Cone-Beam Computed Tomographic Study of the Internal Anatomy of Lower Anterior Teeth

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ABSTRACT

Background

A thorough knowledge of the root and canal morphology and their possible variations are essential for successful endodontic treatment. Methods like staining and clearing techniques, cross sectional method can provide precise information on root canal systems, however, these methods are invasive. Cone-beam computed tomography (CBCT) is the 3-dimensional scans of the maxillofacial skeleton that best visualizes canal morphology and helps in identifying additional canals and roots in vivo.

Objective

To investigate the root canal configuration of mandibular anterior teeth using Cone-beam computed tomography.

Method

A total of 2910 CBCT images, comprising 970 central incisors, lateral incisors, and canines each from 485 patients were assessed. The following assessments were made: (1) The number of roots and root canals (2) Canal configuration according to Vertucci's classification (3) Bilateral occurrences for variations. Also, the gender and age of patients were noted.

Result

The study revealed mandibular anterior teeth predominantly had 1 root with Type I (79.79%, 77.11%, 91.34%) canal configuration followed by type III (20.2%, 22.67%, 5.15%) in central, lateral and canine respectively. Almost 90% incisors had symmetry in the canal configurations. No statistical correlation was found between the gender and root canal configurations. Type III canal configurations in canines were present more in elder age group.

Conclusion

Clinicians must be aware that each tooth may display a different number of roots and types of canal configurations. During endodontic treatment, presuming lower anterior teeth with single root and single canal may lead to missed canals and consequently, treatment failure.

KEY WORDS

Cone-beam computed tomography, Internal anatomy, Mandibular anterior teeth

INTRODUCTION

The success behind the Root Canal Treatment relies upon meticulous attention to the various operative steps involved in it. A comprehensive knowledge of the normal root and canal morphology and their possible variations are essential for locating all the canals and thorough debridement, proper shaping, and complete obturation of the root canal system.[1] The presence of an untreated canal may be a reason for failure. A canal may be left untreated because the dentist fails to recognize its presence.[2]

The anatomic structures of human teeth may take variable forms in terms of the number of roots or root canals, apical foramina, root canal isthmuses, root ramifications, root curvatures, etc. It is crucial to be aware of the complexity of the spaces we are expected to access, shape, clean and fill.[3] It is believed that most of the mandibular anterior teeth has a uniform pattern, with a single root and a single canal. However, it is important to visualize and have knowledge regarding both the expected and aberrant complex internal dental anatomy before undertaking endodontic therapy.

In regard to the significance of adequate knowledge about root morphology and number of canals in mandibular anteriors, and also to increase the success of endodontic treatment, the aim of this study was to a) investigate the number of root and root canals in mandibular anterior teeth and assess root canal configuration on cone-beam computed tomography (CBCT) scans b) evaluate the bilaterality of occurrences for variations and c) determine whether the patient's gender and age influence the findings.

METHODS

A total of 2910 CBCT images of mandibular anterior teeth were collected from 485 patients of both genders aged above 14 years who accepted CBCT projection as a preoperative assessment, diagnosis and treatment planning attending the Dental Department, Dhulikhel Hospital, Kathmandu University Hospital. CBCT images from June 2022 to May 2023 were retrieved from the database of Department of Oral Medicine and Radiology and this study was approved by the Institutional Review Committee of Kathmandu University School of Medical Sciences.

Sample size = $[Z_{1-\alpha/2}{}^2\ p(1-p)]/d^2$

Here, $Z_{1-\alpha/2}$ = Is standard normal variate, at 5% type 1 error ($P < 0.05$) it is 1.96

p = Expected prevalence based on previous studies 27.4 ≈ 28%.[4]

d = Absolute error or precision = 5%

Thus, the minimum sample size was calculated to be 309.6 ≈ 310

The samples were selected based on the following criteria:

1. Available CBCT images of patients who had all permanent mandibular anterior teeth with complete root formation
2. Absence of root canal treatment
3. Absence of coronal or post coronal restorations
4. Absence of root resorption or periapical lesions
5. Absence of calcifications
5. High-quality CBCT images in the area of interest

