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Original research

Cone beam computed tomography evaluation of c-shaped canal morphology in mandibular premolar teeth*

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Purpose
The aim of this study was to evaluate the prevalence and the morphology of c-shaped root canal(s) in mandibular premolars using cone beam computed tomography (CBCT) images.

Materials and Methods
CBCT images of 1095 mandibular premolars were examined at coronal, middle, and apical levels of the root canals. The type, the level, and the position (buccal or lingual) of the c-shaped anatomy were recorded. Absolute counts and percentages of different groups and subgroups of C-shape morphologies were calculated. The Chi-square test was used to compare the prevalence of C-shaped morphology between mandibular first and second premolars. The Z-test for proportions in independent groups was used to analyze the differences in mandibular C-shaped premolar proportions between location (left and right side) and tooth (first or second premolars) (p=0.05).

Results
C-shaped root canal morphology was present in 44 teeth. The percentage of c-shaped morphologies was 6.9% and 1.6% in mandibular first and second premolars, respectively. Comparison of the first and the second premolars showed that C1 type (p=0.008) and C4b type (p=0.013) configurations are more common in the first premolars at the coronal level. In contrast, the C2 type configuration showed significantly higher prevalence in the second premolars (p=0.009). Additionally, the C4c type configuration was significantly frequent on the right premolars at the coronal level (p=0.038).

Conclusion
C-shape canal morphology is a rare but complex anatomic feature in mandibular premolars. Therefore, clinicians should be aware of this complex root canal anatomy for the success of endodontic treatment in mandibular premolar teeth.

Keywords: *C-shaped configuration, cone beam computed tomography, mandibular premolar, prevalence study, root canal anatomy*

Introduction

Definitive knowledge of root and canal morphology, including anatomic variations, is the primary step of endodontic treatment (1). Due to their complex morphology, C-shaped canals may create great challenges during endodontic treatment with respect to shaping, debridement, and obturation (2). C-shaped canal morphology is described as the presence of fins and isthmuses connecting individual canals or merged root canals resulting in a 'C' shaped appearance at cross-sectional views (3). However, this morphology may not be continuous throughout the root length (4). As reported previously, a root canal with C-shaped morphology at the coronal third of the root may not continue as a single C-shaped canal at the middle and apical thirds (5). On the other hand, separated canals de-

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tected at the floor of the pulp chamber may merge and continue as a single C-shaped canal (6). It has been stated that C-shaped molars usually contain a fused root and a longitudinal radicular groove, which is also identified in C-shaped mandibular premolars (1). The radicular groove is defined as a developmental invagination and frequently exhibits on the proximal lingual area of the middle root of the C-shaped mandibular premolars (7). It is important that isthmuses within the root canal system may exist close to this groove, which creates a danger zone concerning a possible complication during endodontic treatment (1, 7). Therefore, the detection of canal morphology and necessary modifications in the shaping and filling of C-shaped canals are essential for successful endodontic treatment of C-shaped canals (2).

C-shaped canal morphology is a well-known anatomic variation in mandibular molar teeth and is mostly found in mandibular second molars (3, 8, 9). However, its presence has been recently reported in mandibular premolars, maxillary molars, and even in maxillary lateral incisors (2). Many studies have investigated the prevalence of C-shaped root canal morphology in mandibular molars; however, there are few studies evaluating C-shaped canal prevalence in maxillary molar and mandibular premolar teeth (3). Therefore, the aim of this study was to evaluate the prevalence and the morphology of the C-shaped root canal(s) in mandibular premolars using cone beam computed tomography (CBCT) images. The null hypothesis was that there would be no C-shaped canal morphology in mandibular premolar teeth.

Material and Methods

Ethical statement

The present study design was approved by the Ethical Committee of Ege University (2021/22-2.1T/33) and followed the principles of the Declaration of Helsinki.

