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Root Number, Canal Number, and Vertucci Root Canal Configuration of Permanent Mandibular First Molars in a Northeastern Iranian Population: A Cone-Beam Computed Tomography Study

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Abstract

Background and Aim: Knowledge of root and canal morphology of mandibular first molars is crucial for successful endodontic treatment. This study aimed to evaluate the root morphology and root canal configuration of mandibular first molars using Cone-Beam Computed Tomography (CBCT) in a selected population.

Materials and Methods: In this retrospective cross-sectional study, CBCT scans of mandibular first molars meeting the inclusion criteria were evaluated. A total of 186 teeth from 136 patients were included after excluding low-quality scans and metallic artifacts. Axial, sagittal, and coronal slices were thoroughly analyzed. Data regarding the number of roots, presence of anatomical variations (such as Radix Entomolaris), and root canal configurations (according to Vertucci's classification) for both mesial and distal roots were recorded. Statistical analysis was performed to assess potential correlations with patient sex and tooth side.

Results: Out of 186 evaluated teeth, 96.8% were two-rooted, and 3.2% exhibited Radix Entomolaris (RE). The mesial roots predominantly presented with two canals (97.8%), with Vertucci Type III (1-2-1) being the most prevalent configuration (33.3%), followed by Type IV (30.1%). In contrast, the distal roots mainly showed a single root (96.8%) and predominantly presented Vertucci Type I configuration (79.6%). No statistically significant correlation was found between canal configurations and patient sex or side ($P > 0.05$).

Conclusion: Mandibular first molars in this population exhibited high anatomical complexity, particularly in mesial roots with multi-canal configurations. CBCT imaging is highly recommended for preoperative identification of anatomical variations and complex canal systems to improve endodontic treatment outcomes.

Keywords: Cone-Beam Computed Tomography, Mandibular First Molar, Root Canal Anatomy, Radix Entomolaris, Vertucci Classification.

Introduction

The permanent mandibular first molar is usually the first permanent tooth to erupt and plays a key role in masticatory function and occlusal stability. Its early eruption and complex occlusal anatomy, together with molar incisor hypomineralization where present, make it highly susceptible to caries [1], and decisions about its endodontic management carry important clinical and economic consequences [2]. Non-surgical root canal treatment can provide durable long-term outcomes [3], but its success depends on thorough disinfection and obturation of the entire canal system and is influenced by several tooth- and treatment-related factors [4]. Missed canals and unrecognized anatomical variations are an established cause of post-treatment apical periodontitis [5, 6].

The mandibular first molar classically has two roots (mesial and distal) and three canals (two mesial and one distal) [7, 8]. However, considerable variation has been reported, including an additional distolingual root (*radix entomolaris*) [9], a middle mesial canal [10, 11], and C-shaped configurations [12]. Canal branching is commonly described using Vertucci's classification (Figure 1) [13], which recognizes eight configurations. Because these variations complicate canal location, instrumentation, and disinfection [5], and because their frequencies differ between ethnic and geographic groups, as reported for Jordanian [14], Saudi [15], and Chinese [16] populations, population-specific data are needed to guide clinicians in each region.

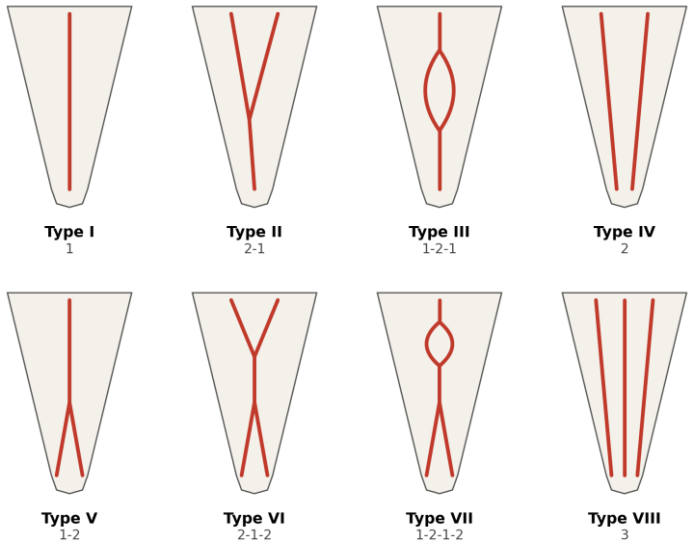


Figure 1. Schematic representation of Vertucci's classification [13] of root canal configurations (types I–VIII). Canals are shown in red; the notation below each type indicates the number of canals from the pulp chamber floor to the apex.

