ORIGINAL RESEARCH

Anatomical Investigation of C-shaped Root Canal Systems of Mandibular Molars in a Middle Eastern Population: A CBCT Study

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Abstract

Aim: The aim of this study is to identify the prevalence of C-shaped root canal systems in mandibular first and second molars in a Lebanese population, and to determine the relationship between C-shaped root canal systems and different factors (age, gender, and tooth location) and to examine the root canal system's morphology along the root.

Materials and methods: The presence of C-shaped root canal systems in 648 mandibular molars from 257 patients was analyzed using cone–beam computed tomography (CBCT). The sample included 296 and 352 mandibular first and second molars, respectively. The frequency of C-shaped canals, their relationship to gender, age, and tooth location, and unilateral or bilateral occurrences were noted. A 3D Slicer 4.10.1 was then used to classify teeth with identified C-shaped anatomy according to Fan's configuration and to determine the distance between the orifice and the cementoenamel junction (CEJ).

Results: C-shaped root canal systems were detected in 1.01 and 9.09% of mandibular first and second molars, respectively. In mandibular second molars, the most prevalent configurations were as follows: C1 at the orifice level, C3 at orifice-2 mm, C2 and C3 in the middle third, and C3 at the apical level. There was no correlation with age, gender, and tooth position. The bilateral occurrence happened in 60% of cases. Orifices were at a mean distance of 3.32 mm below the CEJ. The deepest groove was mostly lingual.

Conclusion: The prevalence of C-shaped root canal systems in the Lebanese population is 1.01 and 9.09% in the first and second mandibular molars, respectively. The CBCT slices showed that the configuration varies along the root and that the orifices are at various distances below the CEJ. Therefore, pre-operatory scans can be beneficial for better understanding and preparation of root canal treatment.

Clinical significance: In the Lebanese population, C-shaped mandibular molars are not a rare finding. Clinicians should consider the different configurations and the possible changes along the root.

Keywords: Cone–beam computed tomography, Mandibular molars, Root canal morphology.

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Highlights

- The prevalence of C-shaped canals in the Lebanese population is of 1.01 and 9.09% in the mandibular first and second molars, respectively.
- The prevalence in the Lebanese population is close to the ones in other west Asian populations.
- The anatomy varies along the root, thus the importance of preoperative CBCT evaluation.
- There is a high chance of bilateral occurrence of C-shaped root canal systems.

Introduction

The C-shaped root canal system is an anatomical variation characterized by a thin dentinal web or fin connecting individual root canals.[1] The clinical implications of this particular anatomy were discussed for the first time in endodontic literature by Cooke and Cox in 1979. Since then, it has been the focus of many research works and articles. The endodontic management of this variation is a clinical challenge, particularly because of the presence of an important volume of irregular areas such as fins, apical deltas, and accessory or lateral canals that may house infected debris and organic remnants.[1,2] These regions are often inaccessible to shaping instruments, therefore complicating the debridement and the 3D sealing of the system and increasing the risks of reinfection.[3] Even with recognition of a C-shaped orifice, it is unclear if this anatomical variation continues to the apical third of the root.[4,5] Preoperative diagnosis of the C-shaped anatomy, and a deep understanding of its different morphologies, may allow the clinician to modify conventional treatment methods to ensure optimal shaping, cleaning, and obturation of the root canal system.

It has been reported that the distribution of C-shaped root canal systems in different populations reveals an ethnic predilection.[3,6,7] The prevalence of this anatomy in mandibular second molars varies depending on the population studied: a prevalence of 2.7% was found in an American population compared to 45.5% in a Korean

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population.[3,8] Very few studies have focused on determining the prevalence of this anatomy in mandibular first molars. Their results vary between 0 and 24.01%.[9,10] Thus, being familiar with the ethnic predilections of C-shaped root canal systems could increase the chances of diagnosis in the early stages of the endodontic treatment, making management of the case easier.

