ORIGINAL ARTICLE

Cone-Beam Computed Tomography Assessment of Mandibular Molar Root and Canal Morphology in a North African Population

Évaluation par tomodensitométrie volumique à faisceau conique de la morphologie des racines et des canaux molaires mandibulaires dans une population tunisienne

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Abstract

Aim: The aim of this study was to evaluate roots and root canal morphology of mandibular first and second permanent molars in a Tunisian population using cone-beam computed tomography (CBCT), providing detailed anatomical data to support clinical endodontic practice.

Methods: This retrospective, descriptive study included 100 CBCT scans from patients referred to the University Dental Clinic of Monastir between January and December 2024. A total of 400 mandibular molars (200 first and 200 second molars) were analyzed. Only teeth with fully developed roots and no prior endodontic treatment were included. Morphological features were assessed in axial, sagittal, and coronal CBCT views. The number of roots, number of canals per root, and canal configurations were recorded based on Vertucci's classification. The presence of radix entomolaris and radix paramolaris was also noted. Statistical analysis was performed using the Chi-square test ($p \leq 0.05$).

Results: Mandibular first molars exhibited predominantly two-rooted anatomy (98%), with 2% presenting a third distolingual root (radix entomolaris). Second molars displayed more variation, with 5% showing a single root, 4% with three roots, and 1% with four roots. Canal configuration analysis revealed that the mesial root of first molars most commonly exhibited Vertucci Type IV (83.7%), while distal roots showed a predominance of Type I (60.2%). In second molars, mesial roots also frequently presented Type IV (51.1%), whereas distal roots overwhelmingly exhibited Type I (94.4%). Three- and four-rooted molars were more commonly found in second molars. Sex and side differences were not statistically significant ($p = 0.579$ and $p = 0.4$, respectively), but root morphology was significantly associated with tooth type ($p = 0.003$).

Conclusion: This CBCT-based study provides the first comprehensive analysis of mandibular molar root and canal morphology in a Tunisian population. The findings confirm substantial anatomical variability, particularly in second molars, and underscore the importance of population-specific data for improving diagnostic accuracy and enhancing the outcomes of endodontic therapy.

Keywords: Dental Anatomy, Morphological Variations, Root canal configuration, Three-Dimensional Imaging, Tunisia

Résumé

Objectif: Cette étude visait à évaluer la morphologie radiculaire et canalaire des premières et deuxièmes molaires permanentes mandibulaires dans une population tunisienne, à l'aide de la tomodensitométrie volumique à faisceau conique (CBCT), afin de fournir des données anatomiques utiles à la pratique endodontique.

Méthodes: Une analyse rétrospective a été menée sur 100 CBCT de patients adressés à la Clinique dentaire universitaire de Monastir entre janvier et décembre 2024. Au total, 400 molaires mandibulaires (200 premières et 200 secondes) avec racines complètement développées et sans traitement endodontique antérieur ont été examinées. Le nombre de racines, des canaux et les configurations canalaires ont été enregistrés selon la classification de Vertucci. La présence de radix entomolaris et de radix paramolaris a été notée. L'analyse statistique a utilisé le test du Chi carré ($p \leq 0,05$).

Résultats: Les premières molaires présentaient majoritairement deux racines (98 %), dont 2 % avec une troisième racine distolinguale. Les deuxièmes molaires étaient plus variables : 5 % à une racine, 4 % à trois racines et 1 % à quatre racines. Les configurations canalaires les plus fréquentes étaient le type IV pour les racines mésiales et le type I pour les racines distales. La morphologie radiculaire était significativement liée au type de dent ($p = 0,003$), mais pas au sexe ni au côté.

Conclusion: Cette étude révèle une variabilité anatomique notable, surtout chez les deuxièmes molaires, soulignant l'intérêt de données spécifiques à chaque population pour optimiser le diagnostic et le traitement endodontique.

