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REVIEW

GEOGRAPHICAL VARIATIONS IN ROOT CANAL ANATOMY OF PERMANENT MOLARS: A SYSTEMATIC REVIEW

Variaciones geográficas en la anatomía del conducto radicular de los molares permanentes: una revisión sistemática

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ABSTRACT

Introduction: The anatomical variability in root canal systems of permanent molars presents significant challenges for endodontic treatment, which still need to be explored. **Objective:** To synthesize scientific evidence on geographical variations in the number of root canals in permanent molars.

Material and Methods: A systematic review was conducted at the University of Medical Sciences of Havana, analyzing the number of root canals in permanent molars. Primary studies in English, Spanish, and Portuguese were included, focusing on the anatomical details of root canals. Clinical case studies, editorials, and studies without specific root canal information were excluded. We searched PubMed, Scopus, and Web of Science for relevant studies published from 1971 to 2023. Sensitivity analysis assessed the impact of methodological quality on the results. Findings were synthesized by geographical region, describing the prevalence of different root canal configurations.

Results: Data from 93 studies encompassing 60,402 molars were analyzed. Significant geographical variations in root canal anatomy were observed. In Africa, first and second upper molars typically had three root canals (45.62% and 41.31%), as did first and second lower molars (59.79% and 67.55%). In America, upper first molars predominantly had four root canals (56.66%). In Asia, most molars had three root canals, except for lower third molars which commonly had two or three canals (42.88% and 57.12%). In Europe, molars generally had three root canals, except for lower third molars which lacked specific data. In Oceania, upper first molars frequently had six root canals (65%).

Conclusions: Significant geographical variations in root canal anatomy of permanent molars were observed, with distinct patterns among different continents. These findings call for standardized, comprehensive research, particularly in underrepresented areas and on third molars, to better inform clinical practice and add to global understanding of molar anatomy.

Clinical significance: Understanding regional root canal variations improves endodontic treatment planning and accuracy. Thus, this knowledge is fundamental for adapting techniques and should inform dental education.

Keywords: *Dental morphology; Endodontics; Geographic variation; Molar; Root canal anatomy; Systematic review*

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RESUMEN

Introducción: La variabilidad anatómica de los sistemas de conductos radiculares de los molares permanentes presenta importantes desafíos para el tratamiento endodóntico, que aún requieren mayor investigación. **Objetivo:** Sintetizar la evidencia científica sobre las variaciones geográficas en el número de conductos radiculares en los molares permanentes.

Material y métodos: Se realizó una revisión sistemática en la Universidad de Ciencias Médicas de La Habana, analizando el número de conductos radiculares en molares permanentes. Se incluyeron estudios primarios en inglés, español y portugués, centrados en los detalles anatómicos de los conductos radiculares. Se excluyeron estudios de casos clínicos, editoriales y estudios sin información específica sobre conductos radiculares. Se realizaron búsquedas en PubMed, Scopus y Web of Science para encontrar estudios relevantes publicados entre 1971 y 2023. El análisis de sensibilidad evaluó el impacto de la calidad metodológica en los resultados. Los hallazgos se sintetizaron por región geográfica, describiendo la prevalencia de las diferentes configuraciones de conductos radiculares.

Resultados: Se analizaron datos de 93 estudios que abarcaban 60.402 molares. Se observaron variaciones geográficas significativas en la anatomía del conducto radicular. En África, los primeros y segundos molares superiores típicamente tenían tres conductos radiculares (45,62% y 41,31%), al igual que los primeros y segundos molares inferiores (59,79% y 67,55%). En América, los primeros molares superiores predominantemente tenían cuatro conductos radiculares (56,66%). En Asia, la mayoría de los molares tenían tres conductos radiculares, excepto los terceros molares inferiores que comúnmente tenían dos o tres conductos (42,88% y 57,12%). En Europa, los molares generalmente tenían tres conductos radiculares, excepto los terceros molares inferiores que carecían de datos específicos. En Oceanía, los primeros molares superiores frecuentemente tenían seis conductos radiculares (65%).

Conclusiones: Se observaron variaciones geográficas significativas en la anatomía de los conductos radiculares de los molares permanentes, con patrones distintivos entre los distintos continentes. Estos hallazgos exigen una investigación estandarizada y exhaustiva, especialmente en zonas con baja representación y en los terceros molares, para fundamentar mejor la práctica clínica y contribuir a la comprensión global de la anatomía molar. **Importancia clínica:** Comprender las variaciones regionales de los conductos radiculares mejora la planificación y la precisión del tratamiento endodóntico. Por lo tanto, este conocimiento es fundamental para adaptar las técnicas y debe fundamentar la formación odontológica.

Palabras clave: *Morfología dental; Endodoncia; Variación geográfica; Molar; Anatomía del conducto radicular; Revisión sistemática*

INTRODUCTION

The morphology of tooth roots and root canals presents a significant challenge in endodontic practice, demanding a thorough understanding for successful treatment outcomes. Various classification systems have been developed to accurately characterize root and canal configurations;[1-3] however, these systems often fall short in capturing the full complexity of dental anatomy. Advanced imaging techniques, such as micro-computed tomography (micro-CT) and cone beam computed tomography (CBCT), have revealed complex details of root canal anatomy, highlighting the limitations of existing classification systems.[4,5] Research into the root and canal morphology of third molars has uncovered new canal configurations previously undocumented, further underlining the unpredictable nature of tooth anatomy and emphasizing the need for continued research in this field.[4-6]

The number of root canals in permanent molars varies depending on the type of tooth and the individual anatomy. Research indicates that maxillary and mandibular molar primaries can have a wide range of root and channel configurations, with the most common being three canals and three roots in maxillary first molars.[7] and two separate roots with two distinct mesial canals and a distal canal for the first mandibular[8] Other studies conclude that a significant proportion of the first permanent maxillary molars have three roots and four canals, with a high prevalence of a second mesio-buccal canal (MB2).[9-11] As such understanding these variations is vitally important to achieving successful endodontic treatments.

Many universities advocate that their curricula have an internationalization that provides knowledge about their graduates' ways of acting in order to be able to perform in any context in their professional lives.[12,13] This research pays homage to the globalization of dental knowledge, recognizing that a dental clinician trained in North America may need to practice in the Middle East. Understanding the frequency of different root canal configurations in various geographic regions is essential for performing endodontic procedures effectively across the globe.

