

Original Article

CBCT-Based Retrospective Assessment of Root Canal Morphology in Permanent Mandibular Incisors: An Indian Subpopulation Study

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Received: 25 June 2025; Revised: 28 October 2025; Accepted: 02 November 2025

ABSTRACT

The purpose of this investigation was to assess and characterize the root canal anatomy of mandibular incisors in a cohort drawn from the Indian subpopulation through the use of cone-beam computed tomography (CBCT). A retrospective, cross-sectional analysis was conducted on 872 CBCT scans of permanent mandibular incisors (both central and lateral) from individuals of Indian descent who presented to the radiology division of a dental teaching hospital from 2014 through 2023. Each tooth was evaluated for the quantity of roots and canals, as well as the canal configuration patterns as defined by Vertucci's classification. The imaging data were reviewed, and a statistical evaluation of the findings was conducted. Of the entire sample of 872 incisors, among the male participants, 472 (99.8%) exhibited a single root, whereas 1 (0.2%) displayed two roots. Among the 400 incisors from female participants, 396 (99.0%) possessed one root, and 4 (1.0%) had two roots. Examining the 436 incisors on the right side, the predominant configuration observed was type 1 in 187 cases (42.9%), followed by type 2 in 112 (25.7%), type 3 in 86 (19.7%), type 4 in 43 (9.9%), type 5 in 6 (1.4%), and type 6 in 2 (0.4%). Regarding the 436 incisors on the left side, type 1 again prevailed, seen in 179 (41.0%), with type 2 in 110 (25.2%), type 3 in 105 (24.1%), type 4 in 38 (8.7%), type 5 in 2 (0.4%), and type 6 in 2 (0.4%). The frequency patterns of Vertucci's classification showed no statistically significant difference between right- and left-sided teeth within the study population ($P > 0.05$). In contrast, the prevalence of differing root counts varied significantly when analyzed across the distinct age brackets of the subjects. Among the right-sided incisors totaling 436, a single root was noted in 433, while two roots were found in 3. Of the 436 left-sided incisors, 434 (99.5%) had a single root, with 2 (0.5%) possessing two. The distribution of root numbers did not reveal a significant difference between the right- and left-side tooth groups. Mandibular central and lateral incisors exhibited no statistically significant sex-based differences concerning either the number of canals or their morphological configurations. Root number distribution, however, differed significantly across age categories. No significant difference was detected in root number distribution between right- and left-sided teeth within the study group. CBCT represents the optimal imaging modality for the meticulous evaluation of the root canal complex. Consequently, thorough radiographic assessment to guide the boundaries of access cavity preparation, supplemented by the application of a dental operating microscope for superior visualization, can aid practitioners in detecting and instrumenting supplementary canals.

Keywords: Cone-beam computed tomography, Endodontics, Mandibular incisors, Root canal configuration, Vertucci's classification

How to Cite This Article: Dupont C, Martin J. CBCT-Based Retrospective Assessment of Root Canal Morphology in Permanent Mandibular Incisors: An Indian Subpopulation Study. *J Curr Res Oral Surg.* 2025;5(2):181-6. <https://doi.org/10.51847/uAD4IKrxdp>

Introduction

Achieving a favorable outcome in endodontic therapy necessitates an exhaustive grasp of radicular morphology and its variations [1]. The treatment

process rests upon three fundamental procedures: (1) detection and complete patency of the root canal, (2) thorough execution of chemomechanical debridement and shaping, and (3) three-dimensional (3D) sealing of the canal space [2].

The literature suggests that morphological alterations can occur at different rates across tooth categories [3-5]. The majority of mandibular incisors contain a solitary root canal [6, 7]. Nevertheless, locating the canal in these teeth can be challenging due to three specific anatomical complexities: the presence of a second canal, a lateral canal, and variations in apical anatomy [8].

The most frequent contributor to endodontic failure in permanent mandibular incisors is undetected canals or unaddressed pathology [9]. An isthmus constitutes a connecting corridor, external communication, or anastomosis linking two tissue-housing channels [10]. Using CBCT imaging, the root apex can be accurately identified through detailed depiction of anomalies, including untreated canals, resorptive defects, canal pathways, degrees of curvature, and apical delta ramifications [10]. Unlike conventional periapical radiography, CBCT provides 3D representations of dental structures while delivering lower radiation exposure than conventional tomography [11].

The principal underlying factor in deficient root canal procedures is compromised treatment quality due to overlooked isthmuses or canals [12]. Root canal anatomy in mandibular teeth also shows variability by patient sex and the demographic characteristics of the population under study [13].