To this date, only one clinical study had been carried out, in 1999, to determine the prevalence of C-shaped root canal systems in a Lebanese population, only in mandibular second molars.[11]

Since then, CBCT has been established as a valuable tool, allowing a more reliable diagnosis of root canal anatomy than the conventional 3D radiography.[2,12]

Therefore, the aim of this study is to use CBCT technology to study the following:

- Evaluate the prevalence and morphology of C-shaped root canal systems in mandibular first and second molars in a sample representing the Lebanese population.
- Correlate the prevalence of C-shaped root canal systems with variables such as age, gender, and tooth location.
- Study the variation of the C-shaped anatomy along the root canal system.

Materials and Methods

The research protocol was approved by the institutional ethics committee (Protocol No. 2019-129). The study was conducted in accordance with the Declaration of Helsinki.

Sample Description

The CBCT images were retrieved from the database of the Department of Radiology, Dental Care Center, Saint Joseph University, Beirut, Lebanon and investigated retrospectively. The patients underwent CBCT scans between 2018 and 2022, for reasons other than this study such as preparation for implant or extraction surgeries, diagnosis purposes, and orthodontic studies. Therefore, they were not exposed to unnecessary radiation and the as low as reasonably achievable (ALARA) principle was respected.

Scans of mandibular first and/or second molars with complete root formation were selected. No previous root canal fillings, metallic or heavy restorations, root canal resorptions, calcifications, open apices, or periapical lesions were the criteria considered in the selection of clear images of the teeth for the study.

A convenience sample of 296 and 352 mandibular first and second molars, respectively, from 257 Lebanese patients (132 males and 125 females) of age between 14 and 77 years (mean age = 36.31 ± 1 4.34 years) was reached, by collecting scans from consecutive and random patients in the database (Table 1).

Table 1: Distribution of teeth in the sample

	Frequency	*%*
Left mandibular first molar (36)	147	22.69
Left mandibular second molar (37)	183	28.24
Right mandibular first molar (46)	149	22.99
Right mandibular second molar (47)	169	26.08
Total	648	100.00

A licensed radiologist performed these scans following the manufacturer's recommendations. These CBCT images were obtained using Newtom VGI, QR SRL, Verona, Italy 9500 3D (Carestream Health, Inc., Marne-la-Vallée, France), operated at 90 kV and 10 mA; a field of view of 70 mm × 120 mm and a voxel size limit of 0.200 mm.

The CBCT Analysis

The CBCT images were analyzed using the NNT 5.6 software (QR s.r.l via Silverstrini, 20-37135-Verona, Italy) with a 60-inch LCD screen with a resolution of 1920 × 1080 pixels in a dimly lit room. Optimal visualization was ensured by adjusting the contrast and brightness of the images.

Serial axial, coronal, and sagittal planes were analyzed. Findings from these 3 different views were correlated together to reach a conclusion.

The presence of C-shaped root canal was confirmed by evaluating the following three criteria introduced by Fan et al.

- Fused roots,
- Presence of a longitudinal radicular groove.
- At least one cross-section of the canal belonging to the C1, C2, or C3 configuration.

The prevalence of C-shaped root canal systems was recorded in the first and second mandibular molars separately. The cross-sectional anatomy was analyzed at four different levels. The unilateral and bilateral occurrences of C-shaped root canal systems were noted. The following characteristics were also noted: Age, gender, tooth position, number of roots and canals, and position of grooves.

Classification

When a C-shaped canal was identified, CBCT scans were converted into a digital imaging and communications in medicine (DICOM) format and processed using the 3D Slicer 4.10.1 software.

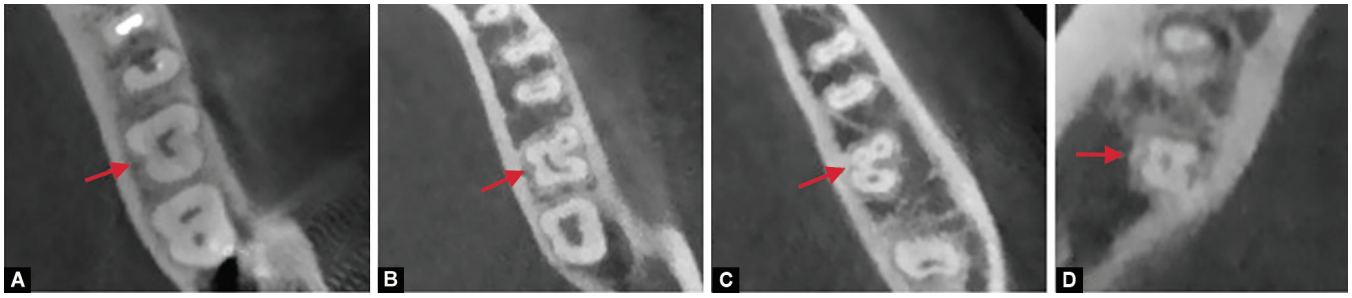
Teeth with identified C-shaped root canal system were then categorized, at the following different levels of the root canal system: (i) Orifice; (ii) coronal third which is orifice – 2 mm; (iii) middle third; and (iv) apical third which is apex + 2 mm.