The study by Martins *et al.*,[14] revealed that the prevalence of a second configuration of root canal number varies widely, from 0.7% in Nigeria to 17.7% in Uruguay. This same research found global variations in the configuration of the number of root canals of 7.5% with significant variations according to ethnicity, sex and age.[14]
The variability in the distribution and number of root canals in human permanent molars complicates endodontic therapy, particularly if the prevalence of these anatomical patterns is not well understood. Providing the dental community with an overview of how these patterns vary by geographic region could significantly contribute to the advancement of dental science. Given the preceding discussion, the overarching research question of this study is: Are there significant differences in the morphology and configuration of root canals in permanent molars across different geographic populations? To address this question, the objective of this research is to synthesize available scientific evidence on geographical variations in the internal anatomy of root canals in permanent molars, identifying significant patterns and differences across various populations.

MATERIALS AND METHODS

A systematic review was conducted from April to July 2024 at the University of Medical Sciences of Havana, following approval by the Scientific Committee. The research adhered to the PRISMA guidelines and utilized *PubMed, Scopus*, and *Web of Science* (WOS) databases for retrieving relevant reports.

Inclusion criteria

Primary research studies, including original investigations, research papers, and clinical trials that reported anatomical aspects related to the number of root canals in permanent molars, were included. Articles were considered if they were written in English, Spanish, or Portuguese. Additionally, articles that did not explicitly report the number of canals per permanent molar but allowed for this information to be inferred were also included.

Exclusion criteria

Exclusion criteria included clinical case reports, opinion pieces, editorials, and review articles, as well as any studies not aligned with the inclusion criteria. Studies focusing on primary or deciduous teeth, those lacking anatomical information on the number of root canals, and articles in languages other than English, Spanish, or Portuguese were excluded. Furthermore, articles not available in full text or those that did not present relevant results in their abstracts for necessary data extraction were omitted.

Search strategy

The search strategy for PubMed included the following formulation: ((Pulp Canal*[Title]) OR (Root Canal*[Title]) OR (dental canal*[Title]) OR (canal*[Title])) AND ((anatomy [Title]) OR (morphology [Title])). Similar keywords were adapted for searches in other databases.

Additionally, the Research Rabbit platform (*https://researchrabbitapp.com/home*) was utilized to retrieve relevant articles not identified in the initial searches. The phrase used was 'root canal morphology of human molars.'

Study evaluation and selection process

Calibration among authors was performed to ensure consistency in evaluating the selected articles. The agreement among reviewers was assessed using Orwin's method (1994), and a kappa statistic was calculated to measure consensus on inclusion or exclusion decisions. Kappa values between 0.40 and 0.59 indicated acceptable agreement, 0.60 to 0.74 indicated adequate agreement, and 0.75 or higher indicated excellent agreement.

The records retrieved from the databases were managed using the EndNote bibliographic software, which facilitated the export of files for the screening process on the Rayyan® platform (*https://rayyan.ai/*). This tool enabled the removal of duplicates and non-relevant records, with researchers making blinded decisions on article suitability. In cases of discrepancy or uncertainty, a third author adjudicated the inclusion outcomes.

Data extraction

Data extracted from the included reports encompassed the author and year of publication, study design, age of the study population, geographic location, number of molars analyzed, dental groups (1st, 2nd, and 3rd upper and/or lower permanent molars), and the number of molars with one to six or more root canals.

Data analysis

Sensitivity analysis was conducted to evaluate the impact of methodological quality on the results. Studies were categorized into two groups:

1) high-quality studies, which employed high-resolution imaging techniques (CT or CBCT) to assess root anatomy, and

2) low-quality studies, which used conventional radiography or less accurate assessment methods.

The systematic review focused on quantitatively synthesizing the results of primary studies to provide a global overview of the number of root canals in permanent molars. The primary goal was to summarize the findings without estimating a specific effect, hence a detailed risk of bias (ROB) analysis for each study was deemed unnecessary. However, to ensure the quality of included evidence, rigorous study selection, critical evaluation, analysis of heterogeneity, and sensitivity analysis were performed.

A narrative synthesis of the findings was conducted, grouping studies by geographic regions, and detailing the prevalence of various root canal configurations (number of canals) in maxillary and mandibular molars for each population. Global and regional heat maps, plots, and tables were generated to visualize the geographic distribution of root canal configuration prevalence in maxillary and mandibular molars.

For the sensitivity analysis, descriptive statistics were performed for each group and the results compared to assess the impact of methodological quality. Data processing was performed using RStudio® 2024.04.1 Build 748. The data frames and RStudio codes used are available at the following link in accordance with open science principles: *https://data.mendeley.com/datasets/xvgf59n75k/2*.

All results were compiled into tables, maps, and graphs showing relative and absolute frequencies to facilitate the understanding of root canal patterns for each molar group across different geographic regions.

Figure 1. PRISMA flow diagram illustrating the study selection process for the systematic review, detailing the stages of identification, screening, eligibility, and inclusion of reports.