Image Acquisition and Evaluation

All the CBCT images were acquired using Rainbow™ CT device (Dentium, South Korea) with maximum KVp of 120 and 150 mA. The X-ray specifications for the images were constant with peak voltage 100 KVp and tube current 12 mA, field of view 16 cm *18 cm, Voxel size 300 µm, and scan time 20 seconds. The 3D axial cross-sections (coronal, middle, and apical-third root section) of roots and root canals were prepared with the Rainbow™ image viewer software program, version 1.0.0.0 (Dentium, South Korea) for analyzing the images. The CBCT images were evaluated on a 34-inch LED screen in a dark room.

The images were evaluated by two endodontists together twice with an interval of 2 weeks between evaluations. The examiners evaluated a maximum of 15 images per day not to impair the result of the analysis. A professional radiologist was consulted to perform a third decisive evaluation and reach a final consensus when there were disagreements. All of the images from the 2910 mandibular anterior teeth were evaluated and following information was recorded:

1. Age of subject
2. Gender of subject
3. Tooth position
4. The number of root and canal for each tooth
5. The root canal configuration for each tooth; according to following criteria of Vertucci[5]:

Type I: a single canal is observed, from the pulp chamber to the apex.

Type II: two separate canals leave the pulp chamber, but unite near the apex forming a single canal.

Type III: one canal leaves the pulp chamber, but divides into two in the middle of the root, and unite again forming a single canal.

Type IV: two separate and distinct canals are present from the pulp chamber to the apex.

Type V: a single canal leaves the pulp chamber, but divides into two canals.

Type VI: two separate canals leave the pulp chamber, unite in the middle third and then divide again into two canals with two separate foramina.

Type VII: one canal leaves the pulp chamber, divides into two canals, become one canal again and divides into two separate canals with two distinct apical foramina.

Type VIII: three separate and distinct canals begin from the pulp chamber to the root apex.

The data were entered in excel and analyzed by using SPSS-22 IBM, Inc., USA statistical software. The categorical data were expressed in the frequency (%). The comparisons for categorical data were done by chi-square test. The continuous variables were expressed in Mean ± SD and comparison of multiple variables were done by one-way ANOVA. P-value < 0.05 was statistically significant.

RESULTS

A comprehensive examination was conducted on 2910 mandibular anterior teeth. This evaluation used CBCT images from 485 patients, comprising 248 females (51.1%) and 237 males (48.9%). The age of participants ranged from 14-68 years with the mean age of 30.25±12.23 years. (Fig. 1)

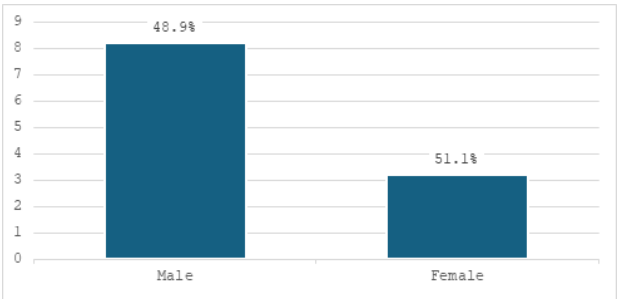

Figure 1. Bar graph illustrating gender-wise distribution of study sample.

Table 1. Prevalence of the number of root canals of mandibular anterior teeth according to tooth position

Tooth Position		1 Root Canal	2 Root Canals	Total
Mandibular Central Incisor n (%)	Left	389 (80.20)	96 (19.79)	485
	Right	385 (79.38)	100 (20.61)	485
	Total	774 (79.79)	196 (20.20)	970
Mandibular Lateral Incisor n (%)	Left	369 (76.08)	116 (23.91)	485
	Right	379 (78.14)	106 (21.85)	485
	Total	748 (77.11)	222 (22.88)	970
Mandibular Canine n (%)	Left	438 (90.30)	47 (9.69)	485
	Right	448 (92.37)	37 (7.62)	485
	Total	886 (91.34)	84 (8.65)	970

Table 1 presents the distribution frequency of root canal numbers in left and right lower anterior teeth from 485 tomographic scans of 2910 teeth. Among 970 mandibular anterior teeth of each type, 774 central incisors (79.79%), 748 lateral incisors (77.11%), and 886 canines (91.34%) were found to have a single canal. Likewise, 196 central incisors (20.20%), 222 lateral incisors (22.88%), and 84 canines (8.65%) had two canals. The data indicate that a single root canal is the most common configuration in mandibular anterior teeth.

