Original Article

C-Shaped Canal Configuration In Mandibular Premolars And Molars: Prevalence, Correlation, And Differences: An *In Vivo* Study Using Cone-Beam Computed Tomography

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ABSTRACT

Aims: To evaluate the prevalence, correlation, and differences of C-shaped canal morphology in mandibular premolars and molars by means of cone-beam computed tomography (CBCT). **Materials and Methods:** A total of 1433 mandibular premolars and molars CBCT scans from the Saudi population were evaluated. Axial sections of the roots were acquired at coronal, middle, and apical levels to evaluate C-shaped canals types. The prevalence, correlation, differences of C-shaped canals, bilateral/unilateral presence, gender differences, and location of external grooves on roots were assessed. **Results:** The prevalence of C-shaped canals in the first premolars was 1.5%, 0.80% in second premolars and 7.9% in second molars, whereas C-shaped canals were absent in first molars. No correlation was found between the presence of C-shaped canals within premolars and molars and between the two groups in the same individual. Both premolars and molars exhibited different types of C-shaped canals, C2 being predominant in premolars and C3 in second molars. Longitudinal external grooves were mostly located on mesiolingual (ML) surface in premolars and lingual in molars. Females showed more prevalence of C-shaped canals in second molars and no differences in premolars. Bilateral symmetry and unilateral presence in premolars and second molars were not significant. **Conclusions:** Although the prevalence of C-shaped canals is significantly higher in mandibular second molars, they are also found in mandibular premolars but in small percentages. No significant differences were found between both genders and both sides. Since they exhibit unpredictable morphology and differences across the root length, the use of small field CBCT is recommended when such anatomy is presented in a tooth indicated for root canal treatment for better management.

KEYWORDS: *CBCT, C-shaped, dental anatomy, mandibular molars, mandibular premolars, the Saudi population*

INTRODUCTION

Increasing knowledge and proper detection of root canal system (RCS) anatomy and its variations in morphology before initiating root canal treatment (RCT) make the procedure more predictable.[1,2] One of the most difficult anatomical variations to appreciate is the C-shaped canal configuration of the RCS. The C-shaped canal provides a clinical challenge to endodontic procedures because its complex and unpredictable anatomy especially the shape at orifice level might differ in middle and apical third of the root.[3,4] It was first

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documented by Cooke and Cox (1979)[3] and is called C-shaped because an axial plane of the canal represents a letter "C" and this system often exhibits webs, fins, and merging of canals.[4] The etiology of C-shaped canal could be related to the failure of Hertwig's epithelial root sheath to fuse on the lingual or buccal root surface according to Manning.[5] The presence of C-shaped RCS is documented in different studies with high prevalence of teeth in mandibular second molars.[6] It is also identified in mandibular premolars[7] and maxillary molars[8] with low prevalence in few studies. Fan *et al.*[9] anatomically studied and classified C-shaped canal system into five categories: [Figure 1]

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 (d) or three (c) 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)

This classification was based on mandibular second molars since two roots have to join for a C-shaped configuration to appear. In case of mandibular premolars which are normally one rooted, C-shaped canal is characterized by presenting an axial shape as C1 or C2.[10] The prevalence of C-shaped canals in second molar has been well studied around the globe with an acceptance that a high presence is in Asian population.[6,11] In a worldwide study (2017) using a cone-beam computed tomography (CBCT), with a total of 3600 teeth from 9 countries: 499 teeth presented C-shaped root canal configuration, representing a global prevalence of 13.9% ranging from the lowest in Brazil 6.8% to the highest in China 44.0%.[12] Alfawaz *et al.*[13] in Saudi population evaluated C-shaped configuration in mandibular second molars by means of CBCT and found 9.1% prevalence rate. In the same population—Saudi Arabian—Al-Fouzan[14] reported 10.6% prevalence rate of C-shaped configuration in mandibular second molar utilizing periapical radiographs and clinical examinations.