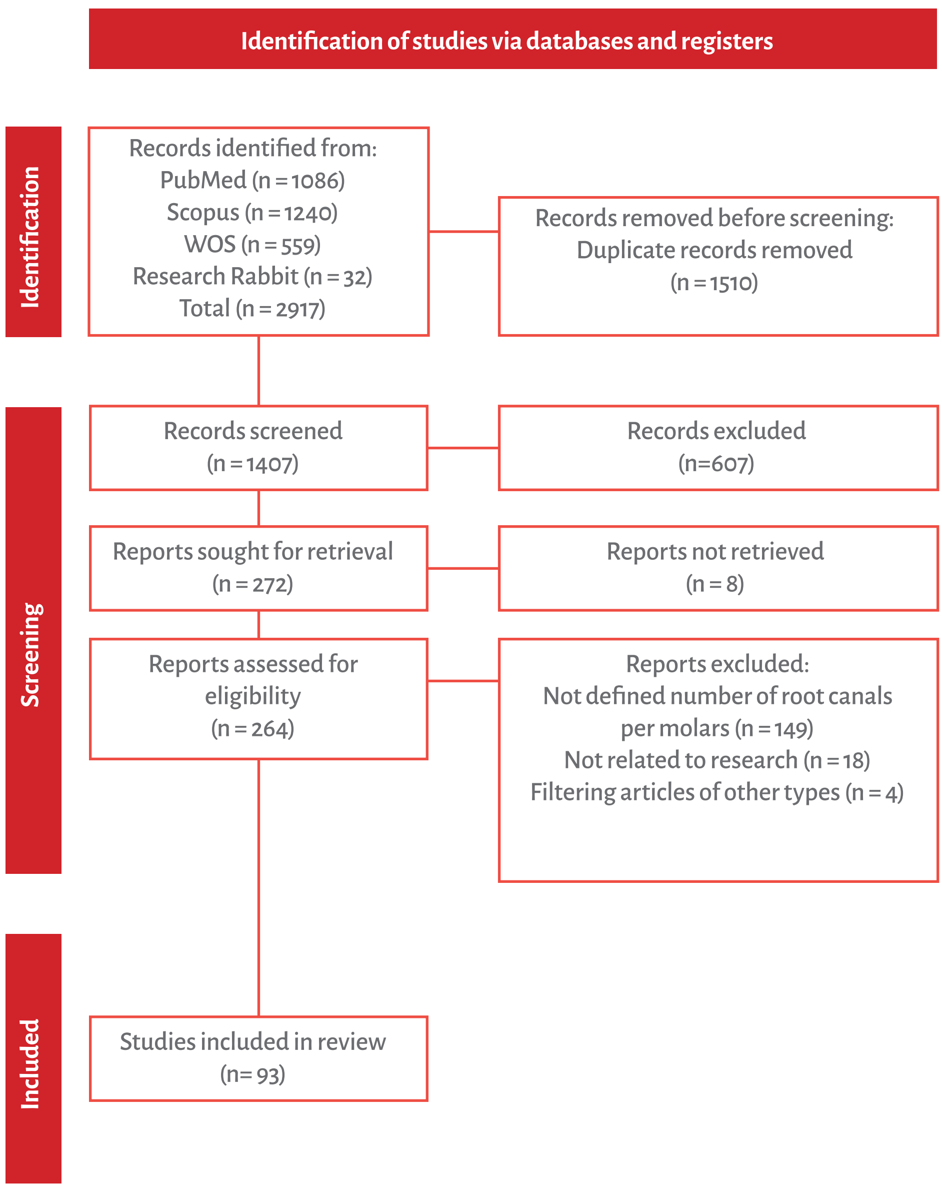


Figure 2.

Annual distribution of the number of articles published in the study

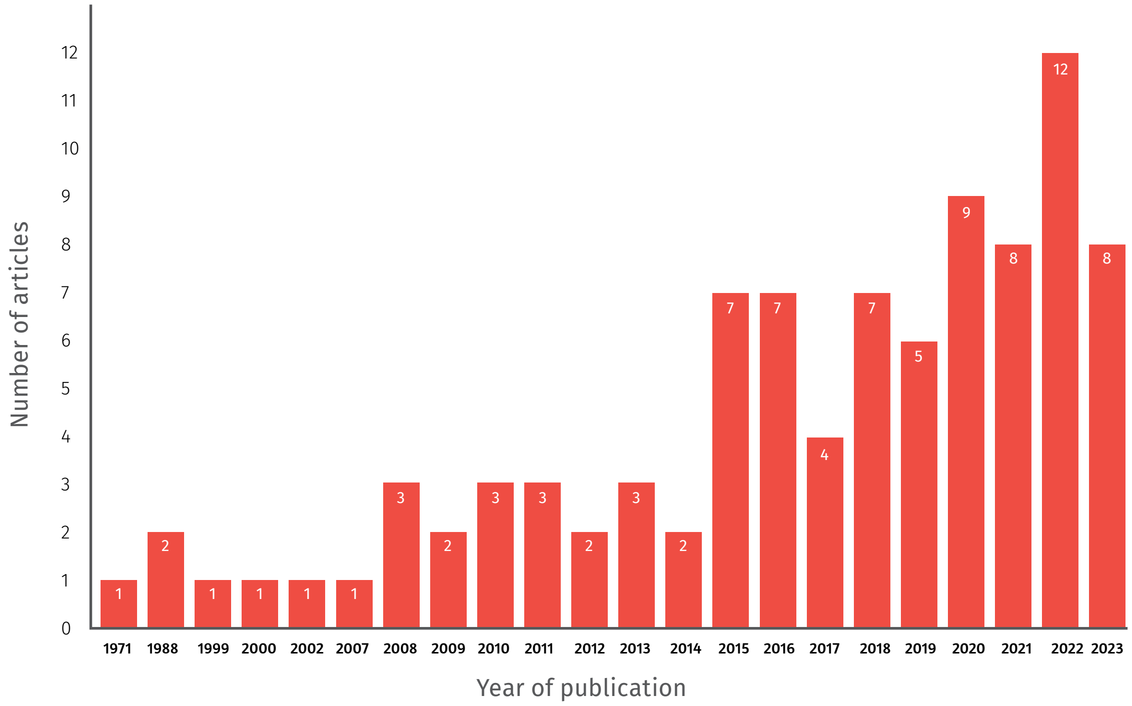


Figure 3.

Distribution of the number of molars assessed in studies across different countries.