Table 2. Distribution of root canal types of mandibular anterior teeth

Tooth Position	Type I	Type III	Type V	2 Roots	Total
Left Mandibular Central Incisor n (%)	389 (80.20)	96 (19.79)	0	0	485
Right Mandibular Central Incisor n (%)	385 (79.38)	100 (20.61)	0	0	485
Left Mandibular Lateral Incisor n (%)	369 (76.08)	115 (23.71)	1 (0.20)	0	485
Right Mandibular Lateral Incisor n (%)	379 (78.14)	105 (21.64)	0	1 (0.20)	485
Left Mandibular Canine n (%)	438 (90.30)	27 (5.56)	1 (0.20)	19 (3.91)	485
Right Mandibular Canine n (%)	448 (92.37)	23 (4.74)	1 (0.20)	13 (2.68)	485

Table 2 depicts the largest proportion of all mandibular anterior teeth of both sides had Type I root canal configuration followed by Type III. In central incisors, Type III root canal configuration was observed in 96 (19.79%) and 100 (20.61%) left and right sides, respectively. For lateral incisors, Type III root canal configuration was observed in 115 (23.71%) on the left side and 105 (21.64%) on the right side. Type V canal configuration was detected in only 1 (0.20%) left lateral incisor. Furthermore, 2 roots were found in 1 (0.20%) right lateral incisor (Fig. 2 A-D).

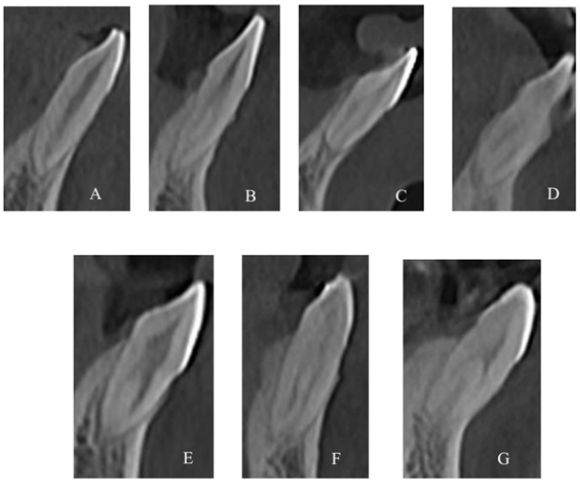

Figure 2 (A-D). mandibular incisors with type I, type II, type V canal configurations and 2 roots; (E-G) mandibular canine with type III, type V canal configurations and 2 roots.

Variations in the root canal configurations of mandibular canines were less common compared to incisors, with the majority of mandibular canines exhibiting a single root and a single root canal. A two-canal configuration (Type III) was

Table 3. **Side-wise distribution of variable root canal types of mandibular anterior teeth**

	Central Incisor			Lateral Incisor			Canine		
	Type III (n=196)	Type V	2 Roots	Type III (n=220)	Type V	2 Roots	Type III (n=50)	Type V	2 Roots (n=32)
Left n (%)	9 (4.59)	0	0	17 (7.72)	1	0	11 (22)	1	15 (46.87)
Right n (%)	13 (6.63)	0	0	7 (3.18)	0	1	7 (14)	1	9 (28.12)
Bilateral n (%)	2*87=174 (88.77)	0	0	2*98=196 (89.09)	0	0	2*16=32 (64)	0	2*4=8 (25)

observed in 27 (5.56%) of left canines and 23 (4.74%) of right canines. Type V configuration was rare, appearing in just 1 (0.20%) of canines on each side. Additionally, 19 (3.91%) of left-sided canines and 13 (2.68%) of right-sided canines had two distinct roots and root canals. (Fig. 2 E-G)

Rest of the root canal configurations (Type II, Type IV, Type VI, Type VII and Type VIII) were not detected in any of the mandibular anterior teeth in this study.