Anatomical studies done using different techniques were utilized to evaluate C-shaped morphology including teeth clearing,[15] histology,[16] and micro-computed tomography (CT)[17] as an *ex vivo* method. Also, *in vivo* techniques such as spiral-CT,[18] CBCT,[8,19] and radiographic evaluation[20] were used. CBCT is a viable 3-dimensional (3D) modality with low radiation dose,[21] which allows examining a relatively big sample size safely and noninvasively to get a reliable prevalence results.[12] On the contrary, very few studies have focused on the prevalence of C-shaped canals in other teeth. Some recent ones from China and Portuguese, using *in vivo* CBCT in mandibular premolars, reported a presence of C-shaped morphology ranging from 1.1% to 2.3% in first premolars.[22-24] In second premolars, the prevalence was 0.6% for both Chinese and Portuguese populations.[23,24] Also, few studies addressed the prevalence of C-shaped morphology in mandibular first molar showing a very small prevalence in different populations.[2] In recent studies using *in vivo* CBCT, the prevalence was 0.19% in Saudi Arabia,[13] 0.6% in Portuguese,[25] and 1.7% in Brazil.[26]

A possible limitation of the abovementioned data is the lack of homogeneity, and upon a comprehensive literature search, no study addressed the correlation and differences between C-shaped canals in mandibular premolars and molars in the same patients. Therefore, the aims of the present *in vivo* (CBCT) retrospective study were to investigate the prevalence of C-shaped configuration in mandibular posterior teeth, a correlation between premolars and molars, and differences of C-shaped types in a Saudi Arabian population.

Materials and Methods

A total of 1433 teeth scans (776 mandibular premolars and 657 mandibular molars) were evaluated after the study protocol was approved by the local institutional review board (IRB: REC39/6-S011). CBCT scans of 208 Saudi patients with an age range between 17 and 60 years taken for different diagnostic reasons were retrieved from the database of College of Dentistry for the period 2015–2017. The CBCT machine used in this study was 3D Accuitomo 170 (MORITA, Japan) with the scanning parameters: 90 Kv, 5–8 mA, 17.5 seconds exposure time and 0.25 mm voxel size. All CBCT images were processed and reconstructed using Morita's i-Dixel 3D imaging software. Serial axial, coronal, and sagittal sections were acquired to evaluate the external and internal morphology of mandibular premolars and molars. Teeth with fully developed roots and closed apices were included in the study. Previously treated root canal, calcification or resorption, and distorted CBCT images were excluded. The CBCT images were evaluated by the same endodontist twice with a 4-week interval in-between. The following parameters were evaluated:

- Prevalence of C-shaped canals in premolars and molars
- Correlation between the presence of C-shaped configuration within premolars, molars, and between them
- Differences of C-shaped canal types between premolars and molars

- Location of longitudinal grooves
- Differences between genders and location in the jaw
- Bilateral symmetry of C-shaped canals in the same patients

C-shaped canals in premolars

A premolar tooth is considered having a C-shaped canal when two anatomical features are present: an external radicular groove and a C1 or C2 configuration present at any position of the RCS as proposed by Martins *et al.*[24] based on Fan *et al.*'s study.[10] The classification of C-shaped canals was done at three different axial levels following Fan *et al.*,[10] that is, at coronal: 2 mm under the cementoenamel junction (CEJ); middle: halfway between coronal and apical; and apical: 2 mm above the anatomic apex.

C-shaped canals in molars

For a molar tooth to be defined as having a C-shaped canal, three anatomical features should be present as described by Fan *et al.*[9]: fused roots; a longitudinal groove; and at least one cross-section of the canal showing a C1, C2, or C3 configuration. Also for the sake of this study the canal system will be considered of C-shape if "C4" type is present in all axial sections. The axial plan was recorded at three different levels: coronal (2 mm below the pulpal floor); middle (full length of the root from the pulpal floor to the apex divided by 2); and apical (2 mm coronal to the radiographic apex).

Statistical analysis

All data were analyzed using the statistical package for the social sciences (SPSS V25; IBM, Chicago, IL) software program. Data were tabulated for the prevalence of C-shaped configuration types and the differences in the independent groups were analyzed using Z-test for proportions. One-sample Chi-square test was used for the distribution of grooves among the study sample. For the association between the C-shaped prevalence and other parameters of the study, Pearson's Chi-square test was used. Bilateral symmetry was tested using Cohen's kappa test. All statistical tests were performed at significant level ($P < 0.05$).

