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Systematic review article

Mapping Root and Canal Anatomy in Saudi Populations Using Cone-Beam Computed Tomography: Prevalence, Classification, and Clinical Implications for Endodontic Practice

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Abstract

Background: Accurate understanding of root and canal anatomy is essential for endodontic success. Cone beam computed tomography (CBCT) improves visualization over 2 D imaging and supports systematic, reproducible interpretation in clinical practice.Objective: To synthesize CBCT based evidence on root and canal morphology in Saudi subpopulations and outline the clinical implications for access, scouting, and preparation.Methods: We followed PRISMA aligned methods to identify English original studies from Saudi centers reporting CBCT findings on permanent teeth. Eligibility included observational designs describing root number, Vertucci configuration, second mesiobuccal canal (MB2), C shaped canals, and relevant inter orifice measurements. Due to heterogeneity in tooth types, reporting schemes, and CBCT parameters, we conducted a structured narrative synthesis.Results: in included studies, mandibular molars most commonly exhibited two roots with three canals, with Vertucci type IV frequent in mesial roots and type I in distal roots. C shaped morphology was reported in mandibular molars, with notable regional and sex related variation. In maxillary molars, MB2 was detected in first molars and less often in second molars; inter-orifice spatial relationships were mapped at the pulp floor level, reinforcing the need for methodical troughing and magnification. Premolars were predominantly single-rooted/single-canal in mandibular arches, whereas maxillary first premolars commonly showed two roots; taxonomy influenced reporting.Conclusions: CBCT guided, tooth specific strategies integrating demographic

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risk cues, standardized interpretation, and meticulous clinical exploration, can reduce missed anatomy and optimize endodontic outcomes. Future multicenter studies using harmonized CBCT acquisition and classification frameworks are warranted to refine prevalence estimates and clinical pathways.

Keywords: Cone Beam Computed Tomography; Root Canal Anatomy; Mesiobuccal Second Canal; C shaped Root Canal; Premolar Morphology; Maxillary Molars; Saudi Arabia; Endodontics.

Introduction

Successful endodontic therapy depends on accurate recognition of root and canal anatomy, because missed treated canals are a major cause of failure (1). Three dimensional cone beam computed tomography (CBCT) overcomes key limitations of 2D radiography, projection, geometric distortion, and anatomical noise, by enabling multiplanar navigation and a systematic, reproducible interpretation workflow that improves diagnostic precision and treatment planning (1).

Population and tooth specific variation is substantial, a study of Saudi studies on mandibular teeth shows predominantly single canal incisors and canines, high frequencies of Vertucci type I configurations in second premolars (96.9%), and common three canal mesial distal patterns in first molars; C-shaped canals appear in 9.8% of mandibular second molars and mid mesial canals in 4.2% of first molars. These findings indicate regional heterogeneity and the influence of imaging modality on reported morphologies (2).

In a CBCT series from northern Saudi Arabia, two roots were frequent in maxillary first premolars (62% on the maxillary left), with Vertucci type IV often observed; mandibular premolars were typically type I (3). Maxillary molars demand particular vigilance for a second mesiobuccal canal (MB2). A systematic review focused on the Indian population show that MB2 detection varies by method, pooled prevalence 64.8% with CBCT, 26.5% with direct vision, higher with magnification and ultrasonic troughing, with male sex associated with greater detection. These method dependent gradients underscore the need to combine careful clinical exploration with appropriate imaging (4).

Saudi CBCT data on maxillary molars show that first molars most often present with three roots and four canals, whereas second molars exhibit more

variability (including 3 root, 3 canal patterns) and high bilateral symmetry; such distributions have direct implications for access design and canal scouting (5).

Anterior teeth display simpler patterns, yet precise knowledge is essential. In a Saudi subpopulation, canines were overwhelmingly single rooted, single canal, with Vertucci type I predominating and an impacted canine prevalence around 7.9%; sex and arch differences were also observed (6). These data inform expectations for canal negotiation and the diagnostic role of CBCT in orthodontic and endodontic planning (6).