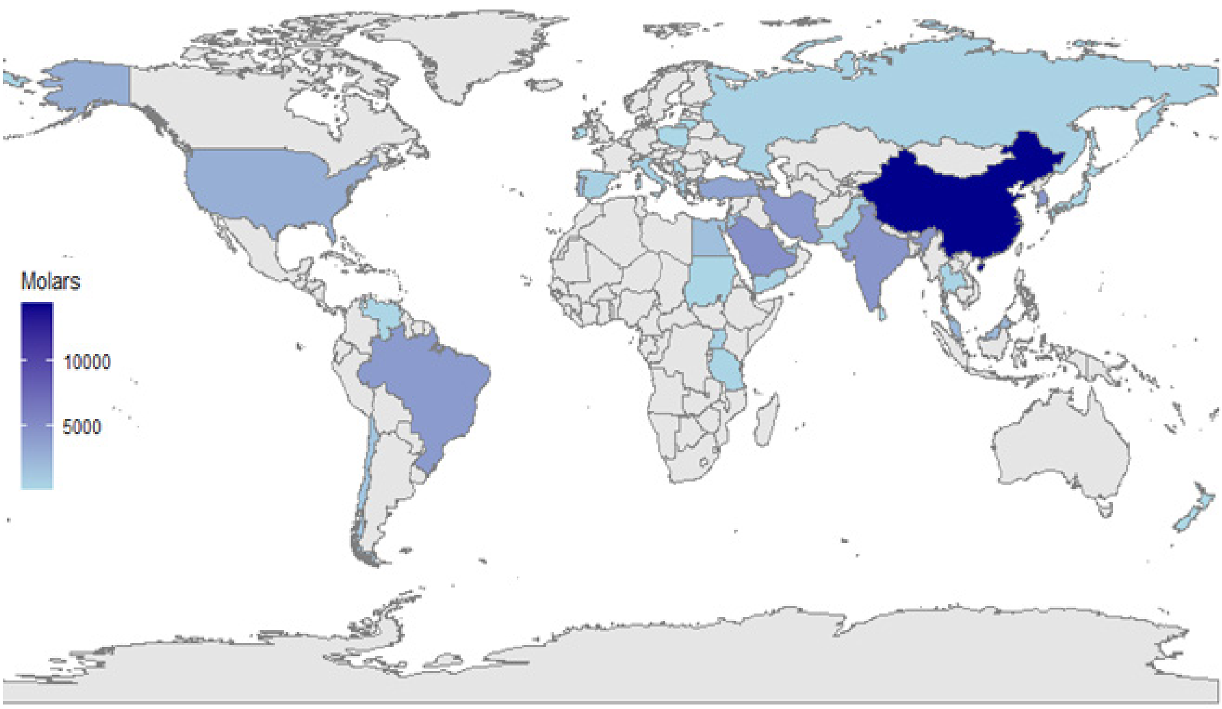
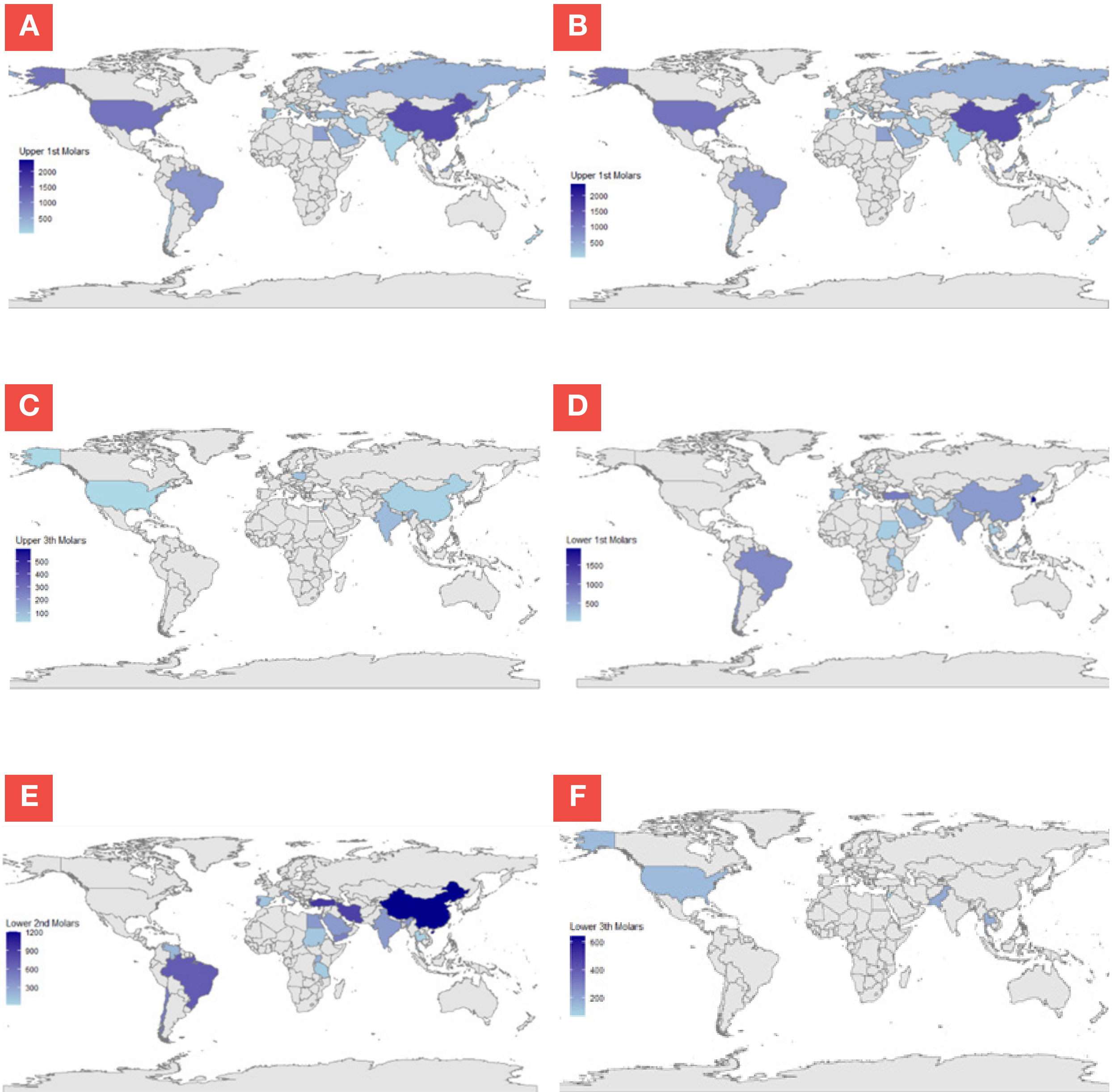


Figure 4.
Country-specific distribution of different molar groups studied.



A. Upper first molars. **B.** Upper second molars. **C.** Upper third molars. **D.** Lower first molars. **E.** Lower second molars. **F.** Lower third molars.

Table 1.
Distribution of the articles included in the study according to key relevant data, such as publication year, geographical location, and root canal configurations.