Results

For inter-rater reliability, two readings of 30% of the study sample were taken with an interval period of 4 weeks. Cohen's kappa test revealed almost perfect agreement of measurement with a value of 0.85 and $P < 0.001$. A total of 208 subjects were included in this study (48% males and 52% females) with a mean age of 28.95 ± 9.80 years (median = 26) ranging from 17 to 59 years. Among 1664 screened teeth, 1433 teeth were valid for analysis. Of those, there were 776 premolars, 397 (51%) first premolars, 379 (49%) second premolars, 657 molars, 290 (44%) first molars, and 367 (56%) second molars.

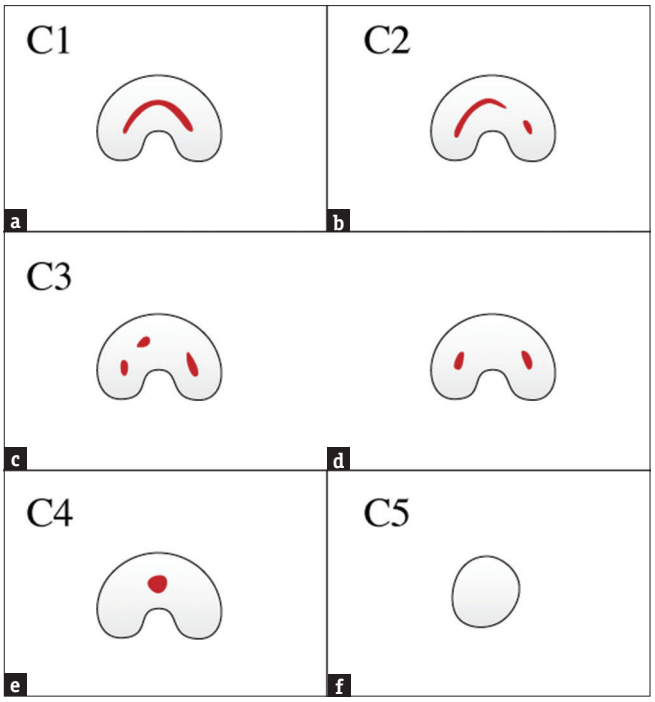

Figure 1: C1: Uninterrupted C with no separation or division (a); C2: The canal shape represents a semicolon resulting from discontinuation of the C outline (b); C3: Two (d) or three (c) separate canals; C4: Only one round or oval shaped canal in the cross section (e); and C5: No canal lumen could be observed (f)

Table 1: Prevalence of C-shaped configuration among the study samples

	C-shaped	*n*(%)	95% CI
Premolars (*n*=776)			
All	No	767 (98.8%)	98% - 100%
	Yes	9 (1.2%)	0% - 2%
1st premolars	No	391 (98.5%)	97% - 100%
	Yes	6 (1.5%)	0% - 2%
2nd premolars	No	376 (99.2%)	98% - 100%
	Yes	3 (0.8%)	0% - 2%
Molars (*n*=657)			
All	No	628 (95.6%)	94% - 97%
	Yes	29 (4.4%)	3% - 6%
1st molars	No	290 (100%)	
	Yes	0 (0.0%)	
2nd molars	No	338 (92.1%)	89% - 95%
	Yes	29 (7.9%)	5% - 11%

Prevalence of C-shaped canals in premolars and molars

Prevalence of C-shaped configuration was found in nine (1.2%; $CI_{95\%}$= 0%–2%) premolars accounting for 6 cases among first premolars (1.5%; $CI_{95\%}$= 0%–2%) and three cases among second premolars (0.8%; $CI_{95\%}$= 0%–2%). [Figure 2] The prevalence in molars was found