Methods

Protocol and reporting

This review was conducted and reported in accordance with PRISMA 2020.

Eligibility criteria

We included original studies conducted in Saudi Arabia that used CBCT to describe root and canal morphology of permanent teeth. Eligible designs were observational cross sectional or cohort analyses reporting at least one of the following: number of roots, Vertucci canal configuration, presence of a second mesiobuccal canal (MB2), C shaped canal prevalence, and intra orifice measurements. Studies focused on primary dentition, non-Saudi populations, cadaveric or in vitro and ex vivo experiments, case reports without CBCT-based prevalence, systematic reviews, editorials, letters, conference abstracts without full data, and duplicates were excluded.

Information sources and search strategy

We searched electronic databases to identify eligible articles and supplemented this with manual screening of reference lists and forward citation tracking of included papers. No prespecified limits on publication year were applied at the search stage. free-text terms and controlled vocabulary were combined around three concepts: tooth and region (maxillary molar, mandibular premolar), morphology (root, canal, Vertucci, MB2, C-shaped), and imaging

modality. Full-text screening was limited to studies available in English or Arabic.

Study selection

Records were screened at title and abstract level, followed by full text assessment against eligibility criteria. All inclusion and exclusion decisions were re checked after a cooling off period to reduce selection error. Reasons for full text exclusion were documented (wrong population, wrong design, not CBCT based, inadequate outcomes, duplicate) (Fig 1).

Data extraction

A standardized form was used to extract study characteristics (first author, year, region, center), design, sample size (patients and teeth), participant characteristics (sex distribution, age where available), CBCT acquisition parameters, tooth type, and outcomes: roots and canals counts, Vertucci types, MB2 prevalence and inter orifice distances, C shaped prevalence and external morphological markers, side, sex differences, and notable measurement definitions. When data were presented only in figures, values were transcribed directly; no study authors were contacted.

Risk of bias assessment

Methodological quality of prevalence and observational studies was appraised using an established checklist appropriate for cross sectional prevalence research (sampling frame, sample size justification, measurement validity, assessor reliability, and completeness of reporting). Given the single reviewer workflow, risk of bias judgments were self audited for consistency.

Synthesis methods

Heterogeneity in tooth type, outcomes, and measurement definitions precluded meta analysis. A structured narrative synthesis was undertaken, grouping findings by jaw and tooth (maxillary molars, MB2; mandibular molars, C-shaped and Vertucci; premolars, root canal counts and Vertucci). subgroup patterns by sex, side, and region were summarized descriptively.

Results

In the included CBCT based cross sectional studies from Saudi centers, mandibular molars show two roots with three canals, and characteristic mesial distal configuration patterns. In a Makkah cohort, 96.5% of mandibular first molars and 96.3% of second molars had two roots; three canals were present in 77.7% and 82.7%, respectively. Vertucci type IV predominated in mesial roots (first molars 75.6%; second molars 48%), while type I predominated in distal roots (first molars 71.7%; second molars 99.1%). C shaped canals were detected in 5.7% of first and 4.0% of second mandibular molars.

A large Jeddah CBCT series reported a higher overall incidence of C shaped morphology (27.3%), with 24.3% in mandibular first molars and 30.3% in second molars. The longitudinal groove was most commonly lingual (53.3%), and prevalence was higher in males for second molars.

Maxillary molar assessments identified an MB2 canal frequently in maxillary first molars, but less often in second molars. MB2 was found in 46.7% of first and 17.7% of second maxillary molars, located palatal to MB1 or along the line connecting MB1 and the palatal canal. In a Riyadh region CBCT study focused on maxillary first molars, the MB2 prevalence reached 86.8%, with a mean MB1 MB2 inter orifice distance of 2.52 ± 0.57 mm at the pulp floor level.