Root canal morphology has traditionally been investigated *ex vivo* by clearing and staining, sectioning, and micro-computed tomography (micro-CT) [17, 18]. Micro-CT offers excellent spatial resolution, but it is restricted to extracted teeth and cannot be applied clinically. Periapical radiography, the most common clinical modality, is limited by anatomical superimposition, geometric distortion, and the loss of bucco-lingual information, so canals may be overlooked [6, 19]. Cone-beam computed tomography (CBCT) overcomes these limitations by providing three-dimensional, non-superimposed views in the axial, coronal, and sagittal planes, and it has been widely used to evaluate mandibular molars in Kuwaiti [20], Yemeni [21], Saudi [8], and Jordanian [14] populations.

In Iran, CBCT studies have examined C-shaped canals and three-rooted mandibular molars [22] and the canal morphology of mandibular molars in a selected population [23]. In Gorgan, a recent CBCT study reported the prevalence and configuration of C-shaped canals in mandibular first and second molars according to Fan's classification [24], but the Vertucci configurations of the mandibular first molar have not been evaluated in this population. Therefore, the present study aimed to assess the frequency of root number, canal number, and Vertucci root canal configuration in permanent mandibular first molars using CBCT in the population of Gorgan, northeastern Iran.

Materials and Methods

Study Design, Setting, and Ethics

This retrospective, cross-sectional radiographic study was conducted using archived cone-beam computed tomography (CBCT) volumetric datasets of patients referred to a private oral and maxillofacial radiology center in Gorgan, northeastern Iran, between 2025 and 2026. All CBCT scans had been acquired previously for valid clinical and diagnostic purposes unrelated to this investigation (such as pre-implant planning, localized impactions, or orthognathic surgery evaluations); consequently, no subject was exposed to unnecessary ionizing radiation. The study protocol was reviewed and granted ethical approval by the Institutional Ethics Committee of Golestan University of Medical Sciences (Ethics code: IR.GOUMS.REC.1404.246). The requirement for informed consent was waived by the Ethics Committee because of the retrospective design of the study and the use of anonymized data. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki.

Sample Selection and Diagnostic Criteria

All archived CBCT scans were numbered, and approximately 300 mandibular first molars were selected from this numbered list by simple random sampling. The eligibility criteria below were then applied to the selected teeth: 114 teeth were excluded because of image artifacts (n = 24), low image quality (n = 83), apical lesions (n = 5), or a C-shaped canal system (n = 2), leaving 186 teeth for analysis. The mesial roots were screened for a middle mesial canal on the axial slices and multiplanar reconstructions; none was observed. Data were analyzed at three levels: the patient level, the tooth level, and the root level.

A total of 186 eligible permanent mandibular first molars derived from 136 unique patients (65 females and 71 males) met the selection criteria. Among these, 50 patients contributed bilateral first molars (28 females and 22 males; n = 100 teeth), whereas 86 patients contributed a unilateral first molar (37 females and 49 males; n = 86 teeth), yielding an anatomical distribution of 95 right (51.1%) and 91 left (48.9%) molars.

The inclusion criteria were:

1. Fully erupted permanent mandibular first molars presenting with complete root development and closed apices.
2. High-resolution CBCT scans with optimal diagnostic clarity of the pulp chamber floor, root canals, and contiguous periradicular architecture.

The exclusion criteria were:

1. Teeth with prior endodontic intervention, intraradicular posts, or full-coverage metallic restorations generating significant beam-hardening or streak artifacts.
2. Presence of extensive root resorption (internal or external), calcific metamorphosis/canal obliteration, or massive periapical lesions obscuring the root apex.
3. CBCT scans with severe motion artifacts or compromised field-of-view diagnostic quality.
4. Teeth with a C-shaped canal system, which falls outside the standard Vertucci classification.

CBCT Acquisition and Imaging Parameters

All volumetric scans were acquired using a CS 8100 3D CBCT scanner (Carestream Health, USA) with a field of view of 8 × 5 cm. The technical imaging parameters were consistently configured across all examinations: a tube voltage of 90 kVp, a tube current of 3.2 mA, an exposure time of 15 s, and an exposure protocol yielding high-resolution volumetric datasets with an isotropic voxel size of 150 μm (0.15 mm). Reconstruction was performed with an axial slice thickness of 300 μm (0.3 mm) and a reconstruction slice interval of 1.0 mm.