Mots clés: Configuration du canal radiculaire, CBCT, Anatomie dentaire, Molaires mandibulaires

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Introduction

A comprehensive understanding of root canal anatomy is a critical determinant of successful endodontic therapy. Optimal treatment outcomes rely on thorough biomechanical instrumentation, effective chemical debridement, and the three-dimensional (3D) obturation of the entire root canal system. Nevertheless, the inherent complexity and variability of root canal morphology often present significant clinical challenges that may compromise therapeutic objectives. It is, therefore, imperative for clinicians to be aware of anatomical variations, including those influenced by racial and ethnic factors, prior to and during endodontic procedures to enhance the predictability of treatment outcomes(1-3).

Numerous studies (2, 4-6) have explored the root canal morphology of mandibular molars; however, the anatomy of their roots and canals is highly variable and influenced by ethnic and genetic factors. Morphological variations commonly observed include the presence of a distolingual root, C-shaped roots and canals, isthmuses between the mesiobuccal and mesiolingual canals, and the presence of a third canal in the mesial root, referred to as the middle mesial canal(2, 4, 5). These anatomical complexities pose challenges to effective endodontic therapy and necessitate precise diagnostic approaches.

Investigations conducted across different populations have revealed considerable differences in the root and canal configurations of mandibular first and second molars(1-5). To assess these variations, a range of techniques has been employed, such as conventional radiography, decalcification, tooth sectioning, resin replication, and advanced computer-aided imaging methods(1, 4). Accurate evaluation of root canal anatomy necessitates the use of multiple imaging planes. Cone-beam computed tomography (CBCT), in particular, has proven to be an invaluable diagnostic tool for detecting atypical and complex root canal configurations, thereby enhancing clinical decision-making in endodontics. CBCT enables three-dimensional visualization of root morphology, including the number of canals and their spatial orientation, whether converging or diverging. As such, CBCT has been increasingly recommended for identifying root canal systems in challenging cases.

To date, no study has examined the root and canal morphology of mandibular permanent molars in a Tunisian population using cone-beam computed tomography (CBCT). Although Touzi et al.(6) conducted a morphological analysis of mandibular first molars in Tunisian individuals using the sectioning method, the absence of CBCT-based investigations limits the precision and clinical applicability of existing data. Given that detailed knowledge of root and canal anatomy significantly enhances the success of endodontic treatment and contributes to improved patient outcomes, further investigation is warranted.

Therefore, the aim of the present study was to evaluate the root and root canal morphology of mandibular first and second permanent molars in a Tunisian population using CBCT, thereby providing clinically relevant anatomical insights specific to this population.

Methods

This observational, retrospective, and descriptive study analyzed mandibular molars using cone-beam computed tomography (CBCT) to assess root and canal morphology. CBCT scans were evaluated based on strict inclusion and exclusion criteria. Root canal configurations were classified according to Vertucci's system, and data were interpreted using standardized imaging protocols.

CBCT scans were obtained from a cohort of patients who attended the University Dental Clinic of Monastir between January and December 2024 for various diagnostic purposes, including facial trauma, odontogenic tumors, preoperative implant planning, and orthodontic assessment. The CBCT scans had been acquired as part of routine diagnostic or treatment planning procedures, and not specifically for research purposes. Only patients who were informed about the secondary use of their imaging data and provided written consent prior to inclusion were considered for analysis; data from those who declined were excluded.

Sample size

No formal sample size calculation was performed, as this was a retrospective and descriptive study. Instead, all CBCT scans that met the inclusion criteria during the study period were included, in order to maximize statistical power and ensure representativeness. This comprehensive approach, frequently adopted in retrospective designs, minimizes the risk of selection bias due to arbitrary sample restriction and provides a reliable overview of root and canal morphology in the target population.

Sample representativeness and randomization

The study sample was derived from a heterogeneous cohort of patients referred for various diagnostic purposes, thereby mirroring a genuine clinical population. This reflects the role of the University Dental Clinic of Monastir as a national referral center, attracting individuals from across Tunisia for specialized dental care. To reduce selection bias, CBCT scans were randomly extracted from the existing radiological database based on clearly defined inclusion and exclusion criteria. This approach provides a diverse and well-balanced sample.

Inclusion criteria

To ensure optimal visualization and accurate anatomical assessment of mandibular molars, the following criteria were applied for image selection:

- Mandibular permanent first and second molars with fully developed roots and intact root structure on both the right and left sides.
- Absence of periapical pathology, including lesions or inflammatory changes.
- Presence of clearly discernible mature molars; only sound teeth or those exhibiting initial decay without cavitation were included.