1st Author	Title	Year	Journal	URL
Rosaline[17]	Analysis of root and canal morphologies of maxillary second molars in a South Indian population using cone-beam computed tomography: A retrospective study	2021	Endodontology	https://doi.org/10.4103/endo.endo_93_21
Aydin[18]	Analysis of root and canal morphology of fused and separate rooted maxillary molar teeth in Turkish population	2021	Niger J Clin Pract	https://doi.org/10.4103/njcp.njcp_316_20
Kim[19]	Morphology of maxillary first and second molars analyzed by cone-beam computed tomography in a Korean population: variations in the number of roots and canals and the incidence of fusion	2012	J Endod	https://doi.org/10.1016/j.joen.2012.04.025
Rahman[20]	Analysis of root and canal morphology of maxillary first and second molars among malay ethnic in the Malaysian population with the aid of cone-beam computed tomography: A retrospective study	2020	Eur J Gen Dent	https://www.thieme-connect.com/products/ejournals/pdf/10.4103/ejgd.ejgd_167_19.pdf
Algarni[21]	Analysis of root canal anatomy and variation in morphology of maxillary first molar using various methods: An *in vitro* study	2019	World J Dentistry	https://doi.org/10.5005/jp-journals-10015-1644
Mantovani[22]	Analysis of the mandibular molars root canals morphology. Study by computed tomography	2022	Braz Dent J	https://doi.org/10.1590/0103-6440202205105
Tian[23]	Analysis of the Root and Canal Morphologies in Maxillary First and Second Molars in a Chinese Population Using Conebeam Computed Tomography	2016	J Endod	https://doi.org/10.1016/j.joen.2016.01.017
Stropko[24]	Canal morphology of maxillary molars: clinical observations of canal configurations	1999	J Endod	https://doi.org/10.1016/s0099-2399(99)80276-3
Donyavi[25]	Assessment of root canal morphology of maxillary and mandibular second molars in the Iranian population using CBCT	2019	Dent Med Probl	https://doi.org/10.17219/dmp/101783
Wang[26]	Assessment of the coronal root canal morphology of permanent maxillary first molars using digital 3D-reconstruction technology based on micro-computed tomography data	2023	J Dent Sci	https://doi.org/10.1016/j.jds.2022.08.011
Mirza[27]	CBCT based study to analyze and classify root canal morphology of maxillary molars – A retrospective study	2022	Eur Rev Med Pharmacol Sci	https://doi.org/10.26355/eurrev_202209_29753
Krishnamurthy[28]	A CBCT Study to Evaluate the Root and Canal Morphology of Permanent Maxillary First Molars in Children	2022	Int J Clin Pediatr Dent	https://doi.org/10.5005/jp-journals-10005-2441
Moazzy[29]	Comprehensive evaluation of root and root canal morphology of mandibular second molars in a Saudi subpopulation evaluated by conebeam computed tomography	2022	BMC Oral Health	https://doi.org/10.1186/s12903-022-02305-z

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1st Author	Title	Year	Journal	URL
Al Shehadat[30]	Cone Beam Computed Tomography Analysis of Root and Canal Morphology of First Permanent Lower Molars in a Middle East Subpopulation	2019	J Int Soc Prev Community Dent	https://doi.org/10.4103/jispcd.JISPCD_41_19
Madfa[31]	Cone beam computed tomography analysis of the root and canal morphology of the maxillary second molars in a Hail province of the Saudi population	2023	Heliyon	https://doi.org/10.1016/j.heliyon.2023.e19477
Kalender[32]	Cone beam computed tomography evaluation of maxillary molar root canal morphology in a Turkish Cypriot population	2016	Biotechnol Biotechnol Equip	https://doi.org/10.1080/13102818.2015.1092885
Celikten[33]	Cone beam CT evaluation of mandibular molar root canal morphology in a Turkish Cypriot population	2016	Clin Oral Investig	https://doi.org/10.1007/s00784-016-1742-2
Pérez-Heredia[34]	Cone-beam Computed Tomographic Study of Root Anatomy of Root Anatomy and Canal Configuration of Molars in a Spanish population	2017	J Endod	https://doi.org/10.1016/j.joen.2017.03.026
Al-Sheeb[35]	Cone-beam computed tomographic study of root morphology, canal configuration, and bilateral symmetry of mandibular first and second molars in a Qatari population	2022	Saudi Endodontic Journal	https://doi.org/10.4103/sej.sej_176_21
Deng[36]	Cone-beam computed tomography analysis on root and canal morphology ofmandibular first permanent molar among multiracial population in East Coast Malaysian population	2018	Eur J Dent	https://doi.org/10.4103/ejd.ejd_82_18
Zheng[37]	A Cone-Beam Computed Tomography study of Maxillary First Permanent Molar Root and Canal Morphology in a Chinese Population	2010	J Endod	https://doi.org/10.1016/j.joen.2010.06.018
Popovic[38]	Cone-beam computed tomography study of tooth root and canal morphology of permanent molars in a Serbian population	2020	Vojnosanit pregl	https://doi.org/10.2298/vsp180322100p
Fu[39]	Coronal root canal morphology of permanent two-rootedmandibular first molars with novel 3D measurements	2020	Int Endod J	https://doi.org/10.1111/iej.13220
Rios[40]	Description of the Morphology of the Root Canal System of the Maxillary First Molar Using Cone-Beam Computed Tomography in a Chilean Population	2023	Int J Morphol	https://doi.org/10.4067/S0717-95022023000200477
Martins[15]	Differences on the Root and Root Canal-Morphologies bet ween Asian and White EthnicGroups Analyzed by Cone-beam Computed Tomography	2018	J Endod	https://doi.org/10.1016/j.joen.2018.04.001
Razumova[41]	Evaluation of Anatomy and Root Canal Morphology of the Maxillary First Molar Using the Cone-Beam Computed Tomography among Residents of the Moscow Region	2018	Contemp Clin Dent	https://doi.org/10.4103/ccd.ccd_127_18