Multiplanar reconstructions (MPR)—including dynamic axial, coronal, and sagittal cross-sections—were inspected using CS Imaging software on a calibrated diagnostic display in a quiet room with dimmed ambient illumination (<50 lux). Contrast, luminance, and digital zoom were manipulated dynamically along the longitudinal tooth axis to optimize the delineation of fine endodontic pathways. Canal configuration was assessed on serial axial slices scrolled from the pulp chamber floor to the apex, reviewing the entire volume in the software; the 1.0-mm interval reconstructions were used for figure preparation.

Morphological Assessment and Classification Protocol

Each mandibular first molar was systematically explored from the pulp chamber floor down to the anatomical apex. The evaluated parameters were logged using a standardized case report form:

1. Root number (tooth level): categorized as two-rooted (separate mesial and distal roots) or three-rooted (presence of an additional distolingual root [*radix entomolaris*] or mesiobuccal root [*radix paramolaris*]).

2. Canal number (root level): evaluated independently for the mesial and distal roots.
3. Internal canal configuration (root level): systematically classified, separately for the mesial and distal roots, according to Vertucci's criteria (types I to VIII) [13]:
    - *Type I (1-1):* a solitary canal extending from the chamber to the apex.
    - *Type II (2-1):* two distinct canals exiting the chamber and converging short of the apex into a single canal.
    - *Type III (1-2-1):* one canal leaving the pulp chamber, bifurcating within the root body, and reuniting into a solitary apical exit.
    - *Type IV (2-2):* two separate, parallel canals coursing continuously to two distinct apical foramina.
    - *Type V (1-2):* a single canal exiting the pulp chamber that bifurcates immediately coronal to the apex into two independent foramina.
    - *Type VI (2-1-2):* two separate canals that coalesce in the root trunk and subsequently bifurcate into two separate apical exits.
    - *Type VII (1-2-1-2):* one canal branching into two, reuniting, and subsequently dividing again into two separate exit canals.
    - *Type VIII (3-3):* three independent canals extending from the chamber floor to three separate apical foramina.

In three-rooted molars (radix entomolaris), the main distal root was taken as the distal root for the Vertucci analysis, so each tooth contributed one distal root to the classification; the additional (distolingual) root was recorded as a supernumerary root, and in all such teeth it was classified as Vertucci type I.

Observer Calibration and Reproducibility

All CBCT images were evaluated by a single trained observer. Before the main assessment, the observer received comprehensive training from an experienced oral and maxillofacial radiologist (the specialist). The observer then evaluated a set of 10 images, and the specialist independently evaluated the same images without knowledge of the observer's results; the inter-observer agreement between the two, measured by Cohen's kappa coefficient, was greater than 0.7 (agreement was in fact complete for all variables in these 10 images). The observer subsequently evaluated the remaining images. To verify reliability, a random 30% of all images (56 teeth) were re-evaluated by the specialist, who was blinded to the observer's

results, and the findings were compared and reconciled. Inter-observer agreement was assessed with Cohen's kappa for the root-level variables: the kappa was 1.000 for the number of distal canals and for the Vertucci type of the distal root, and 0.930 for the Vertucci type of the mesial root (94.6% raw agreement; 3 of 56 disagreements); the number of mesial canals was identical in all re-evaluated teeth (100% agreement), so kappa could not be calculated for this variable because it had no variability.

Statistical Analysis

Statistical evaluations were computed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA).

Descriptive statistics were synthesized as absolute frequencies (n) and relative percentages (%) for the patient-level variable (sex), the tooth-level variables (tooth side and root count), and the root-level variables (canal count and Vertucci morphology), each with an exact (Clopper–Pearson) 95% confidence interval for the main proportions. Root-level data were reported separately for the mesial and distal roots, as roots within a tooth are not independent observations. Because the Vertucci type is a nominal variable, its association with tooth side (right vs. left) and sex was tested with Pearson's chi-square test, using the Fisher–Freeman–Halton exact test (Monte Carlo estimation) for tables with sparse cells and Fisher's exact test for 2 × 2 tables; for the mesial root, types VI and VII were combined for this analysis, and for the distal root, type I was additionally compared with all other configurations. Because patient identifiers were not available in the analysis dataset, teeth from the 50 bilateral patients could not be modeled as clustered observations, and these associations should be interpreted with this limitation in mind. Root number (two- vs. three-rooted) and canal number (one vs. two canals, for the mesial and distal roots separately) were compared between tooth sides and between sexes with Fisher's exact test. A two-tailed P-value of <0.05 was considered statistically significant.