Non-inclusion criteria

Teeth were excluded from the study based on the following conditions that could compromise image clarity or anatomical accuracy:

- History of root canal interventions, including previous endodontic treatment.
- Presence of root anomalies, such as canal calcification, root fractures, resorption, or open apices.
- CBCT scans exhibiting diagnostic artifacts caused by post or crown restorations, adjacent implants, or improper radiographic technique.
- Teeth showing physiological or pathological alterations, including any condition that could impair the visualization or interpretation of root morphology.

CBCT Image evaluation

CBCT examinations were performed in the Department of Dental Anatomy, Faculty of Dental Medicine of Monastir, University of Monastir.

All CBCT images were evaluated independently by two investigators: a specialist in dental anatomy and an endodontist. Each tooth was evaluated separately to achieve conformity. The CBCT images were evaluated after calibration to the anatomical criteria and variants used in this study. Disagreement in images interpretation was discussed between the two dentists until a decision was made.

CBCT images were displayed on a screen (Samsung 24" Full HD IPS) with a resolution of 1,920 × 1,080 pixels. The interpretations of the images took place in a dimly lit room where brightness, magnification and contrast settings were fine-tuned when required using the software to enhance visibility and for proper reading and analysis.

Observed morphological features

All CBCT were evaluated in 3 plans. Axial, sagittal, and cross-sectional slices, with a thickness of 0.5–1 mm were used.

Tooth position (right or left), the morphology of mandibular first and second molars, the number of roots and root canals per root, root canal configuration , based on Vertucci's classification (2) and the presence of radix entomolaris and radix Paramolaris, as defined by Song et al. (7) were recorded and evaluated using CBCT images.

Ethical considerations

The Ethics Committee of the Faculty of Dental Medicine in Monastir reviewed the study and granted ethical approval. All procedures complied with institutional guidelines and ethical standards regarding confidentiality and responsible research conduct. Consequently, the committee approved the request and assigned the approval number 2025026.

Statistical analysis

Bilateral and unilateral occurrences of similar anatomical features were recorded and their relations to sex and tooth location were determined. Statistical software (SPSS for Windows version 22.0 SPSS Inc) was used to analyze the recorded data using Chi square. Statistical significance was set at P≤0.05.

Results

From the available scans, 100 CBCTs were selected, including 400 mandibular molars (100 first and 100 second molars per side) screened from 42 male and 58 female patients.

The results showed that, for the mandibular first molar, no tooth had a single root. Among the 200 teeth analyzed, 196 had two roots, four teeth had three roots. As for the mandibular second molar, 10 teeth had a single root, 180 had two roots, eight had three roots, and two teeth had four roots (Table 1).

Table 1. Number of roots in mandibular first and second molars

	One root		Two roots		Three roots		Four roots		Total	
	n	%	n	%	n	%	n	%	n	%
First molar	**0**	0%	**196**	98%	**4***	2%	**0**	0%	**200**	100%
Second molar	**10**	5%	**180**	90%	**8****	4%	**2**	1%	**200**	100%
Total	**10**	2.5%	**376**	94%	**12**	3%	**2**	0.5%	**400**	100%

* For first mandibular molars with three roots (n = 4), the four teeth had an extra distolingual root (Entomolaris).
** For second mandibular molars with three roots (n = 8), three teeth presented 2 mesiobuccal roots and one distal root, and five teeth showed an extra distolingual root with one mesial root (Entomolaris).

Vertucci's classification was applied to assess the internal root canal morphology of 196 first and 180 second bi-rooted mandibular molars (Table 2). In first molars, the mesial root most commonly exhibited a Type IV canal configuration (83.7%) followed by Types II (8.2%) and Type I (4.1%), while the distal root predominantly showed Type I (60.2%) with a notable proportion of Type IV (26.5%). For the second molar, the mesial root is also dominated by Type IV (51.1%), followed by Type I (28.9%), while the distal root is almost exclusively Type I (94.4%).