Sample selection

A total of 2024 CBCT images taken for various reasons between the years of January 2019 and March 2020 at the department of Oral and Maxillofacial Radiology were examined retrospectively, and images of patients with at least one mandibular premolar were included in the study. Teeth with previous endodontic treatment, internal and/or external root resorptions, immature apices, periapical lesions, full-crown restorations, and CBCT images with severe artifacts due to other restorations were excluded. Consequently, 1095 mandibular premolar images (489 first and 606 second premolars) of 586 patients (229 male and 357 female) were evaluated. The mean age of the patients was 31.8±14.6 years.

Image acquisition

CBCT scans had been previously obtained using Kodak 9000 3D (Kodak Carestream Health, Trophy, France) device at 70kV, 10mA, and 10.8s exposure time, using a 50 x 37 mm field of view (FOV) and a 76 µm isotropic voxel size.

Image assessment

All premolars were analyzed at three axial levels from the cemento-enamel junction to the anatomic apex. Two millimeters below the cemento-enamel junction was accepted as the coronal level; likewise, 2 mm above the anatomic apex as the apical level; and the halfway between the coronal and apical levels was considered as the middle level. C-canal configurations were classified according to the modified classification system described by Fan *et al.* (1). According to this classification, C1 was identified as a continuous 'C' with no separation or division; C2 as a discontinuation in the 'C' outline resembling a semicolon; C3 as two separate round, oval, or flat canals; C4 as one round, oval, or flat canal; C5 as three or more separate canals and C6 as no canal lumen or no intact canal. In addition, C4 configuration was divided into 3 subgroups (C4a, C4b, C4c) as reported by Wu *et al.* (10): C4a (round canal): The long canal diameter is almost equal to the short diameter. C4b (oval canal): The long canal diameter is at least 2 times shorter than the short diameter. C4c (flat canal): the long canal diameter is at least two times longer than the short diameter (Figure 1). As reported previously, mandibular molars and premolars containing the C-shaped canal morphology are often observed with fused roots and a longitudinal radicular groove (1, 5). Therefore, in the current study, teeth with an external radicular groove and with C1 or C2 canal configuration at any axial level were considered as having C-shaped canal morphology (Figure 2). Two oral radiologists and one endodontist made the radiographic evaluations. The type of the C-shaped canal configuration was recorded at each axial level for each mandibular premolar independently along with the number of the roots containing C-shaped anatomy (C1 or C2). In addition, buccal or lingual orientation of the C-shaped canal was recorded for each axial level.

Statistical analysis

Data analysis was performed using the IBM SPSS Statistics 20.0 (SPSS Inc., Armonk, NY, USA). Absolute counts and percentages of different groups and subgroups of C-shape morphologies were calculated for all mandibular premolar teeth. The proportion of each group was determined, as was the range for the true population proportion, to a confidence level of 95%. The chi-square test was used to compare the prevalence of C-shaped morphology between mandibular first and second premolars. The Z-test for proportions in indepen-

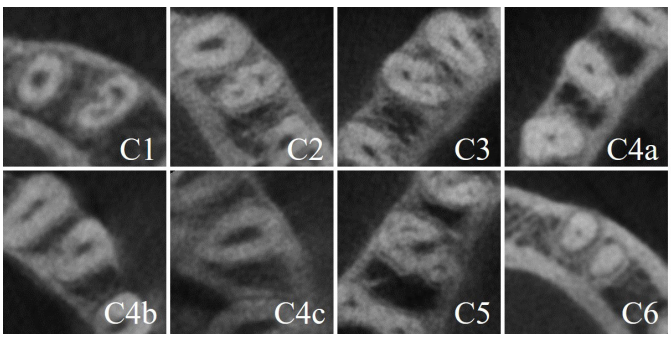

Figure 1. *Classification of the C-shaped canal configuration in mandibular premolars.*