Results

1. Patient-Level Findings (Cohort Characteristics and Symmetry)

A total of 136 distinct patients were evaluated in this investigation:

- Demographic profile: Of the 136 included subjects, 86 patients presented with unilateral evaluable first molars, whereas 50 patients presented with bilateral evaluable first molars. The cohort comprised 65 female (47.8%) and 71 male (52.2%) patients.

- Bilateral distribution and symmetry: Among the 50 patients with bilateral CBCT evaluations (representing 100 paired molars):
  - Root number symmetry: Radix entomolaris (three-rooted molars) was observed in 2 of the 50 bilateral patients (4.0%), and in both it was present on both sides (4 teeth). In the remaining 48 bilateral patients, both molars were two-rooted. Two further three-rooted molars were found in patients with a single evaluable molar, so radix entomolaris was present in 4 of the 136 patients (2.9%; 95% CI 0.8–7.4) overall.
- Sex-associated variations: Root number did not differ significantly between sexes (Fisher's exact test, P = 0.211; the radix entomolaris was present in 1 male and 5 female teeth), and neither did the number of mesial canals (P = 1.000) or distal canals (P = 0.856).

2. Tooth- and Root-Level Findings (n = 186)

The 136 patients contributed a total of 186 permanent mandibular first molars, comprising 95 right molars (51.1%) and 91 left molars (48.9%), evenly allocated between male (93 teeth, 50.0%) and female subjects (93 teeth, 50.0%).

A. Root Number and Radix Entomolaris Prevalence

- Two-rooted molars: Prevailed across the cohort, accounting for 180 out of 186 teeth (96.8%; 95% CI 93.1–98.8), displaying standard mesial and distal roots.
- Three-rooted molars: Identified in 6 teeth (3.2%; 95% CI 1.2–6.9), characterized by an additional distolingual supernumerary root (*radix entomolaris*). In these teeth, the main distal root was used for the Vertucci classification of the distal root, and the additional root was Vertucci type I in all six teeth.
- Radix paramolaris: No instances of an additional mesiobuccal root were detected.
- Root number was not significantly associated with tooth side (right vs. left; Fisher's exact test, P = 1.000).

B. Canal Number Distribution

- Mesial roots: two canals were identified in 182 teeth (97.8%; 95% CI 94.6–99.4), and a single canal in 4 teeth (2.2%; 95% CI 0.6–5.4). No middle mesial canal was observed in any of the 186 teeth. The number of mesial canals did not differ between sides (P = 1.000).

- Distal roots: a single canal was identified in 148 teeth (79.6%; 95% CI 73.1–85.1), and two canals in 38 teeth (20.4%; 95% CI 14.9–26.9); the number of distal canals did not differ between sides (P = 0.857).
- The three-canal configuration (two mesial and one distal canal) was the most frequent, observed in 144 teeth (77.4%; 95% CI 70.7–83.2).

C. Internal Canal Morphology (Vertucci's Classification)

The frequency distribution of canal configurations according to Vertucci's classification revealed striking contrasts between the mesial and distal root complexes (Table 1):

- Mesial roots: seven configuration patterns were observed:
  - Type III (1-2-1): The most prevalent morphology, identified in 62 teeth (33.3%).
  - Type V (1-2): Second most frequent, observed in 46 teeth (24.7%).
  - Type IV (2-2): Found in 43 teeth (23.1%).
  - Type II (2-1): Noted in 26 teeth (14.0%).
  - Types I, VI, and VII: occurring in 4 (2.2%), 3 (1.6%), and 2 teeth (1.1%), respectively.
  - Type VIII (3-3) was absent.
  - Types III, IV, and V together accounted for 151 of 186 mesial roots (81.2%; 95% CI 74.8–86.5).
- Distal roots: four configuration patterns were observed:
  - Type I (1-1): identified in 148 teeth (79.6%).
  - Type III (1-2-1): Present in 26 teeth (14.0%).
  - Type V (1-2): Identified in 10 teeth (5.4%).
  - Type VII (1-2-1-2): Present in only 2 teeth (1.1%).
  - Types II, IV, VI, and VIII were absent.

Representative serial axial CBCT slices illustrating the most common mesial and distal configurations are shown in Figures 2–4.

Table 1. Distribution of Vertucci's canal configurations at the root level, for the mesial and distal roots of each tooth (n = 186 teeth). Values are n (%; exact 95% CI).