Table 2. Root Canal Configuration of Bi-Rooted Mandibular Molars Based on Vertucci's Classification

	Type I	Type II	Type III	Type IV	Type V	Total
First Molar						
M root	8	16	6	164	2	196
	4.1%	8.2%	3%	83.7%	1%	100%
D root	118	8	0	52	18	196
	60.2%	4.1%	0%	26.5%	9.2%	100%
Second Molar						
M root	52	16	10	92	10	180
	28.9%	8.9%	5.5%	51.1%	5.5%	100%
D root	170	0	0	4	6	180
	94.4%	0%	0%	2.2%	3.3%	100%

Among the mandibular molars displaying a three-rooted morphology, the most prevalent canal configurations were Type I and Type IV, according to Vertucci's classification. In the subset of four first molars, the mesial roots consistently exhibited a Type IV configuration, while others roots, including that identified as radix entomolaris demonstrated a Type I canal pattern. Of the eight second molars analyzed, three specimens presented with two mesial roots and a single distal root, each root containing a single canal (Type I). The remaining five second molars showed one mesial root with a Type IV configuration, and two distal roots with a Type I configuration, one of which corresponded to a radix entomolaris. No instances of radix paramolaris were identified among the second molars.

In the second mandibular molars with four roots, two molars were observed in which each root contained a single canal (Type I configuration) across all four roots.

The distribution of root number among mandibular molars was analyzed across sex, tooth type, and anatomical side. Although males showed a slightly higher frequency of three-rooted molars and females had a greater proportion of two-rooted molars, the sex-based differences were not statistically significant (p = 0.579). However, root morphology varied significantly between tooth types (p = 0.003): all one-rooted molars were second molars, and second molars were also more frequently associated with three-rooted anatomy. In contrast, two-rooted morphology was predominant in first molars. Side-related differences were minimal, with nearly equal distribution of root numbers between right and left sides and no significant correlation (p = 0.4). These findings highlight a stronger association between root number and tooth type rather than sex or anatomical side (Table 3).

Table 3. Incidence of number of roots in relation to sex, tooth type and side

Variables		1 Root		2 Roots		3 Roots		4 Roots		p
		n.	%	n.	%	n.	%	n.	%	
Sex	Male	3	30	157	41.8	7	58.3	1	50	0.579
	Female	7	70	219	58.2	5	41.7	1	50	
	Total	10	100	376	100	12	100	2	100	
Tooth type	First Molars	0	0.0	196	52.1	4	33.3	0	0.0	0.003*
	Second Molars	10	100	180	47.9	8	66.7	2	100	
	Total	10	100	376	100	12	100	2	100	
Side	Right Side	6	60	190	50.5%	6	50.0%	1	50.0%	0.4
	Left Side	4	40	186	49.5%	6	50.0%	1	50.0%	
	Total	10	100	376	100	12	100	2	100	

Discussion

This study, conducted on a large CBCT sample, represents the first investigation of root and canal morphology of permanent mandibular molars in a Tunisian population. Our findings showed that the majority of mandibular first and second molars presented two roots in 98% and 90% of cases, respectively. The prevalence of three-rooted molars was 2% for first molars and 4% for second molars. Regarding canal configuration, Vertucci's type IV was predominant in mesial roots and type I in distal roots. No middle mesial canals were observed. Radix entomolaris were also identified, although their frequency was low (3%).

Mandibular molars often display complex root canal anatomies, making precise morphological assessment essential for effective endodontic treatment. A deep understanding of canal configurations is crucial, as they vary according to age, sex, ethnicity, population group, number of teeth, and the research methodologies applied (4).

Number of roots

Our results are consistent with several previous studies reporting that mandibular molars are mostly biradicular(4, 6, 8-14).

Previous investigations, such as those conducted by Wang et al. (15) and Al-Alawi et al. (16) documented infrequent instances of first molars exhibiting a singular root. Consistent with these findings, our study, similar to those of Touzi et al. (6) in Tunisia and Al-Nazhan (17) in Saudi Arabia, did not identify any first molars with a single root.