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1st Author	Title	Year	Journal	URL
Namdar[42]	Evaluation of Root and Canal Morphology of Maxillary First and Second Molars by Cone Beam Computed Tomography in a Northern Iranian Population	2023	JRDMS	https://doi.org/10.52547/jrdms.8.4.265
Wang[43]	Evaluation of root and canal morphology of maxillary molars in a southern chinese sub-population: A cone-beam computed tomographic study	2017	Intl J Clin Exp Med	https://e-century.us/files/ijcem/10/4/ijcem0045172.pdf
Guo[44]	Evaluation of root and canal morphology of maxillary permanent first molars in a North American population by cone-beam computed tomography	2014	J Endod	https://doi.org/10.1016/j.joen.2014.02.002
Al Mheiri[45]	Evaluation of root and canal morphology of maxillary permanent first molars in an Emirati population; a cone-beam computed tomography study	2020	BMC Oral Health	https://doi.org/10.1186/s12903-020-01269-2
Ahmed[46]	Evaluation of Root and Canal Morphology of Maxillary Permanent Molars in an Egyptian Population by Cone-beam Computed Tomography	2017	J Endod	https://doi.org/10.1016/j.joen.2017.02.014
Alrahabi[47]	Evaluation of root canal morphology of maxillary molars using cone beam computed tomography	2015	Pak J Med Sci	https://doi.org/10.12669/pjms.312.6753
Reuben[48]	The evaluation of root canal morphology of the mandibular first molar in an Indian population using spiral computed tomography scan: an *in vitro* study	2008	J Endod	https://doi.org/10.1016/j.joen.2007.11.018
Dibaji[49]	Evaluation of the relationship between bucco-lingual width of mesiobuccal root and root canal morphology of maxillary first molars by cone-beam computed tomography	2022	Dent Res J	https://doi.org/10.4103/1735-3327.336690
Wang[50]	Evaluation of the root and canal morphology of mandibular first permanent molars in a western Chinese population by cone-beam computed tomography	2010	J Endod	https://doi.org/10.1016/j.joen.2010.08.016
Nikoloudaki[51]	Evaluation of the Root and Canal Morphology of Maxillary Permanent Molars and the Incidence of the Second Mesiobuccal Root Canal in Greek Population Using Cone-beam Computed Tomography	2015	Open Dent J	https://doi.org/10.2174/1874210601509010267
Caputo[52]	Evaluation of the Root Canal Morphology of Molars by Using Cone-beam Computed Tomography in a Brazilian Population: Part I	2016	J Endod	https://doi.org/10.1016/j.joen.2016.07.026
Pawar[53]	An *In-Vivo* cone-beam computed tomography analysis of root and canal morphology of maxillary first permanent molars in an Indian population	2021	Indian J Dent Res	https://doi.org/10.4103/ijdr.IJDR_782_19
Monsarrat[54]	Interrelationships in the Variability of Root Canal Anatomy among the Permanent Teeth: A Full-Mouth Approach by Cone-Beam CT	2016	PLoS One	https://doi.org/10.1371/journal.pone.0165329

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1st Author	Title	Year	Journal	URL
McGuigan[55]	An investigation into dose optimisation for imaging root canal anatomy using cone beam CT	2020	Dentomaxillofac Radiol	https://doi.org/10.1259/dmfr.20200072
Matsunaga[56]	Japanese Maxillary First Molar Root Canal Morphology: An Ultrastructural Study Using Micro-Computed Tomography	2022	J Hard Tissue Biol	https://doi.org/10.2485/jhtb.31.109
Ren[57]	Maxillary molar root and canal morphology of Neolithic and modern Chinese	2021	Arch Oral Biol	https://doi.org/10.1016/j.archoralbio.2021.105272
Zhang[58]	Maxillary Molar Root Canal Morphology Using Cone-Beam Computed Tomography: An Epidemiological Study from Shandong Province, China	2023	Int J Morphol	https://doi.org/10.4067/S0717-9502 2023000300775
Lee[59]	Mesiobuccal root canal anatomy of Korean maxillary first and second molars by cone-beam computed tomography	2011	Oral Surg Oral Med Oral Pathol Oral Radiol Endod	https://doi.org/10.1016/j.tripleo.2010.11.026
Verma[60]	A Micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth	2011	Int Endod J	https://doi.org/10.1111/j.1365-2591.2010.01800.x
Tomaszewska[6]	A micro-computed tomographic (micro-CT) analysis of the root canal morphology of maxillary third molar teeth	2018	Ann Anat	https://doi.org/10.1016/j.aanat.2017.09.003
Filpo-Perez[61]	Micro-computed tomographic analysis of the root canal morphology of the distal root of mandibular first molar	2015	J Endod	https://doi.org/10.1016/j.joen.2014.09.024
Asijavičienė[62]	Microcomputed tomography evaluation of the root canals morphology of the mandibular first molars	2020	Stomatologija	Not Available
Kim[63]	Morphology of mandibular first molars analyzed by cone-beam computed tomography in a Korean population: variations in the number of roots and canals	2013	J Endod	https://doi.org/10.1016/j.joen.2013.08.015
Lyra[64]	Morphology ofmesiobuccal root canals of maxillary first molars: A comparison of CBCT scanning and cross-sectioning	2015	Braz Dent J	https://doi.org/10.1590/0103-644020130096
Shetty[10]	Occurrence and Morphology of MB2 Canals in Maxillary First Molars in an Indian Subpopulation: A Cone Beam Computed Tomography Study	2022	JHASNU	https://doi.org/10.1055/s-0041-1736268
Kenawi[65]	Radiographic Investigation of Root Canal Morphology of Permanent Mandibular Molars in Makkah Population (Saudi Arabia) Using Cone Beam Computed Tomography	2022	Int J Dent	https://doi.org/10.1155/2022/1535752
Mohara[66]	Root Anatomy and Canal Configuration of Maxillary Molars in a Brazilian Subpopulation: A 125-μm Cone-Beam Computed Tomographic Study.	2019	Eur J Dent	https://doi.org/10.1055/s-0039-1688736
Xia[67]	Root Anatomy and Root Canal Morphology of Maxillary Second Permanent Molars in a Chongqing Population: A Cone-Beam Computed Tomography Study	2020	Med Sci Monit	https://doi.org/10.12659/msm.922794