Permanent mandibular incisors characteristically present with a single root encompassing a spacious oval-shaped canal, a lateral canal, or an accessory canal that typically diverges from either the coronal or the middle third of the primary canal. The documented rate of missed canals stands at 12.2% for mandibular central incisors and 17.4% for mandibular lateral incisors [14]. Such figures plainly highlight an insufficient understanding of appropriate endodontic management for the existing pathology [12]. Anatomical knowledge serves as a guide to appropriate treatment, particularly given that the buccolingual width of the tooth exceeds its mesiodistal width [11].

A considerable body of research has explored the root canal architecture of central incisors. Through examination of 200 mandibular central and lateral incisors employing demineralization and dye infiltration methods, Vertucci [4] demonstrated that a single canal was present in 70% of central incisors and 75% of lateral incisors. It has been documented that 79% of 500 mandibular incisors, investigated via demineralization and staining, exhibited wide canals and apical foramina [6]. In contrast, a prior study assessing 400 mandibular incisors using decalcification and staining protocols reported that

more than one root canal was present in 67.5% of central incisors and 63% of lateral incisors [7].

CBCT has risen to prominence as a valuable instrument for probing root canal morphology. It delivers high accuracy on par with the histological clearing and staining method [15]. Additionally, it allows simultaneous three-dimensional inspection of multiple teeth. With this in mind, the present investigation was undertaken to evaluate and characterize root canal configurations in mandibular incisors in the Indian subpopulation using CBCT.

Materials and Methods

The investigation adopted a retrospective, cross-sectional framework. Ethical clearance was secured from the relevant institutional review board. A total of 872 cone-beam computed tomographic records of fully erupted mandibular incisors (central and lateral) from an Indian subpopulation, captured at the imaging facility of a dental academic center spanning 2014 to 2023, were sourced for analysis. The subjects ranged in age from 12 to 60 years. Radiographic volumes depicting mandibular permanent central and lateral incisors with finalized root maturation were deemed eligible. Exclusions were applied to scans of suboptimal diagnostic resolution, teeth demonstrating resorptive defects or radiolucent lesions at the periapex, teeth with prior or partially completed endodontic intervention, immature apical development, and cases with coronal restorations or post placements. Each tooth was methodically scrutinized for the total number of roots and canals, and the anatomical pattern of the canal system was classified using the schema proposed by Vertucci [4]:

1. Type I: A solitary uninterrupted conduit travels from the pulp chamber to the apical terminus.
2. Type II: Two discrete canals arise from the chamber, fuse along their course, and conclude in a single apical foramen.
3. Type III: One canal departs the chamber, separates into two branches within the radicular structure, and subsequently reunifies to finish as a single exit.
4. Type IV: Two independent canals emerge from the chamber and persist without merging, each terminating in its own distinct foramen.
5. Type V: A single canal originates in the chamber and undergoes division inside the root mass, resulting in two separate terminal openings.
6. Type VI: Two canals commence separately from the chamber, combine within the root interior, and later split apart once more to emerge as two individual pathways.

7. Type VII: One canal exits the chamber, then splits and reconverges within the radicular space, only to undergo a second division and finish as two distinct canals.
8. Type VIII: Three parallel canals run from the pulp chamber through to the apex.

The inclusion criteria comprised subjects of either sex who retained the full complement of mandibular anterior teeth with closed apices, with no history of root canal treatment, prosthetic crowns, or apical pathology. Grounds for disqualification encompassed individuals lacking anterior dentition, those whose mandibular anterior teeth displayed patent apices, resorptive lacunae, pulpal calcifications, developmental aberrations, a documented orthodontic treatment background, or CBCT datasets compromised by motion artifact or poor contrast.

Sample size estimation

The requisite cohort size was computed employing OpenEpi software (version 3.04, www.OpenEpi). Drawing on mean and standard deviation parameters from a prior investigation, the calculation yielded a target sample size of $n = 872$.

Statistical analysis

The entire dataset was transcribed into Microsoft Excel 2009. Conformity to a normal distribution was assessed using the Kolmogorov–Smirnov and Shapiro–Wilk tests. Categorical data points were represented as absolute frequencies and corresponding percentages (%). Comparative assessment of proportional distributions across disparate subgroupings—namely age strata, biological sex, side, and tooth category—was executed via the Chi-square test or Fisher’s exact method, adopting a threshold of $P < 0.05$ to denote statistical significance. All inferential computations were performed within the Statistical Package for the Social Sciences environment (SPSS version 24.0, IBM Corporation, Chicago, IL, USA).