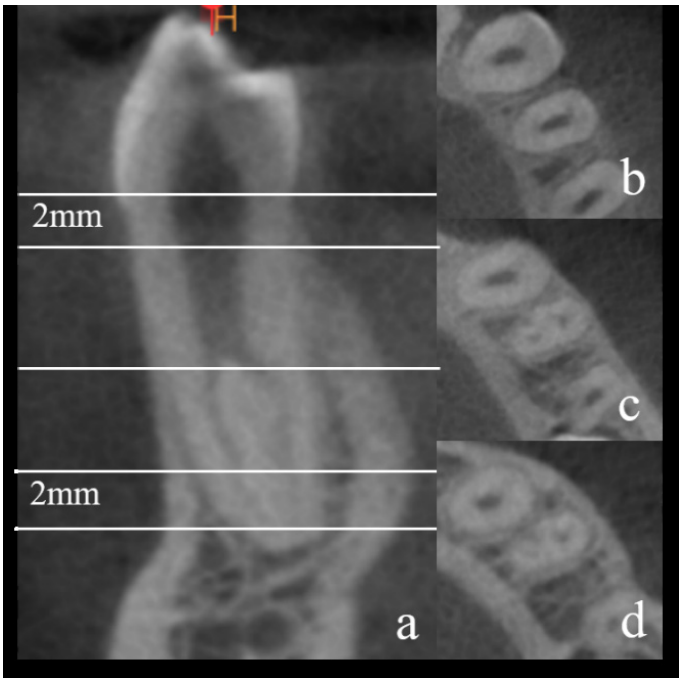

Figure 2. *CBCT image representing the diagnosis of C-shaped configuration. (a) Frontal CBCT image showing a C-shaped mandibular first premolar. (b) Axial CBCT image showing the C4c type configuration at the coronal level. (c) Axial CBCT image showing the C2 type configuration at the middle level. (d) Axial CBCT image showing the C3 type configuration at the apical level.*

dent groups was used to analyze the differences in mandibular C-shaped premolar proportions between location (left and right side) and tooth (first or second premolars). For all groups, a *p* value <0.05 was considered significant.

Results

The null hypothesis was rejected. C-shaped canal morphology was found in 32 (24 male and 8 female) of 586 patients (5.4%). The C-shaped canal percentages for male and female patients were 10.4% and 2.2%, respectively. The mean age of the patients with C-shaped morphology was 22.75±10.56 years. Among 1095 mandibular premolars, 44 teeth were identified as having C-shaped canal morphology with a prevalence of approximately 4%. All premolar teeth with C-shaped canal morphology had an external longitudinal groove, which was located in the mesio-lingual surface of the root. Thirty-four of 489 mandibular 1st premolars and 10 of 606 mandibular 2nd premolars showed C-shaped canal morphology. The prevalences for mandibular first and second premolars were 6.9% and 1.6%, respectively. The C-shaped canal configuration was observed frequently in the right first premolars and least in the left second premolars. The counts and percentages of C-shaped canal configuration for each mandibular premolar tooth were presented in Table 1.

Comparison of different axial levels for C-shaped canal configurations

The most frequent configurations at the coronal level were C4b and C4c. On the other hand, C1 and C2 configurations, which were considered as defining criteria for a C-shaped canal, were more common at the middle level. As for the apical level, the C3 configuration was more prevalent. C5 and C6 configurations were not present at the coronal level, whereas C4a, C5, C6 configurations at the middle level and C4b, C4c, C5 configurations at the apical level were not observed. Cshaped canal configuration prevalence for each axial level was presented in Table 2.

Comparison of first and second premolars

When the first and the second premolars were compared in regard to C-shaped configurations at various axial levels, it was observed that C1 (p=0.008) and C4b (p=0.013) configurations were significantly common in the 1st premolars at the coronal level, whereas C2 (p=0.009) configuration was frequent in the 2nd premolars. No significant differences were observed between the first and the second premolars in terms of C-shaped canal morphology at the middle and the apical levels.