The presence of an additional root is considered a normal morphological diversity (4). In our present study, the prevalence rates of three roots in first molars and second molars were 2 % and 4% respectively. Our findings are similar, higher and lower compared to those documented by Al-Alawi et al, 2019 (16), Nur et al. (18) Wang et al. (15) respectively. These discrepancies could be attributed to ethnic variations(19). The use of CBCT has greatly enhanced the ability to identify uncommon anatomical variations that may be overlooked in conventional two-dimensional radiographs (15). Structures such as distolingual roots, radix entomolaris, and radix paramolaris can present significant clinical challenges if undetected (14, 20, 21).

CBCT facilitates precise localization and characterization of these atypical morphologies, thereby improving diagnostic accuracy and aiding in effective endodontic treatment planning.

Mandibular second molars display notable anatomical diversities, including the occurrence of supernumerary or single roots as documented Kantilieraki (12) and Nur et al.(18) . In our current investigation, mandibular second molars showcased variability in root numbers, with 94% having two roots, 2.5% with one root, 3% with three roots, and 0.5% with four roots, consistent with the findings of Gomez et al.(22).

Although the occurrence of mandibular molars with one or three roots is relatively rare, clinicians should remain vigilant for atypical anatomical variations that may affect diagnosis and treatment outcomes

Root canal configuration

Vertucci's classification (5), widely used in canal morphology studies, defines eight canal types and remains a practical tool for clinical and educational purposes due to its simplicity. However, advanced imaging techniques like CBCT and micro-CT have revealed anatomical complexities that traditional systems may overlook (12, 15, 22-26). To address this, Ahmed et al. (3) proposed a more detailed coding system based on tooth, root, and canal configurations. Though more elaborate, it offers greater precision, especially when used with 3D imaging, making it suitable for research, teaching, and complex clinical cases. Each system holds value depending on the diagnostic context and anatomical complexity (27, 28).

This study found Vertucci Type IV as predominant in mesial roots (83.7%) and Type I in distal roots (60.2%) of bi-rooted mandibular first molars. These results align with previous CBCT and micro-CT studies (6, 11, 15, 17, 18, 29, 30), which consistently report two canals in the mesial root and one in the distal root.

Similarly, Touzi et al. (6), Mukhaimer (24) and Akhlaghi (31) reported type IV and I canal configurations as the prevailing types in mesial and distal roots in Tunisian, Palestinian and Iranian populations, respectively. However, higher frequencies of type II have been found in Kuwaiti, Greek, and Chilean populations (4, 12, 25).

Conversely, Torres (14), in a study analyzing the mesial roots of mandibular molars in Belgian and Chilean populations, reported Type V and Type III as the most frequent configurations, an exceptional finding that contrasts with the commonly observed patterns.

Mandibular second molars showed greater anatomical diversity, with frequent type IV (51.1%) and type I (28.9%) configurations in mesial roots and predominantly type I in distal roots (94.4%), consistent with findings from Saudi Arabian (9), Egyptian (10), and Turkish (32) populations.

In the present study, no cases of mandibular first molars with a single root and single canal were identified, which aligns with their typical multi-rooted anatomy. In contrast, 5% of mandibular second molars exhibited a configuration consisting of a single root and a single canal. This anatomical variation is common and well documented (4, 12, 33). These cases correspond to Vertucci's Type I canal configuration. Such findings underscore the morphological variability of mandibular molars, particularly second molars, which may occasionally present with simplified root canal anatomy, although this remains a rare occurrence.

Additionally, in 2010, De Pablo (19) conducted a systematic review on the root anatomy and canal configuration of mandibular permanent first molars, revealing that the Vertucci type IV canal system was the most frequent, followed by type II. Ethnic and methodological differences may explain these discrepancies, as ethnicity appears more related to root number than to canal configuration (19).

In the current research, it is interesting to note that all additional root canals in the first and second mandibular molars had a Type I configuration according to Vertucci, consistent with the observations of Nur et al. (18) and Mantovani et al. (11) regarding triradicular molars. However, canal configurations varied significantly between the first and second mandibular molars, contrasting with the results reported in studies conducted in Kuwait (4) and Venezuela(22).

Mandibular second molars displayed greater variability in external root morphology compared to first molars. Fused roots are more frequently seen in mandibular second molars compared to first molars (3). This fusion can result in teeth that are conical or square-shaped, with radicular grooves(4). This was found in our study, where 5% of second molars had a single root, compared with none of the first molars.