The categorization was based on Melton's classification with the modifications proposed by Fan et al.

- Category I (C1) (Fig. 1A): Continuous C-shaped canal, with no separation or division.
- Category II (C2) (Fig. 1B): Semicolon C-shaped canal, with dentine separating one canal from the other; but either angle α or β should be no less than 60° (Figs 2 and 3).
- Category III (C3) (Fig. 1C): Separate canals, 2 or more discrete canals with both angles, α and β, less than 60°.
- Category IV (C4) (Fig. 1D): Only one round or oval canal. Canals with a C4 configuration from the orifice to the apex were not classified as C-shaped canals.
- Category V (C5): No canal lumen observed.

Canal configurations C2 and C3 were differentiated by measuring angles α and β using 3D Slicer 4.10.1 software.

Additionally, the distance between the orifices and the CEJ was measured. The CBCT was assessed by two examiners: one endodontist and one general practitioner. A third operator, an experienced endodontist, intervened and reanalyzed the images in case of any doubt or when a consensus could not be reached.



Figs 1A to D: The CBCT slides representing the different C-shaped configuration in mandibular second molars, using the modified Melton classification. (A) C1; (B) C2; (C) C3; (D) C4

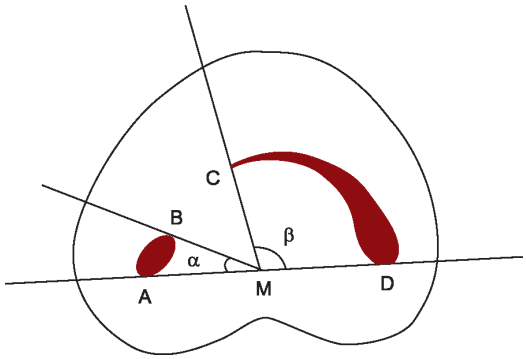


Fig. 2: Measurement of angles α and β for the C2 and C3 categories as explained by Fan et al.[1] A and B are the ends of one canal cross-section; C and D are ends of the other canal cross-section; M is the middle point of line AD; α is the angle between line AM and line BM; β is the angle between lines CM and DM

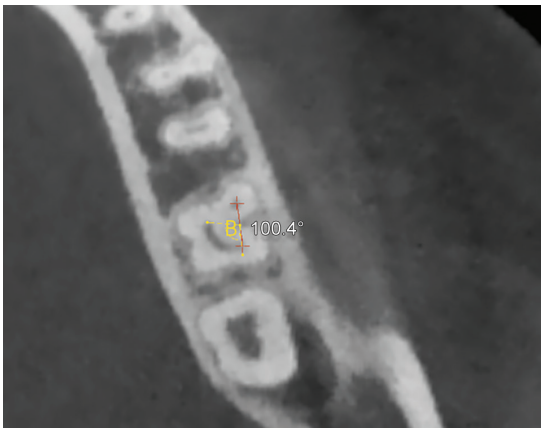


Fig. 3: Measurement of angle β for the C2 canal. Angle β is more than 60°

Statistical Analysis

Statistical analysis was done for the first and second mandibular molars separately. For the first mandibular molars, only descriptive statistics were done due to the small sample of C-shaped molars. For the second mandibular molars, data analysis was executed by the Statistical Package Software for Social Science (SPSS for Windows, version 25.0, Chicago, IL, USA) with a significance level set at $p \leq 0.05$. Correlations were studied using the Chi-squared test. The variables gender, age, or tooth position were correlated with the presence of C-shaped anatomy in tooth 37 and/or 47 of each patient. The Phi coefficient and Cramer's V test were used to calculate the strength of association for 2 × 2 tables and larger tables respectively. Values around 0.10, 0.30, and 0.50 were considered to reflect weak, medium, and strong correlations, respectively.