Vertucci classification	Canal pathway	Mesial root, *n* (%)	Distal root, *n* (%)
Type I	1-1	4 (2.2%; 0.6–5.4)	148 (79.6%; 73.1–85.1)
Type II	2-1	26 (14.0%; 9.3–19.8)	0 (0.0%; 0.0–2.0)
Type III	1-2-1	62 (33.3%; 26.6–40.6)	26 (14.0%; 9.3–19.8)
Type IV	2-2	43 (23.1%; 17.3–29.8)	0 (0.0%; 0.0–2.0)
Type V	1-2	46 (24.7%; 18.7–31.6)	10 (5.4%; 2.6–9.7)
Type VI	2-1-2	3 (1.6%; 0.3–4.6)	0 (0.0%; 0.0–2.0)
Type VII	1-2-1-2	2 (1.1%; 0.1–3.8)	2 (1.1%; 0.1–3.8)
Type VIII	3-3	0 (0.0%; 0.0–2.0)	0 (0.0%; 0.0–2.0)
Total		186 (100.0%)	186 (100.0%)

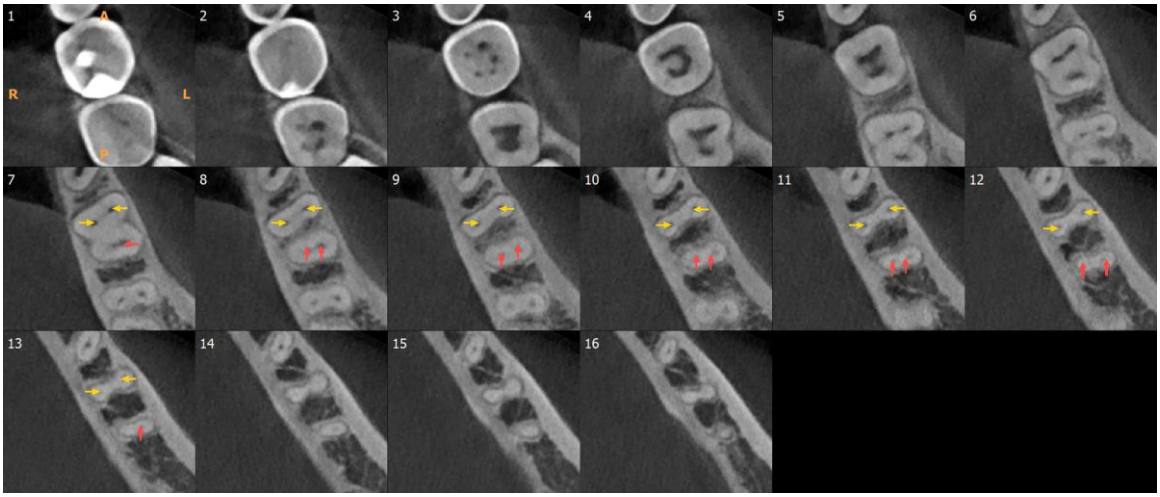


Figure 2. Representative serial axial CBCT slices (1–16) of a mandibular first molar, from the crown level toward the apices, showing Vertucci type IV in the mesial root and type III in the distal root. Yellow arrows indicate canals of the mesial root; red arrows indicate canals of the distal root.

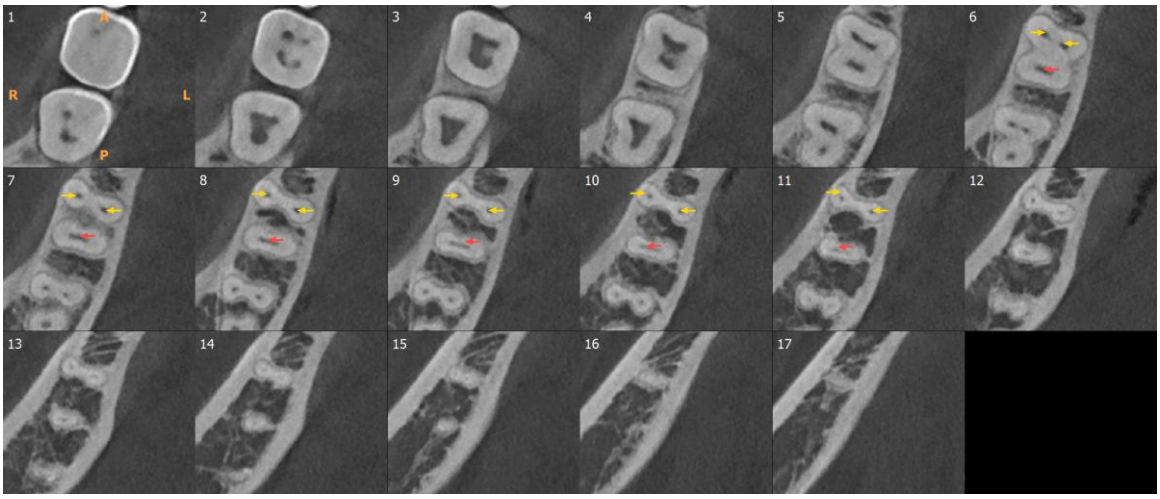


Figure 3. Representative serial axial CBCT slices (1–17) of a mandibular first molar, from the crown level toward the apices, showing Vertucci type V in the mesial root and type I in the distal root. Yellow arrows indicate canals of the mesial root; red arrows indicate canals of the distal root.