Comparison of the left and right premolars

Comparison of the left and right sides revealed that 14 C-shaped premolars were identified on the left side while it was 30 on the right. C4c canal configuration was significantly more prevalent in the right premolars at the coronal level (p=0.038). No significant differences were observed be-

Table 1: *The counts, percentages, and location of mandibular premolars with C-shaped canals*

No & type of teeth	No. of C-shaped canals	%	Location of premolar tooth (right/left)
1095 premolars	44	4	30/14
489 1st premolars	34	6.9	24/10
606 2nd premolars	10	1.6	6/4

Table 2: *Distribution of C-shaped canal configurations* at different levels of root canal (coronal-middle-apical) of mandibular premolar teeth. *According to Fan et al. (1)*

C-shape configuration	1st premolar Axial cross-sections (n)			2nd premolar Axial cross-sections (n)		
	Coronal	Middle	Apical	Coronal	Middle	Apical
C1	5	10	9	-	3	3
C2	1	21	5	4	6	2
C3	1	1	14	-	-	3
C4a	-	-	5	2	-	2
C4b	13	1	-	1	1	-
C4c	14	1	-	3	-	-
C5	-	-	-	-	-	-
C6	-	-	1	-	-	-

tween the right and left premolars as regards to C-shape canal morphology at the middle and the apical levels (p>0.05).

Number of roots and position of the C-shaped canals

Among 44 C-shaped premolars, 28 first premolars and 5 second premolars were single-rooted, while 6 first premolars and 5 second premolars were bi-rooted. Except for a single 2nd premolar, the C-shaped morphology was always found in the buccal root of the bi-rooted teeth (Table 3).

Table 3: *Distribution of the number of roots and position of the C-shaped canal in mandibular premolar teeth*

Number of roots and position of the C-shaped canals	1st premolar	2nd premolar	Total
Single root-single canal	17	1	18
Single root- Buccal	11	4	15
Single root-Lingual	-	-	-
Two roots-Buccal	6	4	10
Two roots-Lingual	-	1	1

Discussion

Successful endodontic treatment requires knowledge of anatomic variations and morphologies of the root canal system (2). Canal systems with different morphologies, such as C-shaped canal morphology, may create considerable risk for treatment failures because infected debris and remnants may remain on root canal walls due to inadequate cleaning and filling (5). It has been stated that the actual number and correct configuration of root canals can be determined more accurately with 3D imaging (11). According to the joint position statement of the American Association of Endodontists (AEE) and the American Academy of Oral and Maxillofacial Radiology (AAOMR), a limited field-of-view (FOV) CBCT can be considered the imaging modality of choice for teeth with complex root canal morphology (12).

Many studies have been published evaluating the prevalence of the C-shaped canal morphology in mandibular first and second molars using 3D CBCT images (4, 13-19). However, the prevalence of C-shaped canal morphology in mandibular 1st and 2nd premolars using CBCT images had not been frequently investigated (3, 20-23).

The prevalence of C-shaped canal morphology for 1st (6.9%) and 2nd (1.6%) premolars in the present study was consistent with the previous CBCT reports showing a low prevalence of C-shaped morphology in mandibular premolars. Kaya Buyukbayram *et al*. (24) and Pedemonte *et al*. (25) reported 4.58% and 1.13% prevalence ratios ranging between 4.58-10.9% for 1st and 1-1.13% for 2nd mandibular premolars, respectively.

It was also emphasized that prevalence ratios of anatomical variations of C-shaped canal configuration for mandibular premolars might differ depending on ethnicity and geography (2, 23). Different studies based on South American and Saudi Arabian populations reported higher prevalence ratios than the present study (21, 23). On the other hand, one Iranian study failed to identify any C-shaped premolars in their study group (26). Some South Korean, Asian, and Saudi Arabian studies stated similar yet lower prevalence ratios, and, unlike the present study, a significant difference between the first and second premolars were reported (20, 22, 27). Side with the ethnic diversity, variabilities with regard to root canal morphology may also depend on the selected study groups, study design, and classification of the C-shaped morphology. Although the difference between the first and second premolars in the present study was insignificant, the higher prevalence observed in 1st premolars agreed with many previous reports suggesting that first premolars tended to demonstrate C-shaped morphology more than 2nd premolars (22, 25, 27, 28).