Results

In 3 of 296 mandibular first molars (1.01%) and 32 of 352 mandibular second molars (9.09%), C-shaped anatomy was found.

- *Mandibular first molars:* Out of three first mandibular molars with C-shaped anatomy, two were found in female patients and one in a male patient. All of these patients were under 25 years; 2 of the teeth were on the left (36) and 1 on the right (46). At the orifice level, the three molars showed a C1 category. However, the anatomy changed in the coronal, middle, and apical thirds, as shown in Table 2. Orifices were located 2.6–4.1 mm below the CEJ. All molars had three canals, within one or two roots. All teeth had two grooves. The deepest one was lingual in two molars and buccal in one.
- *Mandibular second molars:* Table 3 shows the descriptive statistics for mandibular second molars with C-shaped anatomy. Out of the 32 teeth, 18 were found in female patients and 14 in male patients, distributed between 4 age groups. At the orifice level, category C1 was the most prevalent, followed by C2 and C3. In the coronal and middle thirds, the most common categories were C2 and C3. In the apical third, C3 and C4 were dominant. The most changes in configuration happened at the apical level, followed by the coronal level. Only 1 tooth (3.1%) was found to have category C3 at all levels. It had two roots and three canals. Orifices were located 2–6 mm below the CEJ, with a mean of 3.32 mm. Most teeth had two roots and three canals. However, these findings varied between 1 and 3 roots; and 2 and 4 canals. A total of 50% of the C-shaped second molars had only one lingual groove. A total of 40.6% had both lingual and buccal grooves. A total of 9.4% had only 1 buccal groove. The deepest groove was mostly lingual.

No significant differences were found between the presence of C-shaped anatomy and gender or age ($p = 0.520$), nor between the position of the tooth ($p = 0.601$) (Tables 4 to 6). Out of the 20 patients, 8 (40%) had C-shaped anatomy on one side, 12 (60%) had a bilateral occurrence.

Discussion

The purpose of this study was to determine the prevalence of C-shaped anatomy in mandibular molars in the Lebanese population, study the possible related factors, and describe this root canal morphology.

The prevalence of C-shaped anatomy in the literature varies between 0 and 24.01% in mandibular first molars, and 2.7–45.5%

Table 2: Descriptive statistics for the mandibular first molars (n = 3)

	Frequency
Gender	
Female	2
Male	1
Age	
14–25 years	3
Categories at each level	
Orifice	
C1	3
Orifice – 2 mm	
C1	1
C2	2
Middle	
C1	1
C2	2
Apical	
C3	1
C4	2
Number of changes in categories at each level	
Orifice – 2 mm	2
Apical	3
Distance orifice – CEJ	
2.6 mm	1
4.1 mm	2
Number of roots	
1	1
2	2
Number of canals	
3	3
Number of grooves	
2	3
Deepest groove	
Lingual	2
Buccal	1

Table 3: Descriptive statistics for mandibular second molars (n = 32)

	Frequency	*%*
Gender		
Female	18	56.25
Male	14	43.75
Age		
14–25 years	10	31.25
26–32 years	4	12.50
33–48 years	10	31.25
49–77 years	8	25.00
Categories at each level		
Orifice		
C1	22	68.75
C2	5	15.63
C3	5	15.63
Orifice – 2 mm		
C1	6	18.75
C2	10	31.25
C3	16	50.00
Middle		
C1	2	6.25
C2	15	46.88
C3	15	46.88
Apical		
C1	2	6.25
C2	2	6.25
C3	15	46.88
C4	12	37.50
C5	1	3.13
Number of changes in categories at each level		
Orifice – 2 mm	19	59.37
Middle	10	31.25
Apical	22	9.38
Distance orifice – CEJ		
Mean, SD	3.32, 0.85	–
Minimum–Maximum	2.0–6.0	–
Number of roots		
1	5	15.63
2	24	75.00
3	3	9.38
Number of canals		
2	6	18.75
3	2	75.00
4	2	6.25
Number of grooves		
1 Buccal	3	9.40
1 Lingual	16	50.00
2	13	40.60
Deepest groove		
Lingual	9	69.23
Buccal	4	30.77