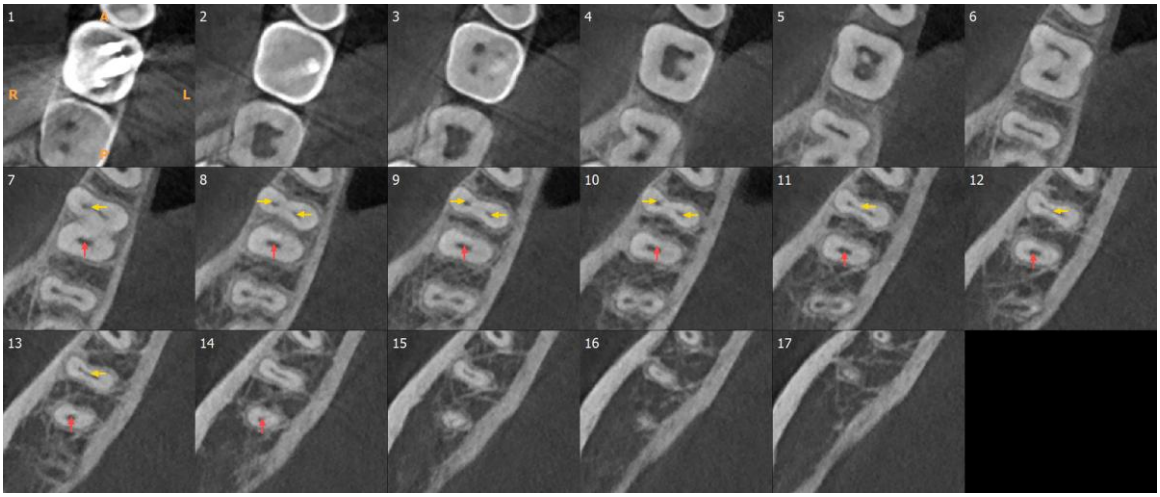


Figure 4. Representative serial axial CBCT slices (1–17) of a mandibular first molar, from the crown level toward the apices, showing Vertucci type III in the mesial root and type I in the distal root. Yellow arrows indicate canals of the mesial root; red arrows indicate canals of the distal root.

3. Association of Vertucci Configuration with Tooth Side and Sex

The association of the Vertucci configuration with tooth side (right vs. left) and sex was tested with the chi-square test, using exact tests for sparse tables:

- Mesial roots: no significant association was found with tooth side ($\chi^2 = 1.68$, df = 5, P = 0.904) or with sex ($\chi^2 = 5.54$, df = 5, P = 0.370); types VI and VII were combined for this analysis.
- Distal roots: no significant association was found with tooth side (P = 0.823) or with sex (P = 0.940); comparing type I with all other configurations gave the same result (side, P = 0.857; sex, P = 0.856).

Discussion

Thorough debridement and three-dimensional obturation of the entire root canal system are the cornerstones of successful endodontic therapy. Missed canals and unforeseen anatomical complexities remain principal etiologies of persistent periapical pathosis and procedural failure [5, 6]. The permanent mandibular first molar is arguably one of the most clinically critical and morphologically variable teeth in human dentition. In this investigation, we evaluated the root and canal configuration of mandibular first molars in an Iranian subpopulation using cone-beam computed tomography (CBCT), deliberately distinguishing between tooth-level anatomical phenotypes and patient-level parameters.

Root Number and Prevalence of Radix Entomolaris

In the present cohort, the typical two-rooted morphology predominated substantially (96.8%), whereas a three-rooted architecture characterized by an additional distolingual root (*radix entomolaris*, RE) was detected in 3.2% of specimens. These findings align closely with epidemiological observations in Caucasian and Middle Eastern cohorts. Specifically, Senan et al. [21] documented an identical 3.2% prevalence of RE in a Yemeni population, while Al-Habib et al. [8] and Madani et al. [23] reported occurrences of 3.89% and 1.9% in Saudi and northern Iranian cohorts, respectively.