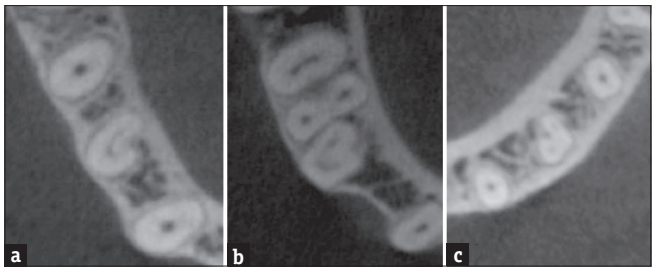

Figure 2: Example of axial cone-beam computed tomography (CBCT) sections for mandibular premolars in middle level: a) shows type C1; b) shows type C2; c) shows type C3

Table 2: C-shaped configuration types by axial levels in premolars and molars (%)

		Premolars			
		C1	C2	C3	C4
Axial level	Coronal	0 (0.0)	1 (11.1)	0 (0.0)	8 (88.9)
	Middle	2 (22.2)	6 (66.7)	1 (11.1)	0 (0.0)
	Apical	0 (0.0)	4 (44.4)	5 (55.6)	0 (0.0)
Total		2 (7.4)	11 (40.7)	6 (22.2)	8 (29.6)
χ^2=30.46; *P*<0.001					

		Molars				
		C1	C2	C3	C4	NA
Axial level	Coronal	11 (37.9)	10 (34.5)	1 (3.4)	5 (17.2)	2 (6.9)
	Middle	3 (10.3)	7 (24.1)	13 (44.8)	6 (20.7)	0 (0.0)
	Apical	6 (20.7)	1 (3.4)	17 (58.6)	5 (17.2)	0 (0.0)
Total		20 (23.0)	18 (20.7)	31 (35.6)	16 (18.4)	2 (2.3)
χ^2=29.44; *P*<0.001						

NA: not available

Table 3: Groove location in C-shaped premolars and molars

Teeth	Groove	*n*(%)	*P*
Premolars	Mesial	1 (11.1)	NC
	Lingual	2 (22.2)	
	Mesiolingual	6 (66.7)	
Molars	Buccal	8 (27.6)	<0.001
	Lingual	17 (58.6)	
	Buccal and Lingual	1 (3.4)	
	NA	3 (10.3)	

NC: not computed; NA: not available

in 29 cases (4.4%; $CI_{95\%}$= 3%–6%). All these cases, however, were found only in second molars accounting for 7.9% ($CI_{95\%}$= 5%–11%) [Table 1].

Correlation between the presence of C-shaped configuration within premolars, molars, and between them

Among the 208 patients included in this study, 26 had C-shaped configuration in premolars or molars. There were 4 (15.4%) subjects having a C-shaped configuration in first premolars, 3 (11.5%) subjects having in second premolars, and 19 (73.1%) subjects having in second molars. No patient had C-shaped canal in first and second premolars. Also, no patient had C-shaped system in first and second molars or between the two groups (premolars and molars) in the same patient.

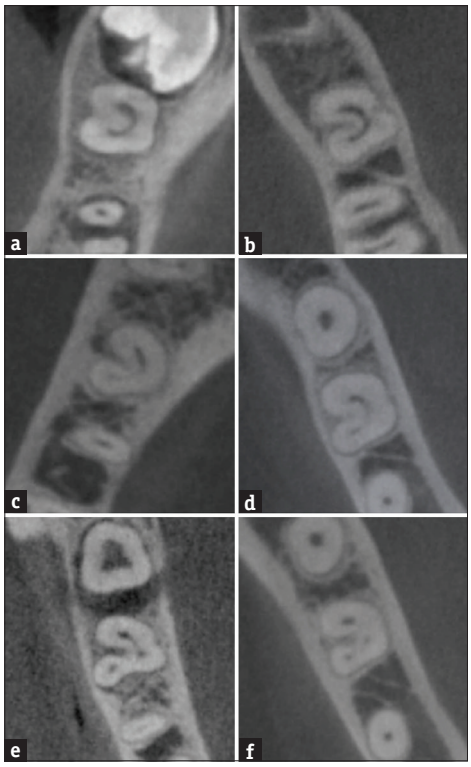

Figure 3: Example of different axial CBCT sections for mandibular second molars middle level shows: type C1 (a and b); type C2 (c and d); and type C3 s (e and f)