Middle mesial canal

The absence of middle mesial canals in our sample aligns with their generally low prevalence, ranging from 0.1% to 22.1% across populations (19, 23, 25).

In a recent study utilizing CBCT, Aldosimani (34) identified 12 middle mesial canals, accounting for 0.9% of the cases examined. Specifically, nine of these canals were found in the mandibular first molar (1.3%), while the remaining three were observed in the mandibular second molar (0.4%).

Radix molaris

In the present study, an additional root (radix entomolaris) was detected in 12 mandibular molars (3%). This finding corroborates the rarity of such a morphological variation, which has been shown to be influenced by ethnic background (20). Although previous investigations have consistently reported a higher prevalence of radices in mandibular first molars and a lower occurrence in second molars (4), the opposite trend was observed in the current sample, as mandibular second molars exhibited the highest frequency of radix, consistent with the findings of Demirbuga et al. (1), who reported a greater prevalence of radix entomolaris in second molars (3.45%) compared to first molars (2.06%) in a Turkish population. However, the prevalence of radix entomolaris was notably (4.3%) in a Saudi population, as reported by Al-Alawi (16), compared to the present study 2%. In the study of Bhatia

(21), the prevalence of radix entomolaris in mandibular first molars was higher compared to second molars, which is inconsistent with our study.

Influence of demographic factors on root canal anatomy

These differences suggest anatomical variations occurring during molar development. Research has revealed that sex may influence the number of canals, canal configurations, and overall root anatomy, highlighting the importance of considering sex-based differences in endodontic diagnosis and treatment planning (25, 35, 36). Although several studies have investigated sex-based variations in root canal morphology, our findings align with those reporting no statistically significant differences between males and females regarding the number of roots (4, 22, 30, 37). Notably, Mashyakhy et al. (37) reported a highly significant difference between males and females in canal configuration specifically associated with the distal roots of the mandibular first and second molars, however, these differences did not extend to root count. Since our study did not assess canal configuration, future research may benefit from including this parameter to explore potential anatomical disparities more comprehensively.
Conversely, Martins et al. (13) identified significant sex-related differences in canal morphology in permanent teeth within a Portuguese population. It is important to note that our study did not investigate potential associations between root canal anatomy and patient demographic characteristics.

Strengths and limitations

A major strength of this study lies in the use of CBCT, which provides accurate three-dimensional visualization of root and canal morphology and overcomes the limitations of conventional radiographs (15, 23). Furthermore, this research includes the largest CBCT dataset from a Tunisian population to date, thereby offering valuable local reference data. Nevertheless, some limitations must be acknowledged. First, canal configurations were not analyzed according to demographic variables, which could have provided insight into potential sex- or age-related differences, as reported in other studies (13, 25, 35-37). Second, although CBCT is highly effective, it does not match the resolution of micro-CT, which remains the gold standard for detailed evaluation of accessory anatomy(23, 25, 26, 28). Then all CBCT images were sourced exclusively from the Monastir University Dental Clinic. Although this institution serves as a national referral center and receives patients from across Tunisia, the single-center design may introduce selection bias and limit the generalizability of the findings to the broader Tunisian population.

Clinical implications

A precise understanding of mandibular molar anatomy—particularly second molars—is crucial for successful endodontic treatment. Their pronounced variability in root and canal morphology can complicate procedures and, if undetected, may lead to persistent infection and treatment failure (38). CBCT significantly improves diagnostic accuracy by revealing hidden anatomical features shaped by genetic, environmental, and developmental factors, including population-specific variations (39).

Conclusion

In this study, Type IV and Type I canal configurations were the most prevalent, while radix entomolaris showed a low frequency and was more commonly observed in second molars. No middle mesial canal or radix paramolaris was detected. These findings indicate that, although Tunisian mandibular molars share many features with other populations, they also exhibit distinct ethnic-specific traits, underscoring the importance of individualized clinical and radiographic assessment. While the data provide a useful reference for practice and education, further large-scale research is needed to comprehensively assess variations in root canal morphology in permanent mandibular molars within the Tunisian population.

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