In the present study, males showed a significantly higher rate of C-shaped mandibular premolars than females. A previous study conducted on the Turkish population similarly found a higher prevalence in males and determined a significant relationship between gender and C-shaped canal morphology (29). However, another study conducted on the Turkish population could not find any difference between genders (24). Overall review of the literature demonstrated some studies reporting higher prevalence for males in terms of C-shaped morphology in mandibular premolars (20, 22, 28), while others showed higher prevalence for females (30). Moreover, there were many studies that could not state a significant distinction between genders in regard to C-shaped canal morphology in mandibular premolars (23, 24, 27). It is clear that there is no definite association between gender and C-shaped canal configuration in mandibular premolars. This lack of information may be related to the small sample sizes resulting from the lower prevalence of C-shaped canal configuration in mandibular premolars, as well as the use of low-resolution images with high voxel sizes for the detection of this anatomical variation. Further controlled studies are required to determine the proper relationship between gender and C-shaped canal prevalence in mandibular premolars with high sample sizes from different populations and high-quality radiographic images.

It has been reported that there is no accepted classification system for C-shaped canals for mandibular premolars. Nevertheless, it is interesting that some studies did not describe the classification system used to rank the C-shaped canal configuration (25, 31). The modified classification of Fan *et al*. (1) was preferred in the present study for mandibular premolar C-shaped canal evaluations since it was a detailed classification and predominantly preferred in recent studies that enabled objective comparisons.

It was demonstrated previously that similar to the prevalence of C-shaped morphology, the type of canal configuration might also vary depending on nationality (20). Yet, findings of the present study showing higher rates of C4b and C4c configurations at the coronal level and C1 & C2 configurations at the middle level are consistent with the result of many previous studies (21-24, 29, 30). In the mandibular molar teeth with C-shaped canal morphology, the orifice usually appears as a continuous C shape (C1) or a semicolon-like form (C2) (5). However, in mandibular premolars, C-shaped configuration appears as an oval, round or flat-shaped canals in the coronal third of the root and reveals its C-shaped canal form in the middle third (21, 23, 28). Mandibular premolars with C-shaped canals have also been distinguished by the presence of an ex-

ternal radicular groove frequently developing on the proximal lingual area of the middle root[7] and mesio-lingual surface placement has been reported as the most common position of the radicular groove (5, 22, 23, 27, 28). In the present study, all premolar teeth with C-shaped canal morphology demonstrated a mesio-lingual radicular groove.

Studies evaluating C-shaped canals in mandibular molars proved that C-shaped canal configuration tends to be located at the root fusion, where the radicular groove develops (5). Similarly, C1 and C2 configurations have been observed to be associated with the external radicular groove in mandibular premolars (21); which creates a danger zone during endodontic treatment (1). Owing to the close proximity of the radicular groove to the isthmuses and C-shaped canals, the dentin wall facing the groove may become relatively thin, particularly in the middle third of the root (1, 5). Gu *et al*. (32) confirmed that the dentin thickness between the root surface and the canal was the thinnest at the location of the radicular groove. Therefore, clinicians should be aware of this morphological discrepancy and should be careful to avoid stripping perforation during the instrumentation of C-shaped canals. The distinction of this morphological variation is also crucial for the planning of endodontic post placement.

Another endodontic challenge observed with C-shaped canal morphology has been stated as the unusual anatomy of the pulp chamber (2, 6). Studies evaluating the C-shaped canals in mandibular molars proved that the floor of the pulp chamber is situated deeply, and the orifice of the C-shaped canal begins below the cementoenamel junction (5). Ariciouglu *et al.* (29) reported a significant correlation between taurodontism and C-shaped configuration in mandibular molars. To our knowledge, there are no published studies evaluating the presence of taurodontism in C-shaped mandibular premolars. However, similar to the results of the present study, many studies have reported that, in the mandibular premolar teeth, the coronal third of the root of the canal begins as an oval, round or flat, and the C-shaped configuration appears in the apical half of the root (20). In addition, Vertucci type V configuration was highly associated with C-shaped canal morphology in mandibular premolars (24, 28), and the bifurcation in such teeth was usually detected at the middle third of the root (30). Therefore, clinicians should be conscious and attentive to variable canal configurations that can be seen in the middle and apical thirds of the root in the mandibular premolars, as well as possible unusual anatomy of the pulp chamber for the success of endodontic treatment.

