandibular second molars across various regions, and to compare morphological differences between regions, thereby providing clinicians with a more reliable basis for treatment planning. Another limitation of this study stems from the inclusion of both left and right mandibular second molars in the population cohort. While this approach comprehensively evaluates symmetry, it may slightly reduce the overall prevalence of C-shaped canals.

Abbreviations

CBCT	Cone-beam computed tomography
3D	3-dimensional

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Author contributions

M. Pataer and A. Abulizi designed the data acquisition, critically revised the manuscript for important intellectual content, collected and analyzed data, and prepared Tables 1, 2, 3 and 4; Figs. 3 and 4; they contributed equally to this article. S. Jumatai compiled the clinical materials and prepared Figs. 1 and 2. X. Zhang and X. Zhang prepared Table 5 and 6. J. Zhao conceptualized and designed this study, coordinated and supervised data collection, revised the manuscript, collected data, and served as the corresponding author.

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Data availability

The dataset supporting the conclusions of this article is included within the article. The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

The study received approval from the Institutional Review Board of the First Affiliated Hospital of Xinjiang Medical University (approval number [K202403-38]). All reports were conducted in accordance with the ethical standards of the Declaration of Helsinki and the relevant guidelines and regulations of the People's Republic of China.Informed consent was obtained from the patients, next of kin, or legal guardian.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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