Mandibular premolar morphology was largely simple and showed clinically relevant variability, especially in first premolars. In a Jazan cohort of 776 teeth, 99.5% of first premolars and 100% of second premolars had one root; however, two canals occurred in 29.5% of first premolars versus 2.1% of second premolars. Vertucci distributions were: first premolars, type I 69.5%, type III 6.3%, type V 22.2%, type VII 0.3%; second premolars, type I 96.8%, type III 1.6%, type V 0.8%; with no right, left differences. Additional regional work from Hail inspected 1000 mandibular premolars using standardized CBCT protocols, reinforcing the need to anticipate anatomic variation when planning access and instrumentation.

A Taibah University study concluded that maxillary premolars presented with two roots and type IV configurations, whereas mandibular premolars typically had one root with type I, underscoring CBCT value for case difficulty assessment.

These studies indicate a predictable two root and three canal patterns in mandibular molars with notable, but regionally variable, burdens of C-shaped anatomy; clinically important MB2 prevalence in maxillary first molars (with defined intra orifice spatial relationships) and lower rates in second molars; and simple mandibular premolar anatomy with two canal frequency in first premolars. These distributions emphasize careful pre operative imaging and targeted exploration to avoid missed canals and to tailor canal preparation.

Fig 1: PRISMA consort chart of selection

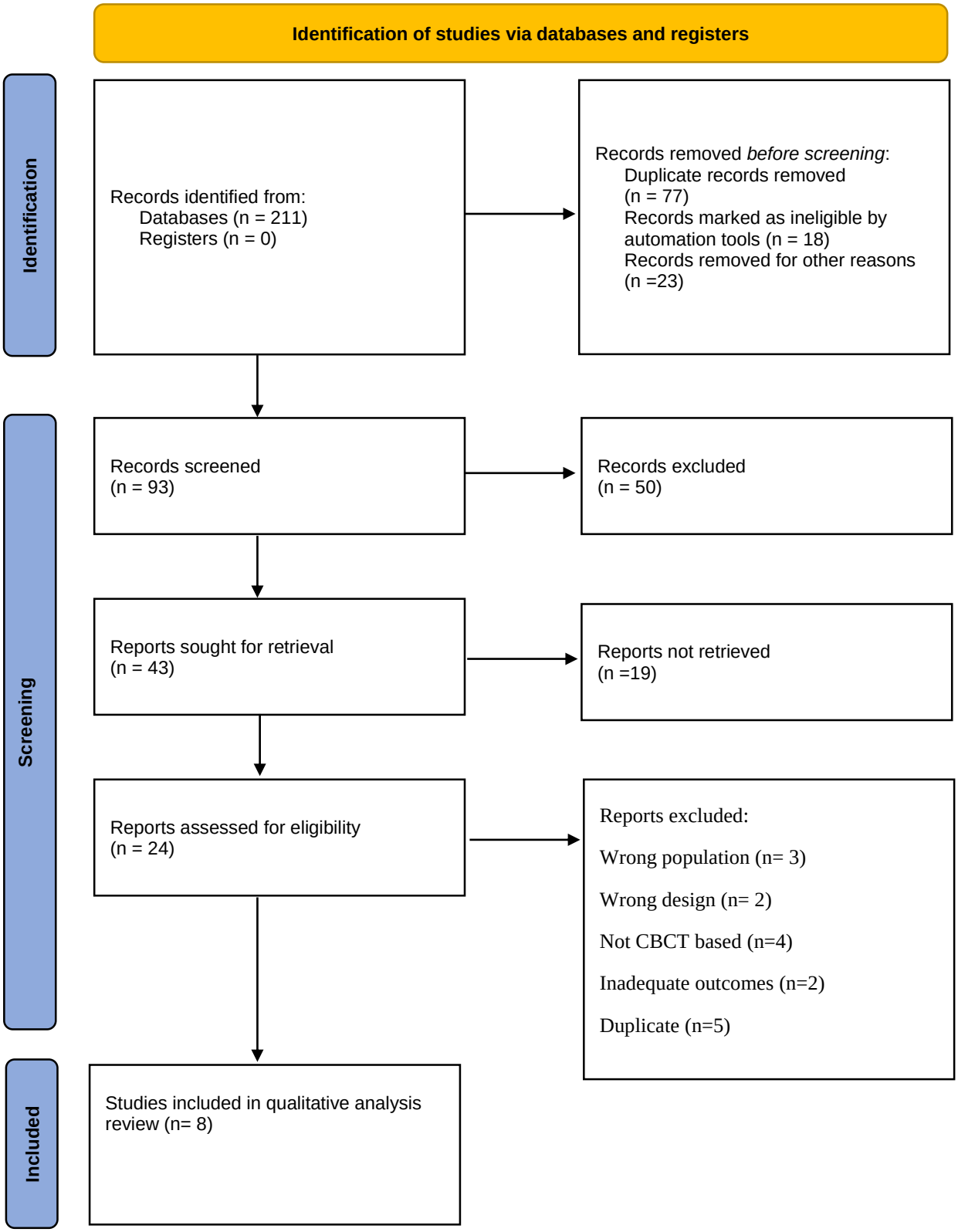

Table 1: characteristics and main findings of the included studies

Citation	Study design	Sample size	Population characteristics	Main findings