Conclusion

According to the results obtained, C1 and C2 configurations, which were suggested as the defining criteria for C-shaped canal morphology, tend to be more frequent at the middle third of the root canal in mandibular premolar teeth. Therefore, if the presence of C-shaped morphology in mandibular premolars is suspected clinically, we recommend examining particularly the middle axial level at CBCT images. Presence of various forms of C-shaped root canals requires extra knowledge and care in terms of shaping, irrigation and obturation for successful endodontic treatment. Therefore, clinicians should be aware of diagnosing possible variations in mandibular premolar teeth.

Türkçe özet: *Mandibular premolar dişlerde c-şekilli kanal morfolojisinin konik ışınlı-bt ile değerlendirmesi. Amaç: Bu çalışmanın amacı, mandibular premolar dişlerdeki C-şekilli kök kanal(lar)ının prevalansının ve morfolojisinin konik ışınlı bilgisayarlı tomografi (KIBT) görüntüleri kullanılarak değerlendirmesidir. Gereç ve Yöntem: 1095 mandibular premolar dişe ait KIBT görüntüsü koronal, orta ve apikal kök seviyelerinde incelenerek C-şekilli anatominin tipi, seviyesi ve pozisyonu (bukkal veya lingual) kaydedildi. Farklı gruplara ve altgruplara göre C-şekilli morfolojinin dağılımı ve yüzdesi hesaplandı. Mandibular birinci ve ikinci premolar dişler arasında C-şekilli morfolojinin prevalansının karşılaştırılması amacıyla Ki-kare testi kullanıldı. Farklı konum (sol ve sağ) ve diş grupları (birinci ve ikinci premolar dişler) arasındaki C-şekilli morfoloji farklılıklarının analiz edilmesi amacıyla ise Z-testi kullanıldı (p=0,05). Bulgular: 44 mandibular premolar dişte C-şekilli kök kanal morfolojisi saptandı. Mandibular birinci ve ikinci premolar dişlerdeki C-şekilli morfolojilerin yüzdesi sırasıyla %6,9 ve %1,6 olarak hesaplandı. Birinci ve ikinci premolar dişlerin karşılaştırılması sonucu, birinci premolar dişlerin koronal seviyesinde C1 tipi (p=0,008) ve C4b tipi (p=0,013) konfigürasyonların daha yaygın olduğunu belirlendi. Buna karşılık, ikinci premolar dişlerde ise C2 tipi konfigürasyonun anlamlı olarak yaygın olduğu gözlendi (p=0,009). Ek olarak, sağ premolar dişlerin koronal seviyesinde C4c tipi konfigürasyonun anlamlı derecede sık görüldüğü saptandı (p=0,038). Sonuç: C-şekilli kanal morfolojisi, mandibular premolar dişlerde nadir olarak izlenen karmaşık bir anatomik varyasyondur. Klinisyenlerin mandibular premolar dişlerde görülen bu karmaşık kök kanal anatomisi hakkında farkındalık sahibi olması, endodontik tedavinin başarısı açısından önem taşımaktadır. Anahtar kelimeler: C-şekilli kanal morfolojisi, konik ışınlı bilgisayarlı tomografi, kök kanal anatomisi, mandibular premolar, prevalans çalışması*

Ethics Committee Approval: The present study design was approved by the Ethical Committee of Ege University (2021/22-2.1T/33).

Informed Consent: Not required.

Peer-review: Externally peer-reviewed.