Table 3 shows the side-wise distribution of variable root canal types. In central, lateral incisors and canine 88.77%, 89.09% and 64% participants had bilateral distribution of Type III canal configuration, respectively. Whereas, 2 roots in canine were present majorly in the unilateral side with 46.87% on left and 28.12% on right side.

Table 4 presents a comparative analysis of root canal configurations in lower central incisors, lateral incisors and canines between female and male participants. There was no statistically significant variation in the distribution of root canal configurations between female and male participants ($p > 0.05$). However, type V canal configuration was present only in three female participants.

Mandibular Canines had significantly different root canal types with age ($p < 0.05$). The mean age for Type III in mandibular left canine was 36.6 ± 16.3 and for right canine was 40.1 ± 17.5 which is higher than other types. However, central and lateral incisors showed no significant differences in root canal types with age (Table 5).

DISCUSSION

This study used CBCT scanning to investigate the root canal morphology of mandibular anterior teeth. A total of 2910 CBCT images of mandibular anterior teeth from 485 patients were evaluated, including 970 central incisors, lateral incisors and canines each. In the existing literature on root

Table 4. **Gender-wise distribution of root canal types of mandibular anterior teeth**

Teeth	Gender	Type I	Type III	Type V	2 Roots	P-Value
Left Mandibular Central Incisor (n, %)	Female	201 (81.04%)	47 (18.95%)	0	0	0.634
	Male	188 (79.32%)	49 (20.67%)	0	0	
Right Mandibular Central Incisor (n, %)	Female	197 (79.43%)	51 (20.56%)	0	0	0.976
	Male	188 (79.32%)	49 (20.67%)	0	0	
Left Mandibular Lateral Incisor (n, %)	Female	187 (75.40%)	60 (24.19%)	1 (0.40%)	0	0.491
	Male	182 (76.79%)	55 (23.20%)	0	0	
Right Mandibular Lateral Incisor (n, %)	Female	191 (77.01%)	56 (22.58%)	0	1 (0.40%)	0.443
	Male	188 (79.32%)	49 (20.67%)	0	0	
Left Mandibular Canine (n, %)	Female	218 (87.90%)	15 (6.04%)	1 (0.40%)	14 (5.64%)	0.116
	Male	220 (92.82%)	12 (5.06%)	0	5 (2.10%)	
Right Mandibular Canine (n, %)	Female	230 (92.74%)	11 (4.43%)	1 (0.40%)	6 (2.41%)	0.664
	Male	218 (91.98%)	12 (5.06%)	0	7 (2.95%)	

p-values obtained from Chi-square analysis. $p < 0.05$ considered statistically significant.

Table 5. **Age-wise distribution of root canal types of mandibular anterior teeth (Mean ± S.D.)**

Teeth	Type I	Type III	Type V	2 Roots	p-value
Left Mandibular Central Incisor	30.3 ± 12.5	29.9 ± 11.0	-	-	0.778
Right Mandibular Central Incisor	30.4 ± 12.6	29.8 ± 10.8	-	-	0.658
Left Mandibular Lateral Incisor	30.2 ± 12.5	30.6 ± 11.5	15 (n =1)	-	0.440
Right Mandibular Lateral Incisor	30.3 ± 12.3	30.1 ± 11.9	-	29 (n=1)	0.983
Left Mandibular Canine	29.8 ± 11.9	36.6 ± 16.3	27 (n =1)	32.2 ± 11.4	0.037
Right Mandibular Canine	29.8 ± 11.8	40.1 ± 17.5	27 (n=1)	27.5 ± 7.9	0.001

p-values obtained from one-way ANOVA. $p < 0.05$ considered statistically significant.
Post-Hoc analysis could not be performed as at least one group had < 2 cases.