in mandibular second molars.[3,8–10] According to this study, in the Lebanese population, it is 1.01–9.09% in mandibular first and second molars, respectively. This great difference can be caused by ethnicity, variations in sample sizes, and study designs.

Ethnicity seems to play an important role in the prevalence of C-shaped canals.[13] For the second mandibular molar, the highest prevalence of C-shaped canals was found among the Asian continent compared to Europeans (4.58–8.5%),[14,15] Australians (12.8%),[16] and Americans (2.7–15.9%).[8,17–19] These high numbers were more specifically found in East Asian populations like Chinese (0.6–41.27%) and Koreans (31.3–45.5%).[3] The prevalence among the West Asian populations was as follows:

- Lebanese, 19.1%[11]
- Iranian, 6.96–21.4%[7,20]
- Jordanian, 10%[9]
- Saudi Arabian, 10.6%[6]
- Turkish, 8.9%[21]

Table 4: Correlation between the presence of C-shaped anatomy and gender Person Chi-squared = 0.414; *df* = 1; Asymptotic significance (two-sided) = 0.520

	Gender		
	Female	*Male*	*Total*
C-shaped			
Yes			
n	11	9	20
% Gender	10.60%	8.00%	9.30%
No			
n	93	103	196
% Gender	89.40%	92.00%	90.70%
Total			
N	104	112	216
% Gender	100.00%	100.00%	100.00%

Yes = 37 and/or 47 in each patient, so *n* = 20

Table 5: Correlation between the presence of C-shaped anatomy and age Person Chi-squared = 2.291; *df* = 3; Asymptotic significance (two-sided) = 0.514

	Age				
	25 and below	*26–32*	*33–48*	*49 and above*	*Total*
C-shaped					
Yes					
n	5	2	4	9	20
% Age	10.90%	5.00%	6.90%	12.50%	9.30%
No					
n	41	38	54	63	196
% Age	89.10%	95.00%	93.10%	87.50%	90.70%
Total					
N	46	40	58	72	216
% Age	100.00%	100.00%	100.00%	100.00%	100.00%

Yes = 37 and/or 47 in each patient, so *n* = 20

Table 6: Correlation between the presence of C-shaped anatomy and tooth position. Person Chi-squared = 0.274; *df* = 1; Asymptotic significance (two-sided) = 0.601

	Position		
	Left (37)	*Right (47)*	*Total*
C-shaped			
Yes			
n	18	14	32
% Gender	9.80%	8.20%	9.10%
No			
n	165	156	321
% Gender	90.20%	91.80%	90.90%
Total			
N	183	170	353
% Gender	100.00%	100.00%	100.00%

In this study, the prevalence of C-shaped canals in mandibular second molars was 9.09%, which is close to the values found in other west Asian populations. The difference with the results obtained by Haddad et al. in the Lebanese population could be due to the differences in the methodology and sample size.

Few studies have investigated the prevalence of C-shaped canals in mandibular first molars. In the Jordanian[9] and the Greek[22] populations, no C-shaped canals were found in the mandibular first molars. However, in a Turkish population, the prevalence was of 0.85%[23] which is close to the values found in this study (1.01%). Higher numbers were found in Brazilian populations (2.40–24.01%).[10,24]