Author contributions: BGB, BHŞ participated in designing the study. EA, ACU participated in generating the data for the study. EA, ACU participated in gathering the data for the study. BGB, BHŞ participated in the analysis of the data. EA wrote the majority of the original draft of the paper. ACU participated in writing the paper. EA, ACU has had access to all of the raw data of the study. BGB, BHŞ has reviewed the pertinent raw data on which the results and conclusions of this study are based. EA, ACU, BGB, AM, BHŞ have approved the final version of this paper. EA guarantees that all individuals who meet the Journal's authorship criteria are included as authors of this paper.

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References

1. Fan B, Yang J, Gutmann JL, Fan M. Root canal systems in mandibular first premolars with C-shaped root configurations. Part I: Microcomputed tomography mapping of the radicular groove and associated root canal cross-sections. J Endod 2008;34:1337-41. [CrossRef]
2. Jafarzadeh H, Wu YN. The C-shaped root canal configuration: a review. J Endod 2007;33:517-23. [CrossRef]
3. Martins JNR, Marques D, Silva EJNL, Caramês J, Mata A, Versiani MA. Prevalence of C-shaped canal morphology using cone beam computed tomography - a systematic review with meta-analysis. Int Endod J 2019;52:1556-72. [CrossRef]
4. Helvacioglu-Yigit D, Sinanoglu A. Use of cone-beam computed tomography to evaluate C-shaped root canal systems in mandibular second molars in a Turkish subpopulation: a