Differences of C-shaped canal types between premolars and molars

C-shaped configuration types for each axial level in premolars and molars are presented in Table 2. The most dominant configuration type in premolars was C2 (40.7%) which was found in all axial levels. C1 and C4 were, however, found only in the middle and coronal levels, respectively [Figure 3]. According to the method we used, nine premolars in general exhibited C-shaped canals, seven exhibited C2 type, 78%, and (two exhibited C1 type, 22%. The most frequent C-shaped configuration type in second molars was C3 which was found in 31 levels (35.6%) predominantly in the middle and apical levels, followed by C1 in 20 levels (23.0%). Only one coronal level was found with C3 and one apical level with C2 [Figures 3 and 4]. There were 2 cases (2.3%) that did not show C-shaped in the coronal section, canals were totally separate and no complete fusion had happened of the roots yet.

Location of longitudinal grooves

As shown in Table 3, the longitudinal grooves in premolars were located frequently in ML location (6 cases, 66.7%) while, in second molars, the

Table 4: Prevalence of C-shape in premolars and molars by location and gender (%)

		Location		*P*
		Right	Left	
ALL Premolars	Absent	379 (98.4)	388 (99.2)	0.337
	Present	6 (1.6)	3 (0.8)	
1st premolars	Absent	194 (98.0)	197 (99.0)	0.449
	Present	4 (2.0)	2 (1.0)	
2nd premolars	Absent	185 (98.9)	191 (99.5)	0.619
	Present	2 (1.1)	1 (0.5)	
2nd molars	Absent	319 (96.4)	309 (94.8)	0.348
	Present	12 (3.6)	17 (5.2)	
		Gender		*P*
		Male	Female	
ALL Premolars	Absent	96 (96)	105 (97.2)	0.713
	Present	4 (4)	3 (2.8)	
1st premolars	Absent	94 (97.9)	105 (98.1)	1.000
	Present	2 (2.1)	2 (1.9)	
2nd premolars	Absent	96 (98.0)	101 (99.0)	0.616
	Present	2 (2.0)	1 (1.0)	
2nd molars	Absent	94 (94)	90 (87.4)	0.148
	Present	6 (6)	13 (12.6)	

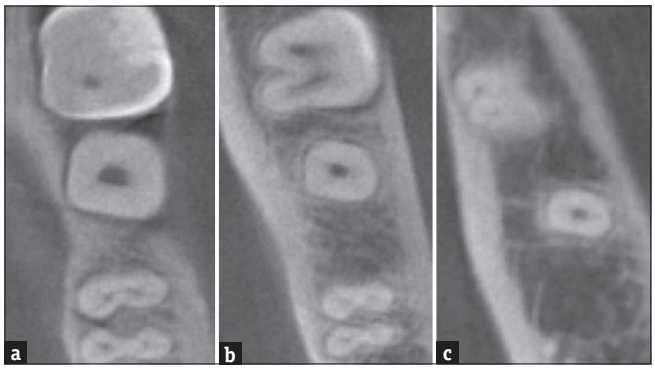

Figure 4: Example of axial CBCT sections for mandibular second molars. a) coronal level shows type C4; b) middle level shows type C4; c) apical level shows type C4

location of the longitudinal groove was significantly higher on the lingual side (58.6%; $P < 0.001$). Three roots were completely conical and no grooves were detected in these teeth.

Differences between genders and locations in the jaw

No significant differences were found between both genders and between both sides in relation to the presence or absence of C-shaped configuration in premolars and second molars, in total or separately [Table 4].