Several techniques have been proposed for identifying and describing the C-shaped anatomy. Among these is the staining and clearing technique on extracted teeth.[9] For extracted teeth, the difference between first and second molars has to be made visually based on the tooth morphology, which could be subjected to error. And using extracted teeth does not allow evaluating the correlation between gender and age, nor the study of bilateral occurrences. In other studies, clinical and radiographical examinations were used.[6,11] The main anatomical feature of C-shaped canals is the presence of fins or webs that connect the root canals.[25] However, 2D conventional radiographs do not give a precise description of the complex root canal morphology as compared to 3D scans. And clinical examination without magnification and illumination may result in errors in identifying root canal anatomies and does not allow for a detailed understanding of the anatomy at levels below the one visualized clinically. The CBCT and micro-CT offer a 3D evaluation of the internal anatomy of teeth. However, micro-CT is an *in vitro* evaluation technique, where examined teeth are extracted, thus making it difficult to reach a sufficient sample made of specific teeth. In addition to that, patient related factors, such as age or gender, cannot be correlated with the scan's findings.[15] Therefore, CBCT was found to be the most adequate method of evaluation for this study. To reduce image artifacts, teeth with previous root canal treatment or metallic and heavy restorations were excluded, and only scans with a voxel size of 200 µm were selected knowing that this measure proved to be successful on detecting C-shaped morphologies in previous studies.[21,26,27]

In our study, no correlation was found between the presence of C-shaped anatomy in mandibular second molars and gender or age ($p = 0.520$), nor between the position of the tooth ($p = 0.601$). In their literature review, Fernandes et al. found that in the majority of studies similar observations were made.[3] However, some authors have found that there is a higher prevalence of C-shaped canals in mandibular second molars in females compared to males.[2,10,12,28]

A total of 60% of patients presented with a bilateral occurrence of C-shaped canals in mandibular second molars. In other studies, bilateral occurrence ranged between 38% and 85.90%. Kato et al. stated that in general, there is symmetry in tooth morphology, especially when it comes to unusual root canal morphologies such as the C-shaped canals.[18] Therefore, it is important for dentists to consider the possibility of a C-shaped canal on the opposite side if a patient has a C-shaped canal in a mandibular second molar.

Melton et al. showed that the cross-sectional configuration changes along the length of the root.[4] In our study, the configuration was noted atfour4 different levels. In mandibular second molars, the most common configuration at the orifice level was C1. At 2 mm below orifices, it was C3. In the middle third, C2 and C3 were equally predominant. At the apical level, C3, followed by C4 were most found. In a study by Kim et al, the authors found that

the most frequently observed configuration at the apical level was C3 which is in accordance with our results.[12] They also pointed out that this configuration is difficult to treat due to the presence of a narrow isthmus, which was responsible for 23.8% of the endodontic failures they found.[2] Our study showed that the majority of changes in configurations happened at the apical level, which cannot be visualized clinically even with magnification. This finding highlights the importance of preoperative CBCT to better understand this complex anatomy.

Only 1 (3.1%) of the 32 mandibular second molars presented with the same configuration (C3) at all levels. This value is close to the one found by Janani et al. in an Iranian population.[20]

Most teeth had two roots and three canals. These results are similar to the ones found in Iranian population.[20]

In all cases, no orifices were found at the level of the CEJ. They were all located below that level, which is in accordance with the findings of Fan et al.[1] In the second mandibular molar, the orifices were located at a mean distance of 3.32 mm below the CEJ, so care must be taken to search for all the orifices using magnification and lighting while treating such anatomies.

Knowing the location of the deepest groove is important to prevent strip perforations during mechanical preparation.[29] In our study, the deepest groove was most frequently lingual in the first and second mandibular molars. This finding is similar to those of others.[12,15,21,30] 100% of mandibular first molars had two grooves. In mandibular second molars, 40.6% of mandibular second molars with C-shaped canals had two grooves, 50% had only a lingual groove and 9.4% had a buccal groove. These values are close to the ones found by Helvacioglu-Yigit and Sinanoglu in the Turkish population.[21]

This study is limited by the lower resolution of the CBCT compared to the micro-CT. Therefore, further studies should focus on the micro-CT, in order to better understand the intricate anatomy of C-shaped mandibular molars, especially in the apical third of the roots where some CBCT images were not very clear.

Conclusion

The prevalence of C-shaped canals in the Lebanese population is of 1.01 and 9.09% in the mandibular first and second molars, respectively, with a high chance of bilateral occurrence. This anatomy varies along the root, with frequent changes at the apical level. The CBCT can be a useful clinical tool for understanding the complex root canal system and treatment planning.

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