canal morphology, several destructive and non-destructive methods have been utilized for the study of the internal tooth anatomy. In extracted teeth, staining and clearing techniques are able to provide precise information on root canal systems. Recently, in the field of endodontics, the use of in vivo cone-beam computed tomographic scanning has become an important tool to investigate the internal anatomy of the root canal system.[1] In clinical situations, CBCT imaging is a noninvasive technique that was reported to be as accurate as the modified canal staining and clearing technique for evaluating root canal systems.[6] In contrast to traditional radiography which provides 2-dimensional images obtained from 3-dimensional structures, CBCT scanning provided 3-dimensional images in axial, sagittal, and coronal sections that could avoid geometric distortions and anatomic overlaps.[7] Also, the reliability of CBCT to detect the root canal anatomy has been demonstrated when compared to histologic sections viewed under an optical microscope.[8]

Several other methods used are cross sectional method, digital radiography, contrast enhancement radiography, demineralization and staining of canals, and micro-computed tomographic imaging.[5-7,9-14] CBCT scanning is an extraoral imaging system that produces 3-dimensional scans of the maxillofacial skeleton. In clinical situations, at various stages of root canal treatment, conventional periapical radiography is commonly used but it only provides 2-dimensional images in which the roots may overlap with the surrounding tissue.

Vertucci, using staining and clearing method, found the following prevalence for the lower central incisors: 70% Type I, 5% Type II, 22% Type III and 3% Type IV.[10] Similarly, for lateral incisors: 75% Type I, 5% Type II, 18% Type III and 3% Type IV.[10] A CBCT study done by Martins et al. found 72.3% Type I, 2.5% Type II, 24.2% Type III, 0.1% Type IV, 0.3% Type V, 0.4% Type VII for lower central incisors and 69.8% Type I, 6.3% Type II, 23.1% Type III, 0.3% Type V, 0.2% Type VII for lower lateral incisors.[15] Shemesh et al. analyzed and found type I in 59.5% and 62.1% and type III in 33.7% and 31.9% of mandibular central and lateral incisors, respectively.[16] The result of Han et al.'s study found largest proportion of central incisors (84.29%) and lateral incisors (72.64%) had Type I canal configurations followed by Type III in 6.53% and 15.53% respectively.[1] Similarly, Santos et al. also found the greater incidence for Type I in 84.58% and 78.77%; followed by Type III in 13.95% and 20.36% of central and lateral incisors respectively.[17] Another study conducted in Nepalese population by Sandhya et al. also showed type I canal configuration was most prevalent followed by type III in 21.4% central incisors and 23.8% lateral incisors.[4] All the findings from these studies are in congruent with those from our study, with Type I (79.79%, 77.11%) being the most prevalent followed by Type III (20.2%, 22.67%) for mandibular central and lateral incisors. In contrast to our study, Al-Qudah AA and Awawdeh LA concluded that, in the teeth with two canals, Type II canal configuration (10.9%) was more prevalent than Type III (6.7%).[13] Also, Baxter et al. identified prevalence for Type II canal configuration (22% for central incisors and 21.3% for lateral incisors) and teeth with a Type III configuration were not found in his study.[18] In this study, types II, IV, VI, VII and VIII in both central and lateral incisors were not detected at all, and type V was present in 0.20% of lateral incisors. However, in various studies, types II, IV, V, VIII and all other different morphologies were rare and type VI and VII were not detected at all.[1,4,15-17]

With regards to mandibular canine, 91.34% had Type I canal configuration, followed by Type III (5.15%) and Type V (0.20%). Additionally, 2 roots were found less frequently (3.29%) in this study. The findings are in accordance with the CBCT analysis conducted by Han et al. where the incidence was: 93.73% Type I, 3.25% Type III, 0.54% Type V and 1.32% 2 rooted Canines.[1] Also, 0.62% Type II canal configuration was detected in his study, however, Type IV, Type VI, Type VII and Type VIII canal configurations were not identified, like this study. Martin et al. found the following: 90.2% Type I, 3.3% Type II, 2.7% Type III, 1.4% Type IV and 2.3% Type V.[15]