Kenawi et al., 2022 (7)	Retrospective CBCT cross sectional study of mandibular molars	208 patients (Makkah)	Saudi subpopulation, adults imaged for various indications in Makkah region	First molars: 96.5% two roots, 77.7% three canals; second molars: 96.3% two roots, 82.7% three canals; mesial Type IV common; distal Type I common; C-shaped: 5.7% (first), 4.0% (second).
Al-Zubaidi et al., 2022 (8)	CBCT cross sectional analysis of mandibular premolars	1000 premolars	Saudi subpopulation, Hail region; fully developed roots; sex, side compared	First premolars: Type I 70.0%; second premolars: Type I 91.1%; most teeth single-rooted; minimal sex, side differences.
Madfa et al., 2023 (9)	CBCT cross-sectional study of maxillary second molars	499 teeth from 250 people (Hail)	Saudi subpopulation, Hail; adult CBCTs analyzed for root, canal, orifice counts	Three roots in 93.2%; three canals in 54.3%; orifice pattern most often three; MB2 present in 49.7% overall; MB Vertucci: I 57.2%, II 10.3%, IV 7.8%, V 18.0%, VIII 5.8%.
Al-Habib and Howait, 2021 (10)	CBCT cross-sectional study of MB2 in maxillary first molars	106 scans (KAU Dental Hospital)	Saudi subpopulation; maxillary first molars focused; CBCT orifice mapping	MB2 prevalence 86.8%; inter-orifice distance MB1, MB2: 2.52 ± 0.76 mm; MB2, palatal: 3.58 ± 0.86 mm; joins at coronal (14.15%), middle (38.68%), apical (37.75%).
Alnowailaty and Alghamdi, 2022 (11)	Retrospective CBCT cross sectional (Jeddah)	300 CBCT scans (2013, 2021) analyzed; MB2 evaluated in MFMs and MSMs	Saudi citizens, Jeddah; equal gender numbers; adult scans; single hospital source	MB2 prevalence: 46.7% in MFM, 17.7% in MSM; mean PMB1, PMB2 distance: 1.87 ± 0.42 mm (MFM), 1.24 ± 0.76 mm (MSM); PMB2, PP: 0.74 ± 0.21 mm (MFM), 0.43 ± 0.18 mm (MSM).