Bilateral symmetry of C-shaped canals in the same patients

For first premolars, four patients (1.9% of the study sample) had a C-shaped configuration in their mandibular first premolars and two of them had bilateral C-shaped canal (0.96%). Within the four subjects, two (50%) had C-shaped configuration in right and left sides, and two subjects (50%) had C-shaped configuration on the right side only. In second premolars, three subjects (1.4% of the study sample) had C-shape in their mandibular second premolars. Of them, two subjects (66.3%) had C-shaped configuration on the right side only, and only one subject (33.4%) had C-shaped configuration on the left side. Nineteen patients (9% of the study sample) were found to have C-shaped configuration in their mandibular second molars. Out of them, 10 subjects (53%)—representing 4.8% of the total sample—had C-shaped configuration on both right and left sides. Two patients (10%) had C-shaped configuration on the right side only, and seven subjects (37%) had C-shaped configuration in left side only. Cohen's kappa test for symmetry revealed nonsignificant bilateral symmetry with a value of 0.196 and $P = 0.253$.

Discussion

Micro-CT is the most advanced and noninvasive *ex vivo* tool that is recently being used to study external and internal teeth morphology providing researchers with high anatomical details compared to teeth clearing and CBCT methods.[27] This *ex vivo* modality has been used to evaluate C-shaped canal configuration in mandibular premolars and molars.[7,9,10] Micro-CT high-resolution images helped to properly visualize and classify C-shaped canals,[9,10] however, it cannot be properly used in prevalence studies because of limited sample size, lack of information regarding gender, and precise location of the tooth in the jaw. CBCT is an *in vivo* valid method to evaluate teeth anatomy and morphology which provided good amount of details.[28] It is used widely in endodontics and for prevalence studies with a voxel size used for C-shaped molars ranged from 0.075 to 0.25 mm,[12] which is consistent with this study.

Mandibular premolars

Mandibular premolars showed a low prevalence of C-shaped configuration in this study (1.5%, and 0.8% in first and second premolars, respectively). These data are in agreement with previous findings from two other CBCT studies in Chinese populations: one of them reported 1.4% prevalence of first premolar[22] and the other one 1.1% for first premolar and 0.6% for the second premolar.[23] The actual number of examined teeth and consequently the number of C-shaped canals found was low in both the studies. Yang *et al.*[22] found 5 C-shaped canals in 440 first premolar teeth, while Yu *et al.*[23] reported 2 out of 178 C-shaped canals in first premolars and 1 out of 178 in second premolars. More recently, a CBCT study in Portuguese population found 31 C-shaped canals in 2012 mandibular premolars, with

a prevalence of 2.3% in first premolars and 0.6% in second premolars.[24] This study had a slightly higher prevalence in first premolars compared to our findings, while, inconsistent in regard to second premolars with our results. None of the two studies from China mentioned how they classified C-shaped canals, whereas, this and Martins' *et al.*'s[24] studies were based on Fan's criteria.[10] Mandibular first premolars were studied in *ex vivo* using micro-CT.[7,10] These studies found C-shaped RCS presents a continuous "C" with no separation or division (type C1) or a canal shape resembling a semicolon resulting from a discontinuation in the "C" outline (type C2) while the more complex C1 and C2 configurations were present mainly in the middle third of the root. The micro-CT studies[7,10] also found a relation between the external and internal morphology, where C-shaped canals were found on premolars with external longitudinal grooves. Our *in vivo* CBCT study provided similar results regarding the presence of C1 and C2: moreover, all C-shaped canals exhibited detectable external grooves.

Mandibular first molars

Not surprisingly, in this study, no C-shaped canal was found in 290 mandibular first molars. Recent prevalence studies using CBCT have reported extremely small percentages: in a Saudi Arabian population it was 0.19% in 529 first molars,[13] in Portuguese population 0.6% in 695 first molars,[25] and slightly higher 1.7% in a Brazilian population in 234 first molars.[26] Only few case reports of C-shaped mandibular first molars were reported in a systematic review by De Paplo *et al.*[2] on the anatomy of mandibular first molar.