retrospective study. Int Endod J 2013;46:1032-8. [CrossRef]
5. Fan B, Cheung GS, Fan M, Gutmann JL, Bian Z. C-shaped canal system in mandibular second molars: Part I--Anatomical features. J Endod 2004;30:899-903. [CrossRef]
6. Cooke HG 3rd, Cox FL. C-shaped canal configurations in mandibular molars. J Am Dent Assoc 1979;99:836–9. [CrossRef]
7. Lu TY, Yang SF, Pai SF. Complicated root canal morphology of mandibular first premolar in a Chinese population using the cross section method. J Endod 2006;32:932-6. [CrossRef]
8. Fernandes M, de Ataide I, Wagle R. C-shaped root canal configuration: A review of literature. J Conserv Dent 2014;17:312-9. [CrossRef]
9. Vertucci FJ. Root canal morphology and its relationship to endodontic procedures. Endod Topics 2005;10:3–29. [CrossRef]
10. Wu MK, R'oris A, Barkis D, Wesselink PR. Prevalence and extent of long oval canals in the apical third. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:739-43. [CrossRef]
11. Patel S, Patel R, Foschi F, Mannocci F. The Impact of Different Diagnostic Imaging Modalities on the Evaluation of Root Canal Anatomy and Endodontic Residents' Stress Levels: A Clinical Study. J Endod 2019;45:406-13. [CrossRef]
12. Special Committee to Revise the Joint AAE/AAOMR Position Statement on use of CBCT in Endodontics. AAE and AAOMR Joint Position Statement: Use of Cone Beam Computed Tomography in Endodontics 2015 Update. Oral Surg Oral Med Oral Pathol Oral Radiol 2015;120:508-12. [CrossRef]
13. Alfawaz H, Alqedairi A, Alkhayyal AK, et al. Prevalence of C-shaped canal system in mandibular first and second molars in a Saudi population assessed via cone beam computed tomography: a retrospective study. Clin Oral Investig 2019;23:107–12. [CrossRef]
14. Kim HS, Jung D, Lee H, Han YS, Oh S, Sim HY. C-shaped root canals of mandibular second molars in a Korean population: a CBCT analysis. Restor Dent Endod 2018;2018;43:e42. [CrossRef]
15. Rahimi S, Shahi S, Lotfi M, Zand V, Abdolrahimi M, Es'haghi R. Root canal configuration and the prevalence of C-shaped canals in mandibular second molars in an Iranian population. J Oral Sci 2008;50:9-13. [CrossRef]
16. Shemesh A, Levin A, Katzenell V, et al. C-shaped canals-prevalence and root canal configuration by cone beam computed tomography evaluation in first and second mandibular molars-a cross-sectional study. Clin Oral Investig 2017;21:2039-44. [CrossRef]
17. von Zuben M, Martins JNR, Berti L, et al. Worldwide Prevalence of Mandibular Second Molar C-Shaped Morphologies Evaluated by Cone-Beam Computed Tomography. J Endod 2017;43:1442-7. [CrossRef]
18. Yang SE, Lee TY, Kim KJ. Prevalence and Morphology of C-Shaped Canals: A CBCT Analysis in a Korean Population. Scanning 2021;2021:9152004. [CrossRef]
19. Zhang X, Xiong S, Ma Y, et al. A cone-beam computed tomographic study on mandibular first molars in a Chinese subpopulation. PLoS One 2015;10:e0134919. [CrossRef]
20. Arayasantiparb R, Banomyong D. Prevalence and morphology of multiple roots, root canals and C-shaped canals in mandibular premolars from cone-beam computed tomography images in a Thai population. J Dent Sci 2021;16:201–7. [CrossRef]
21. Chaintiou Piorno R, Consoli Lizzi EP, Gualtieri AF, Rodríguez PA. C-Shaped canal system in mandibular premolars evaluated by cone-beam computed tomography in a population of the Autonomous City of Buenos Aires, Argentina. Arch Oral Biol 2021;123:105040. [CrossRef]
22. Jang YE, Kim Y, Kim B, Kim SY, Kim HJ. Frequency of non-single canals in mandibular premolars and correlations with other anatomical variants: an in vivo cone beam computed tomography study. BMC Oral Health 2019;19:272. [CrossRef]
23. Srivastava S, Gaikwad RN, Alsalhi N, Alrogaibah NA. Cone-beam Computed Tomographic Analysis of C-shaped canals and Radicular Grooves in Mandibular Premolars: Prevalence and Related Factors. J Contemp Dent Pract 2019;20:1350-4. [CrossRef]
24. Kaya Büyükbayram I, Sübay RK, Çolakoğlu G, Elçin MA, Ordulu Sübay M. Investigation using cone beam computed tomography analysis, of radicular grooves and canal configurations of mandibular premolars in a Turkish subpopulation. Arch Oral Biol 2019;107:104517. [CrossRef]
25. Pedemonte E, Cabrera C, Torres A, et al. Root and canal morphology of mandibular premolars using cone-beam computed tomography in a Chilean and Belgian subpopulation: a cross-sectional study. Oral Radiol 2018;34:143-50. [CrossRef]
26. Hajihassani N, Roohi N, Madadi K, Bakhshi M, Tofangchiha M. Evaluation of root canal morphology of mandibular first and second premolars using cone beam computed tomography in a defined group of dental patients in Iran. Scientifica (Cairo) 2017;2017:1-7. [CrossRef]
27. Mashyakhy MH, Chourasia HR, Jabali AH, et al. C-shaped canal configuration in mandibular premolars and molars: Prevalence, correlation, and differences: An In Vivo study using cone-beam computed tomography. Niger J Clin Pract 2020;23:232-9. [CrossRef]
28. Martins JNR, Francisco H, Ordinola-Zapata R. Prevalence of C-shaped Configurations in the Mandibular First and Second Premolars: A Cone-beam Computed Tomographic In Vivo Study. J Endod 2017;43:890-5. [CrossRef]
29. Aricioğlu B, Tomrukçu DN, Köse TE. Taurodontism and C-shaped anatomy: is there an association? Oral Radiol 2021;37:443–51. [CrossRef]
30. Brea G, Gomez F, Gomez-Sosa JF. Cone-beam computed tomography evaluation of C-shaped root and canal morphology of mandibular premolars. BMC Oral Health 2021;21:236. [CrossRef]
31. Yu X, Guo B, Li KZ, et al. Cone-beam computed tomography study of root and canal morphology of mandibular premolars in a western Chinese population. BMC Med Imaging 2012;12:18. [CrossRef]
32. Gu YC, Zhang YP, Liao ZG, Fei XD. A micro-computed tomographic analysis of wall thickness of C-shaped canals in mandibular first premolars. J Endod 2013;39:973-6. [CrossRef]