Alnowailaty and Alghamdi (2), 2022 (12)	CBCT cross sectional prevalence study (Jeddah)	Random screening of 2,946 scans; included Saudi residents with more than 1 mandibular 1stM, 2ndM	Saudi population, Jeddah; CBCT in oral and maxillofacial radiology dept.	Overall C-shaped prevalence 27.33% (1stM 24.33%, 2ndM 30.33%); higher in males; lingual groove in 53.35% of C-shaped molars (key external marker).
Mashyakhy et al., 2022 (13)	In-vivo CBCT cross-sectional of mandibular premolars	776 premolars	Saudi subpopulation (southern region); fully formed roots; axial, coronal, sagittal evaluation	First premolars: 99.5% one root; canals: 69.5% one, 29.5% two; Vertucci I 69.5%, III 6.3%, V 22.2%, VII 0.3%. Second premolars: 100% one root; canals: 96.8% one; Vertucci I 96.8%.
Mirah et al., 2023 (14)	Cross-sectional CBCT of maxillary and mandibular premolars	500 CBCTs; 2,442 premolars (18, 75 y; 250 F, 250 M)	Saudi subpopulation (western region); Taibah Univ. dataset; STROBE-adherent methods	Maxillary 1st premolars commonly 2 roots (82.6%); maxillary 2nd premolars mostly 1 root (66.6%); mandibular premolars mostly 1 root (84.8, 96.1%); significant sex differences in some Vertucci types.

Discussion

Our findings indicate that successful endodontic outcomes depend on anticipating anatomic variation and tailoring access, shaping, and obturation accordingly; incomplete instrumentation and obturation is leading mechanisms of failure (15). Consistent with contemporary mapping work, clinically relevant variability spans tooth types, sex, and geography, underscoring the need for structured pre-operative assessment and judicious use of three-dimensional imaging (1).

C-shaped morphology is a prime example. Large scale synthesis shows the pattern is uncommon in mandibular first molars but markedly enriched in second molars (0.3% vs 12%), with East Asian cohorts demonstrating especially high second-molar prevalence (39.6%) compared with other regions (9 to 11%) (16). These epidemiologic gradients matter clinically: pre-operative suspicion should be heightened in second molars and in patients from high-prevalence regions, and canal scouting, irrigation strategies should anticipate fins and isthmuses characteristic of the C-shape (17).

For maxillary molars, our interpretation aligns with pooled CBCT analyses indicating that a second mesiobuccal canal (MB2) is far more frequent in first than second molars (70% vs 39%). Given the clinical difficulty of MB2 identification, adjunctive imaging and methodical inspection of the pulpal floor are justified in first molars and in men, where pre-test probability is higher (1,16).

Premolar anatomy in our material also mirrors modern reviews: maxillary first premolars commonly present with two canals, roots, whereas maxillary second premolars more often have a single root, canal; women and Asian populations show higher probabilities of single-rooted, single-canal anatomy (18). These patterns dovetail with Mn2P syntheses indicating a predominantly single-root, (1-1-1, 1" configuration but with meaningful variation that warrants vigilance (15).

Micro computed tomography (micro-CT) is the ex-vivo reference for internal morphology due to its nondestructive, high-resolution (10-20 μm) capability and ability to quantify complex apical anatomy (Karobari et al. 2022). Because micro-CT is ex vivo, CBCT is the practical in-vivo tool; its multiplanar navigation increases sensitivity for pathoses and anatomic variants when 2D radiographs are insufficient, provided interpretation follows a systematic, reproducible workflow (1). Modality influences prevalence estimates: C-shaped mandibular premolars appear far more often in micro-CT series (66-68%) than in CBCT-based in vivo studies, highlighting potential under-detection on clinical imaging and the importance of correlating imaging with meticulous clinical exploration (16).

These anatomic realities carry procedural implications. In teeth predisposed to MB2 or C-shaped systems, access refinement under magnification, extended troughing, and augmented irrigant activation are prudent to address fins, isthmuses, and lateral anatomy that instrumentation alone may miss (16,17). For premolars more likely to be single-canal, especially in women and Asian patients, clinicians can prioritize conservative shaping while remaining alert to less common splits in the apical third (15,18).

Conclusion

Cone beam computed tomography interpreted with a standardized workflow, reveals clinically relevant anatomic variation in Saudi populations. High yield patterns include frequent second mesiobuccal canals in first maxillary molars and variable canal systems in mandibular molars, including C shaped anatomy.

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