Mandibular second molars

Mandibular second molars have the highest prevalence of C-shaped configuration compared to the other teeth investigated in this study: 29 out of 367 second molar teeth (7.9%) exhibited this morphological configuration. The prevalence of C-shaped canals in mandibular second molars is very well studied since Cooke and Cox,[3] with a higher prevalence in the Asian population.[11,12,29] Fernandes *et al.*[29] in a systematic review found variations in the presence of C-shaped canals among geographic locations using different methodologies ranging from 2.7% to 44.5%. A 2017 *in vivo* study[12] using CBCT, where samples collected from around the globe, reported 499 C-shaped molars out of 3600 second molar teeth. The prevalence was ethnically variable, ranging from the lowest in Brazil with 6.8% to the highest in China with 44.0%. The results of this study (7.9%) fit in the low range of this worldwide prevalence study. In addition, our findings are consistent with two recent CBCT studies on mandibular second molars in Middle East[13] and Western Europe[25] populations, which reported 9.1% of 681 teeth and 8.5% of 1088 teeth, respectively. To define variability of C-shaped morphology Fan *et al.*[9] used micro-CT to examine 58 extracted mandibular second molars with fused roots: they came up with the classification modifying the original work of Melton *et al.*[16] In his study, the cross-section shape of the canals at 11 different levels and the associated external grooves were assessed. Most orifices were found within 3 mm below the CEJ. A majority of C-shaped canals demonstrated an orifice with an uninterrupted "C" configuration and the cross-sectional shape varied greatly corono-apically. Teeth with deep grooves had at least one section with C1, C2, or C3 configurations. These findings related to second mandibular molars were found in our CBCT study.

In this study, we investigated the correlations of both prevalence and configuration of the C-shaped canal between premolars and molars: no study so far has addressed this issue. Results showed no correlation in C-shaped prevalence between the first and second premolars in the same patients. The same results were found for the first and second molars, and no patient with C-shaped canal in mandibular premolars had a C-shaped configuration in a mandibular second molar. Interestingly, this study showed a difference between premolars and molars in regard to the type of C-shaped canals, where C2 was predominant in premolars and C3 in second molars. Martins *et al.*[24] found the same high prevalence of type C2 in mandibular premolars, and Alfawaz *et al.*[13] reported similar results regarding C3 type in mandibular second molars. These differences between the two teeth groups could be clinically relevant: moreover, second molars generally showed higher variations in different cross-sections compared to premolars.

Differences were found in regard to the presence of radicular grooves: in premolars, they were mostly located in the ML surface. This finding is consistent with Fan *et al.*'s[10] and Martins *et al.*'s[24] studies. In the second molars, they were more frequent in the lingual radicular surfaces, in agreement with other studies.[13,25,30] Gender association with the prevalence of C-shaped canal was also investigated in this study and differences were found between premolars and second molars. Sex had no impact on the prevalence of C-shaped canal in premolars, while Martins *et al.*'s[24] study showed higher prevalence in male individuals. In second molars, this study showed that females exhibited significantly higher percentage of C-shaped canals compared to males. This finding is in agreement with other studies in Saudi

Arabian and Portuguese populations suggesting higher prevalence in female populations,[13,25] while other ones from China[19] and Turkey[30] found no associations with gender.

Concerning left and right teeth, there was 0.96% bilateral C-shaped symmetry out of 194 patients with both right and left first premolars present and none in the second premolars. Martins *et al*.[24] reported (1.4% and 0.29%) in first and second premolars, respectively, which are slightly higher than our findings. In the second molars, 4.8% of patients exhibited bilateral symmetry out of 166 who have both contralateral second molars present. Out of 19 patients with C-shaped canals, 53% showed the bilateral presence of C-shaped configuration, where, Zheng *et al*.[19] found a higher prevalence of bilateral symmetries 81% in Chinese population compared to our results. These differences may be related to the smaller number of C-shaped canals in mandibular premolars, further studies should be conducted with bigger sample size in different populations to evaluate the clinical relevance of these correlations.

Conclusion

The prevalence of C-shaped canals in mandibular premolars was relatively low, while in the second molars it was higher. No C-shaped canals correlation was found between premolars and molars and between the two groups in the same patients. Also, no significant differences were found between both genders and between both locations (right and left) in the jaw with regard to the prevalence of C-shaped canals. Types of C-shaped canals in premolars were mainly C2 and in second molars C3. Such individual variations suggest the use of CBCT small field-of-view to improve diagnosis and/or performance of endodontic treatment when C-shaped canals are present or suspected.

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Conflicts of interest

There are no conflicts of interest.

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