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1st Author	Title	Year	Journal	URL
Atram[68]	Root and canal anatomy of mandibular first molar teeth of an Indian population	2020	Endodontology	https://doi.org/10.4103/endo.endo_71_19
Peiris[16]	Root and canal morphology of human permanent teeth in a Sri Lankan and Japanese population	2008	Anthropol Sci	https://doi.org/10.1537/ase.070723
Rwenyonyi[69]	Root and canal morphology of mandibular first and second permanent molar teeth in a Ugandan population	2009	Odontology	https://doi.org/10.1007/s10266-009-0100-0
Senan[70]	Root and Canal Morphology of Mandibular Second Molars in a Yemeni Population: A Cone-beam Computed Tomography	2021	Eur Endod J	https://doi.org/10.14744/eej.2020.94695
Shehabeldin Mohamed[71]	Root and canal morphology of mandibular second molars in an Egyptian subpopulation: a cone-beam computed tomography study	2023	BMC Oral Health	https://doi.org/10.1186/s12903-023-02939-7
Prasanna Neelakantan[72]	Root and canal morphology of mandibular second molars in an Indian population	2010	J Endod	https://doi.org/10.1016/j.joen.2010.04.001
Ahmed[73]	Root and canal morphology of permanent mandibular molars in a Sudanese population	2007	Int Endod J	https://doi.org/10.1111/j.1365-2591.2007.1283.x
Gulabivala[74]	Root and canal morphology of Thai mandibular molars	2002	Int Endod J	https://doi.org/10.1046/j.1365-2591.2002.00452.x
Al-Qudah[4]	Root and canal morphology of third molar teeth	2023	Sci Rep	https://doi.org/10.1038/s41598-023-34134-7
Mashyakhy[75]	Root and Root Canal Morphology Differences Between Genders: A Comprehensive *in-vivo* CBCT Study in a Saudi Population	2019	Acta Stomatol Croat	https://doi.org/10.15644/asc53/3/5
Qi[76]	Root and root canal morphology of mandibular second permanent molars in the Gansu province population: A CBCT study	2022	Aust Endod J	https://doi.org/10.1111/aej.12692
Ahmad[77]	Root and root canal morphology of third molars in a Jordanian subpopulation	2016	Saudi Endod J	https://doi.org/10.4103/1658-5984.189350
Demirtaş[78]	Root canal anatomy of maxillary first molars in a Turkish population using cone-beam computed tomography	2023	J Dent Mater Techniq	https://doi.org/10.22038/JDMT.2023.70840.1557
Pawar[79]	Root canal morphology and variations in mandibular second molar teeth of an Indian population: an *in vivo* cone-beam computed tomography analysis	2017	Clin Oral Investig	https://doi.org/10.1007/s00784-017-2082-6
Gomez[80]	Root canal morphology and variations in mandibular second molars: an in vivo cone-beam computed tomography analysis	2021	BMC Oral Health	https://doi.org/10.1186/s12903-021-01787-7
Ceperuelo[81]	Root canal morphology of Chalcolithic and early bronze age human populations of El Mirador Cave (Sierra de Atapuerca, Spain)	2014	Anat Rec (Hoboken)	https://doi.org/10.1002/ar.22958
Shahi[82]	Root canal morphology of human mandibular permanent molars in an Iranian population	2008	J Dent Res Dent Clin Dent Prospects	https://doi.org/10.5681/joddd.2008.004 first
Sidow[83]	Root canal morphology of human maxillary and mandibular third molars	2000	J Endod	https://doi.org/10.1097/00004770-200011000-00011
Chourasia[84]	Root canal morphology of mandibular first permanent molars in an Indian population	2012	Int J Dent	https://doi.org/10.1155/2012/745152
Sana[85]	Root Canal Morphology of Mandibular First Permanent Molars in Pakistani Sub-population- An in vitro study	2021	Pak J Med Health Sci	https://doi.org/10.53350/pjmhs211561314

Table 1 continues on the next page →

1st Author	Title	Year	Journal	URL
Naseri[86]	Root Canal Morphology of Maxillary Second Molars according to Age and Gender in a Selected Iranian Population: A Cone-Beam Computed Tomography Evaluation	2018	Iran Endod J	https://doi.org/10.22037/iej.v13i3.19278
Alamri[87]	Root canal morphology of maxillary second molars in a Saudi sub-population: A cone beam computed tomography study	2020	Saudi Dent J	https://doi.org/10.1016/j.sdentj.2019.09.003
Habiba Suleiman[88]	Root canal morphology of native Tanzanian permanent mandibular molar teeth	2018	Pan Afr Med J	https://doi.org/10.11604/pamj.2018.31.24.14416
Weng[89]	Root canal morphology of permanent maxillary teeth in the Han nationality in Chinese Guanzhong area: a new modified root canal staining technique	2009	J Endod	https://doi.org/10.1016/j.joen.2009.02.010
Pan[90]	Root canal morphology of permanent teeth in a Malaysian subpopulation using cone-beam computed tomography	2019	BMC Oral Health	https://doi.org/10.1186/s12903-019-0710-z
Singh[91]	Root canal morphology of South Asian Indian maxillary molar teeth	2015	Eur J Dent	https://doi.org/10.4103/1305-7456.149662
Skidmore[92]	Root canal morphology of the human mandibular first molar	1971	Oral Surg Oral Med Oral Pathol	https://doi.org/10.1016/0030-4220(71)90304-5
Walker[93]	Root form and canal anatomy of mandibular first molars in a southern Chinese population	1988	Endod Dent Traumatol	https://doi.org/10.1111/j.1600-9657.1988.tb00287.x
Walker[94]	Root form and canal anatomy of mandibular second molars in a southern Chinese population	1988	J Endod	https://doi.org/10.1016/s0099-2399(88)80192-4
Abarca[95]	Root morphology of mandibular molars: a cone-beam computed tomography study	2015	Folia Morphol	https://doi.org/10.5603/fm.a2019.0084
Estrela[96]	Study of Root Canal Anatomy in Human Permanent Teeth in A Subpopulation of Brazil's Center Region Using Cone-Beam Computed Tomography - Part 1	2015	Braz Dent J	https://doi.org/10.1590/0103-6440201302448
Mathew [9]	Study of the morphology of MB2 canals in maxillary first molars using CBCT	2018	Indian J Public Health Res Dev	https://doi.org/10.5958/0976-5506.2018.00495.3
Naseri[97]	Survey of Anatomy and Root Canal Morphology of Maxillary First Molars Regarding Age and Gender in an Iranian Population Using Cone-Beam Computed Tomography	2016	Iran Endod J	https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5069906/pdf/iej-11-298.pdf
Plotino[98]	Symmetry of root and root canal morphology of maxillary and mandibular molars in a white population: a cone-beam computed tomography study in vivo	2013	J Endod	https://doi.org/10.1016/j.joen.2013.09.012
Fu[99]	Three-dimensional analysis of coronal root canal morphology of 136 permanent mandibular first molars by micro-computed tomography	2022	J Dent Sci	https://doi.org/10.1016/j.jds.2021.07.021
Demirbuga[100]	Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular first and second molars in Turkish individuals	2013	Med Oral Patol Oral Cir Bucal	https://doi.org/10.4317/medoral.18473
Zhang[101]	Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals	2011	Int Endod Journal	https://doi.org/10.1111/j.1365-2591.2011.01904.x
Khattak[102]	Use Of Tooth Clearing Technique To Determine Root And Canal Morphology Of Permanent Mandibular Third Molars In Population Of Peshawar: An *In vitro* Cross-Sectional Study	2021	KMUJ	https://doi.org/10.35845/kmuj.2021.21653
Yang[103]	Variations of root and canal morphology of mandibular second molars in Chinese individuals: a cone-beam computed tomography study	2022	BMC Oral Health	https://doi.org/10.1186/s12903-022-02299-8

Table 2.
Distribution of molars by dental arch and the countries involved in the studies.