The prevalence of RE exhibits striking racial and geographic dimorphism. While RE is documented in less than 5% of Caucasian, African, and Western Eurasian cohorts, it reaches substantial frequencies (10% to over 30%) in populations of Mongoloid descent, including Korean and Chinese groups [25, 26]. Clinically, recognizing an RE is imperative. Because the orifice of the distolingual root is typically situated distolingually relative to the main distal canal and frequently displays severe coronal curvature, conventional two-dimensional periapical radiographs often fail to project it clearly due to structural superimposition [21, 23]. Inadequate modification of the access cavity—specifically failing to extend the preparation trapezoidally toward the distolingual line angle—can lead to missed RE canals, instrument fracture, or procedural strip perforations.

Mesial Root Canal System: The High-Complexity Paradigm

A striking finding of this study was that 97.8% of mesial roots contained two distinct canals, with internal morphologies displaying extreme anatomical heterogeneity across seven Vertucci configurations [13]. Vertucci Type III (1-2-1) emerged as the single most prevalent

configuration (33.3%), followed by Type V (1-2, 24.7%), Type IV (2-2, 23.1%), and Type II (2-1, 14.0%).

The high prevalence of Type III (1-2-1) in our cohort represents an intriguing anatomical pattern. While classic studies and several regional CBCT reports—such as those by Madani et al. [23] in northern Iran (Type IV: 57.0%, Type II: 31.5%), Senan et al. [21] in Yemen (Type II: 57.0%, Type IV: 35.6%), and a Saudi systematic review by Mashyakhy et al. [15]—have typically identified Types IV or II as dominant, our findings resonate with micro-computed tomography observations by Şallı and Egil [18], who identified Type III as the most frequent configuration (25%). These variations between cohorts underscore that canal divergence, confluence, and branching along the middle and apical thirds of the root are influenced not only by ethnic background but also by the imaging modality and voxel resolution employed.

Clinically, the predominance of Type III (1-2-1) and Type V (1-2) holds profound therapeutic relevance. A Type III canal system branches after leaving the pulp floor and subsequently reunites before exiting through a solitary apical foramen [13]. Such anatomical loops, intercanal communications, and isthmuses harbor persistent necrotic tissue and bacterial biofilms that are virtually inaccessible to mechanical rotary instrumentation alone. Consequently, effective eradication of intracanal bioburden in these teeth depends heavily on hydrodynamic irrigation protocols, ultrasonic activation (PUI), and negative-pressure irrigation rather than mechanical file enlargement alone.

Distal Root Architecture: Structural Conservatism

In sharp contrast to the intricate mesial root systems, the distal roots exhibited remarkable morphological simplicity. A single distal canal predominated in 79.6% of teeth, and Vertucci Type I (1-1) accounted for 79.6% of all distal roots, followed by Type III (14.0%) and Type V (5.4%).

This marked predilection for a single distal canal concurs with numerous global CBCT investigations. In a Jordanian subpopulation, Abu Zaghlan et al. [14] reported a distal Type I prevalence of 77.8%, while Wang et al. [26] (62.9%) and Mashyakhy et al. [15] corroborated Type I as the overwhelmingly dominant configuration. In contrast, Senan et al. [21] reported a higher frequency of Type III (48.8%) compared with Type I (41.0%). Notably, all 38 distal roots with two canals showed a branching pattern from a single orifice (Type III, V, or VII), and no distal root had two completely separate canals (Types II, IV, or VI were absent). This suggests that, whenever an additional distal canal is identified, its internal trajectory usually

follows a bifurcating or converging system rather than completely separate, parallel pathways [14, 27]. Clinicians must maintain a heightened index of suspicion whenever a single distal canal orifice does not align symmetrically along the buccolingual midline of the distal root trunk. Table 2 summarizes how the present findings compare with the studies discussed above.

Table 2. Comparison of the present findings with previously published studies discussed above.

Study	Population	RE (%)	Mesial root: most frequent Vertucci type(s), %	Distal root: most frequent Vertucci type(s), %
Present study	Gorgan, Iran	3.2	III (33.3)	I (79.6)
Madani et al. [23]	Northern Iran	1.9	IV (57.0); II (31.5)	—
Senan et al. [21]	Yemen	3.2	II (57.0); IV (35.6)	III (48.8); I (41.0)
Al-Habib et al. [8]	Saudi Arabia	3.89	—	—
Mashyakhy et al. [15] (systematic review)	Saudi Arabia	—	IV or II predominant	I predominant
Abu Zaghlan et al. [14]	Jordan	—	—	I (77.8)
Wang et al. [26]	Western China	—	—	I (62.9)
Şallı and Egil [18] (micro-CT)	—	—	III (25.0)	—

RE, radix entomolaris. —, not reported in the studies as discussed in the text.