Results and Discussion

Within the collective pool of 872 incisor specimens, the enumeration of roots was stratified by patient sex. Observations indicated that in the male subset, a solitary root was present in 472 cases (99.8%), with a mere 1 instance (0.2%) manifesting a bifurcated root structure. Among the 400 incisor elements from female participants, single-rooted anatomy characterized 396 (99.0%), while dual roots were encountered in 4 (1.0%). Statistical comparison of root number

frequencies failed to reveal any significant disparity between the sexes in the studied sample ($P > 0.05$). The distribution of incisors across Vertucci’s typological categories, cross-tabulated by sex, was determined and is displayed in **Table 1**. The analysis confirmed that the proportional representation of Vertucci’s configurational types did not diverge meaningfully between male and female subgroups within the investigation ($P > 0.05$).

Table 1. Distribution of incisors as per Vertucci’s classification according to sex.

Side	Vertucci’s classification	Number of teeth (%)
Male (n = 472)	Type 1	200 (42.4)
	Type 2	128 (27.1)
	Type 3	104 (22.0)
	Type 4	34 (7.2)
	Type 5	4 (0.8)
	Type 6	2 (0.4)
Female (n = 400)	Type 1	166 (41.5)
	Type 2	94 (23.5)
	Type 3	87 (21.8)
	Type 4	47 (11.8)
	Type 5	4 (1.0)
	Type 6	2 (0.5)
χ^2 ; DF; P	6.062; 5; 0.300 (NS)	

The prevalence of root counts across incisors was next examined by laterality. Data showed that of the 436 incisors situated on the right, 433 (99.3%) were monoradicular, and 3 (0.7%) possessed a pair of roots. Consistent with this, of the 436 left-sided counterparts, 434 (99.5%) exhibited a single root, whereas 2 (0.5%) exhibited two roots. The laterality-based comparison of root number distribution yielded no statistically significant distinction ($P > 0.05$).

As summarized in **Table 2**, the segregation of incisors into Vertucci’s categories by side was visualized. This evaluation indicated a non-significant difference in the distributional pattern of Vertucci types between teeth of the right and left quadrants ($P > 0.05$).

Table 2. Distribution of incisors according to Vertucci’s classification by laterality.

Side	Vertucci’s classification	Number of teeth (%)
Right side (n = 436)	Type 1	187 (42.9)
	Type 2	112 (25.7)
	Type 3	86 (19.7)
	Type 4	43 (9.9)
	Type 5	6 (1.4)
	Type 6	2 (0.4)

Left side (n = 436)	Type 1	179	(41.0)
	Type 2	110	(25.2)
	Type 3	105	(24.1)
	Type 4	38	(8.7)
	Type 5	2	(0.4)
	Type 6	2	(0.4)
χ²; DF; P	4.392;	5;0.495	(NS)

Root quantity as a function of specific tooth identity was also appraised. It was observed that of the 436 central incisors, 434 (99.5%) were single-rooted, and 2 (0.5%) bore a double root. Out of the 436 lateral incisors, 433 (99.3%) were supported by one root, with 3 (0.7%) anchored by two. The analytic outcome showed no significant difference in root number prevalence between central incisors and lateral incisors ($P > 0.05$).

As elaborated in **Table 3**, the grouping of incisors in line with Vertucci's classification by tooth type was recorded. The proportionate spread of Vertucci's configurations was not significantly different between the central and lateral incisor cohorts ($P > 0.05$).

Table 3. Distribution of incisors as per Vertucci's classification according to the type of teeth.

Tooth	Vertucci's classification	Number of teeth (%)
Central incisors (n = 436)	Type 1	183 (41.9)
	Type 2	112 (25.7)
	Type 3	97 (22.2)
	Type 4	40 (9.2)
	Type 5	4 (0.9)
	Type 6	0
Lateral incisors (n = 436)	Type 1	183 (41.9)
	Type 2	110 (25.2)
	Type 3	94 (21.6)
	Type 4	41 (9.4)
	Type 5	4 (0.9)
	Type 6	4 (0.9)
χ²	DF	P
4.077	5	0.538 (NS)

Abbreviation: NS = Not significant.

The relationship between root morphology and chronological age was explored further. Among the 204 incisors falling within the 12–24 years bracket, monoradicular status was upheld by 200 (98.0%), while biradicular anatomy was noted in 4 (2.0%). In the 25–36-year-old stratum, all 216 incisors demonstrated a single root. An identical uniformity was found in the 37–48 years cluster, where the entirety of 256 incisors were single-rooted. Within the 49–60 years age group, 195 of 196 incisors (99.5%) had one root, with the remaining 1 (0.5%) having two. The variation in root

number frequencies across these age-defined bands was statistically significant ($P < 0.05$).