Predominantly, mandibular incisors and canines are presented with a uniform pattern, with a single root and a single canal. Nevertheless, 1 canal at the beginning of the orifice and then dividing into 2, which could either fuse again to form 1 root foramen (Type III) or remain separate to form 2 root foramens (Type V) were not infrequent. For performing successful root canal treatment, clinician must remove pulp tissues or necrotic debris within it by locating all the canals.

In central and lateral incisors as well as canine 88.77%, 89.09% and 64% participants had bilateral distribution of Type III canal configuration, respectively. Zhao et al. concluded that the double root canals are most common in mandibular lateral incisors.[19] Also, the highest incidence of symmetry of double root canal is also observed in mandibular lateral incisors which is in accordance with the findings of our study. The present study revealed that almost 90% mandibular incisors had symmetry in the canal configurations, which is clinically important while treating bilateral homonymous teeth. If the second canal is identified in one mandibular incisor, the dentist should be aware of the likelihood that a second canal is present in the opposite incisor.[20] In contrast, Baxter et al. concluded that the internal anatomy of a mandibular incisor cannot be exactly predicted from the root canal anatomy of the contralateral tooth as the prevalence of symmetry regarding root canal number and configuration is only moderate.[18]

In this study, no statistical correlation was found between the gender and root canal configurations. The gender non-interference with the internal anatomical findings of mandibular anterior teeth is in accordance with previous studies.[17,21,22] In the study by Sert and Bayirli , the male/

female ratio for prevalence of a second canal was 1:1.07 for mandibular central incisors and 1:1.03 for mandibular lateral incisors, and no significant gender prevalence was concluded.[21] However, the study conducted by Lin et al. showed a slight male predominance for mandibular incisors having a second canal, with a male/female ratio of 1.37:1 ($p < 0.05$).[20]

The association of age with morphological changes in various studies shows contradictory results. Thomas et al. noticed, with advancing age, the isthmus is created by the dentine deposition in the middle of canals having a large cross section and the canal may be divided into two narrow root canals.[23] This morphological alterations explain why the prevalence of Vertucci type I decrease and type III canal configuration increases with age in lateral incisors and canines.[17] Martins et al. reported the greater frequency for Vertucci type I configurations in the younger groups whilst multiple root canal system configurations were frequent in older patients.[24] On contrary, Kayaoglu et al. related the frequency of two root canals inversely with age, resulting in the narrowing and calcification of root canal space probably due to the deposition of secondary dentin.[22] However, Lin et al. found no significant differences in the prevalence of a second root canal among the age groups in mandibular incisors.[20] In this study, central and lateral incisors showed no significant differences in root canal types with age, but canines had significantly different root canal types with Type III canal configuration presenting more in elder age group. This may be due to the canines displaying a narrow canal mesiodistally and broad canal buccolingually, with continuous deposition of dentin, the proximal canal walls unite resulting in division of single canal into two canals buccolingually.[17,23]

The current study was done in a patient visiting a tertiary care center of Nepal located in Bagmati Province; thus, the results of this study cannot be generalized to other provincial population as well as globally. Also, the influence of Ethnic diversity on variation of canal morphology has not taken into consideration in this study.

CONCLUSION

Mandibular anterior teeth having single root with a tapering canal and a single foramen is the exception rather than the rule. In this study, all the central incisors had 1 root, only 1 of the lateral incisors had two roots. High prevalence for two-rooted canine was observed compared to incisors. However, two canalled anteriors with type III canal configuration were more frequently observed, 20.2% central incisors, 22.67% lateral incisors and 5.15% canines. Consequently, in treating each mandibular anterior tooth the clinician must assume that complex anatomy occurs often enough to be considered normal. The adequate knowledge about root morphology and number of canals in mandibular anterior teeth signifies the success of endodontic treatment.

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