Patient-Level Considerations and Bilateral Symmetry

Because patient identifiers were not available in the analysis dataset, the analyses were performed at the tooth and root levels, and patient-level information was limited to sex and to the root number of patients with bilateral molars. Among the 50 patients who underwent bilateral CBCT evaluation (100 molars), root number was fully symmetric: RE was found in 2 patients and was present on both sides in both, whereas the remaining 48 patients had two-rooted molars bilaterally. This finding is of direct clinical relevance: when an endodontist diagnoses a supernumerary root on one side, the contralateral molar should be examined for the same variation. Given the very small number of bilateral RE cases, however, symmetry should not be assumed to be guaranteed.

Furthermore, our analysis revealed no statistically significant sex predilection across root numbers, canal numbers, or Vertucci configurations ($P > 0.05$), aligning with observations by Alazemi et al. [20], Kim et al. [25], and Madani et al. [23]. No significant sex difference was observed in this sample; however, the small number of three-rooted molars (5 of 6 in female patients) limits the power to detect a sex difference in root number.

Strengths and Limitations

The non-invasive, three-dimensional assessment provided by CBCT at an isotropic voxel size of 150 μm allowed sub-millimeter visualization of root canal morphology without the destructive artifacts associated with clearing or sectioning techniques. Furthermore, root-level data were reported separately for the mesial and distal roots, and exact 95% confidence intervals were provided for the main proportions to convey the precision of the estimates.

Nevertheless, certain limitations must be acknowledged. First, although CBCT spatial resolution (150 μm) is clinically optimal, it remains lower than micro-CT (<20 μm), which may limit the visualization of extremely fine apical deltas, accessory canals, and very narrow isthmuses. Second, teeth with C-shaped canal systems (two teeth) were excluded from the standard Vertucci analysis according to the predefined protocol, because the Vertucci classification does not describe this configuration. C-shaped canals were examined in our previous study based on the same CBCT database (scans acquired in 2021–2023, with no patient overlap with the present sample), in which C-shaped morphology was found in only 2 of 157 mandibular first molars (1.27%) but in 11.15% of second molars [24]. This is in line with the very small number of C-shaped first molars encountered here; C-shaped systems are therefore only marginally represented in the present sample. In addition, no middle mesial canal (MMC) was observed in any of the examined teeth. Because MMCs are usually very fine, their absence from our sample may be attributable to the limited spatial resolution of CBCT rather than to a true absence of this variation, and our data should not be used to estimate MMC prevalence in this population. Third, a considerable proportion of the randomly selected teeth (83 of approximately 300) were excluded because of low image quality, which may introduce selection bias. Fourth, only inter-observer agreement was assessed, and intra-observer reproducibility was not evaluated. Furthermore, because patient identifiers were not available in the analysis dataset, teeth from the 50 bilateral patients could not be modeled as clustered observations, so the associations of Vertucci type with tooth side and sex should be interpreted with caution. Finally, multi-center studies with larger sample sizes across different geographic provinces of Iran are encouraged to elucidate broader ethnic variations.

Conclusions

Within the limitations of this CBCT study:

1. The vast majority of mandibular first molars in this Iranian cohort presented with two roots (96.8%), with *radix entomolaris* occurring in 3.2% of teeth.
2. The mesial root demonstrated substantial anatomical complexity, with Vertucci Type III (1-2-1) being the most common configuration (33.3%), a configuration to be considered during canal location and irrigation.
3. The distal root exhibited notable conservatism, dominated by Vertucci Type I (1-1, 79.6%).

All distal roots with two canals showed a branching configuration (Vertucci type III, V, or VII), and neither tooth side nor patient sex was significantly associated with the Vertucci configuration of the mesial or distal root.

Declarations

Ethics approval and consent to participate: The study was approved by the Ethics Committee of Golestan University of Medical Sciences (IR.GOUMS.REC. 1404.246). Only anonymized, previously acquired CBCT examinations were used; no additional imaging was performed for research. The requirement for new informed consent for this retrospective secondary analysis was waived by the approving committee.

Clinical trial code: Not applicable

Consent for publication: Not applicable

Availability of data and materials: The anonymized dataset is available from the corresponding author on reasonable request, subject to institutional and ethics requirements.

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