As shown in **Table 4**, the categorization of incisors according to Vertucci's classification was examined in relation to age distribution. The prevalence profile of Vertucci's types differed significantly across the study's discrete age groups ($P < 0.05$).

Table 4. Distribution of incisors according to Vertucci's classification by age group.

Age group (years)	Vertucci's classification	Number of teeth (%)
12–24 (n = 204)	Type 1	96 (47.1)
	Type 2	45 (22.1)
	Type 3	45 (22.1)
	Type 4	16 (7.8)
	Type 5	0
	Type 6	2 (0.9)
25–36 (n = 216)	Type 1	82 (37.9)
	Type 2	77 (35.6)
	Type 3	49 (22.7)
	Type 4	9 (4.2)
	Type 5	2 (0.9)
	Type 6	0
37–48 (n = 256)	Type 1	101 (39.4)
	Type 2	53 (20.7)
	Type 3	60 (23.4)
	Type 4	40 (15.6)
	Type 5	0
	Type 6	2 (0.8)
49–60 (n = 196)	Type 1	87 (44.4)
	Type 2	47 (23.9)
	Type 3	40 (20.4)
	Type 4	16 (8.2)
	Type 5	6 (3.1)
	Type 6	0
χ²; DF; P		50.930; 15; 0.001*

In routine clinical care, the foremost impediment to the successful execution of endodontic therapy in mandibular permanent incisors is the clinician's inability to detect a second canal. The documented frequency of accessory canals in lower incisors has been reported to vary widely, ranging from 45% to 11.5% [14, 16].

Cone-beam computed tomography permits the volumetric, three-dimensional visualization of anatomical microstructures [15, 17]. Studies have demonstrated that the diagnostic fidelity of CBCT in mapping root canal architecture stands on par with the established clearing and staining methodology, going so far as to replicate the latter's precision in ascertaining Vertucci's classification types [5]. This imaging modality is broadly accepted as an uncomplicated, efficient, noninvasive approach and a

trustworthy means of quantifying root canal morphological parameters [18]. The technique of choice for detecting supernumerary roots is undoubtedly CBCT-assisted assessment [19].

The core pathological mechanism responsible for therapeutic failure in lower anterior teeth revolves around the undiagnosed lingual canal, whose neglect leads to pulpal tissue necrosis within that space and the subsequent liberation of bacterial metabolites or toxic substances, which thereafter traverse to the periapical zone via the apical foramen [20, 21]. As a corrective measure, the lingual dentinal bulge should be excised, and the lingual compartment of the pulp chamber must be expanded sufficiently to guarantee direct line-of-sight entry to any remaining canal orifices housed within mandibular anterior teeth [22].

Quantitative morphological data drawn from a Northeast Indian population sample indicate that a single canal (conforming to Vertucci's Type I descriptor) was present in 63.75% of teeth examined, meaning supplementary canal prevalence in the mandibular anterior segment was calculated at 36.25%, with Type III configurations predominating. Echoing the findings of other researchers, 64% of canal bifurcations were observed to originate in the middle third of the root, whereas 23.3% originated in the cervical third [23].

Several published reports have suggested that the presence of two root canals in mandibular incisors occurs more frequently in female patients than in male patients [19, 24]. By comparison, the current investigation failed to establish any correlational link between biological sex and root canal architectural patterns, a result that corresponds closely with the conclusions drawn by Arslan *et al.* [25], who executed a retrospective inquiry into the root canal morphologies of mandibular incisors through the lens of CBCT imaging within a Turkish demographic. Their dataset comprised 374 mandibular incisor images extracted from the CBCT archives of 101 patients. Their analysis documented that 196 teeth had a single canal (Type 1), while 178 teeth harbored two canals across a spectrum of anatomical arrangements. Additionally, it was noted that complicated canal configurations occurred more frequently in males than in females.

Conclusion

No distinctions based on patient sex were observed with respect to either the total count of root canals or the radicular morphological presentation of mandibular central and lateral incisors. The prevalence of root numbers differed substantially across the age strata in the study cohort; notably, of the 436 right-sided

incisors, 433 had a single root, while the remaining 3 had a pair of roots. Among the 436 left-sided incisors, 434 (99.5%) were monoradicular, and a mere 2 (0.5%) presented with a bifurcated root structure. A statistical comparison of root number frequencies between right- and left-sided tooth groups showed no significant difference. CBCT is the ideal radiographic modality for the comprehensive analysis of the endodontic canal system. Consequently, meticulous radiographic scrutiny, ongoing strategic anticipation, and the integration of a dental operating microscope for enhanced magnification can substantially assist the practitioner in both locating and successfully negotiating any additional canal passageways.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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