Countries (ISO2)	Total of Molars Molar		1st Upper Molar		2nd Upper Molar		3th Upper Molar		1st Lower Molar		2nd Lower Molar		3th Lower Molar	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
United Arab Emirates	1329	2.20	522	2.60	0	-	0	-	807	7.64	0	-	0	-
Brazil	4053	6.71	1143	5.70	1038	6.01	0	-	1157	10.95	715	6.98	0	-
Chile	1221	2.02	199	0.99	0	-	0	-	510	4.83	512	5.00	0	-
China	14423	23.88	6054	30.21	5180	30.01	43	4.02	1203	11.39	1943	18.96	0	-
Cyprus	1616	2.68	373	1.86	438	2.54	0	-	384	3.64	421	4.11	0	-
Egypt	1565	2.59	605	3.02	610	3.53	0	-	0	-	350	3.42	0	-
Spain	580	0.96	155	0.77	150	0.87	0	-	138	1.31	137	1.34	0	-
France	589	0.98	149	0.74	167	0.97	0	-	130	1.23	143	1.40	0	-
Greece	812	1.34	410	2.05	402	2.33	0	-	0	-	0	-	0	-
Hong Kong	200	0.33	100	0.50	100	0.58	0	-	0	-	0	-	0	-
Ireland	3	0.00	3	0.01	0	-	0	-		-	0	-	0	-
India	4352	7.21	1692	8.44	600	3.48	100	9.35	761	7.21	1199	11.70	0	-
Iran	4246	7.03	836	4.17	2339	13.55	0	-	209	1.98	862	8.41	0	-
Italy	596	0.99	161	0.80	157	0.91	0	-	117	1.11	161	1.57	0	-
Jordan	1390	2.30	0	-	0	-	681	63.64	0	-	0	-	709	58.16
Japan	153	0.25	100	0.50	53	0.31	0	-	0	-	0	-	0	-
South Korea	4452	7.37	1271	6.34	1242	7.19	0	-	1939	18.36	0	-	0	-
Sri Lanka	213	0.35	0	-	213	1.23	0	-	0	-	0	-	0	-
Lithuania	62	0.10	0	-	0	-	0	-	62	0.59	0	-	0	-
Malaysia	2015	3.34	824	4.11	890	5.16	0	-	301	2.85	0	-	0	-
New Zealand	20	0.03	20	0.10	0	-	0	-	0	-	0	-	0	-
Pakistan	393	0.65	0	-	0	-	0	-	200	1.89	0	-	193	15.83
Poland	78	0.13	0	-	0	-	78	7.29	0	-	0	-	0	-
Portugal	2242	3.71	714	3.56	589	3.41	0	-	463	4.38	476	4.65	0	-
Qatar	450	0.75	0	-	0	-	0	-	195	1.85	255	2.49	0	-
Serbia	138	0.23	138	0.69	0	-	0	-	0	-	0	-	0	-
Russia	410	0.68	410	2.05	0	-	0	-	0	-	0	-	0	-
Saudi Arabia	4793	7.94	1447	7.22	1781	10.32	0	-	575	5.44	990	9.66	0	-
Sudan	200	0.33	0	-	0	-	0	-	100	0.95	100	0.98	0	-
Thailand	351	0.58	0	-	0	-	0	-	118	1.12	60	0.59	173	14.19
Turkey	3391	5.61	940	4.69	703	4.07	0	-	823	7.79	925	9.03	0	-
Tanzania	231	0.38	0	-	0	-	0	-	146	1.38	85	0.83	0	-
Uganda	447	0.74	0	-	0	-	0	-	224	2.12	223	2.18	0	-
United States of America	2698	4.47	1775	8.86	611	3.54	168	15.70	0	-	0	-	144	11.81
Venezuela	190	0.31	0	-	0	-	0	-	0	-	190	1.85	0	-
Yemen	500	0.83	0	-	0	-	0	-	0	-	500	4.88	0	-
Total	**60402**	**100,00**	**20041**	**33.18**	**17263**	**28.58**	**1070**	**1.77**	**10562**	**17.49**	**10247**	**16.96**	**1219**	**2.02**

Table 3.

Distribution of the number of root canals for each molar group in relation to the continents.

1st Upper Molar	Total of Molars		1 Canal		2 Canals		3 Canals		4 Canals		5 Canals		6 Canal	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	605	3.02	0	-	0	-	276	45.62	175	28.93	154	25.45	0	-
Americas	3117	15.55	0	-	21	0.67	1314	42.16	1766	56.66	16	0.51	0	-
Asia	14159	70.65	3	0.02	124	0.88	7743	54.69	6182	43.66	97	0.69	10	0.07
Europe	2140	10.68	16	0.75	41	1.92	1323	61.82	732	34.21	28	1.31	0	-
Oceania	20	0.10	0	-	0	-	3	15.00	4	20.00	0	-	13	65.00
Sub- To-tal	20041	33.18*	19	0.09	186	0.93	10659	53.19	8859	44.20	295	1.47	23	0.11
2nd Upper Molar	**Total of Molars**		**1 Canal**		**2 Canals**		**3 Canals**		**4 Canals**		**5 Canals**		**6 Canal**	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	610	3.53	0	-	0	-	252	41.31	133	21.80	225	36,89	0	-
Americas	1649	9.55	8	0.49	60	3.64	876	53.12	703	42.63	2	0.12	0	-
Asia	13539	78.43	148	1.09	2494	18.42	7885	58.24	2970	21.94	42	0.31	0	-
Europe	1465	8.49	21	1.43	355	24.23	809	55.22	268	18.29	12	0.82	0	-
Oceania	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Sub- To-tal	17263	28.58*	177	1.03	2909	16.85	9822	56.90	4074	23.60	281	1.63	0	-
3th Upper Molar	**Total of Molars**		**1 Canal**		**2 Canals**		**3 Canals**		**4 Canals**		**5 Canals**		**6 Canal**	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Americas	168	15.70	4	2.38	10	5.95	101	60.12	46	27.38	6	3.57	1	0.60
Asia	824	77.01	74	8.98	112	13.59	421	51.09	203	24.64	14	1.70	0	-
Europe	78	7.29	18	23.08	12	15.38	42	53.85	6	7.69	0	-	0	-
Oceania	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Sub- To-tal	1070	1.77*	96	8.97	134	12.52	564	52.71	255	23.83	20	1.87	1	0.09
1st Lower Molar	**Total of Molars**		**1 Canal**		**2 Canals**		**3 Canals**		**4 Canals**		**5 Canals**		**6 Canal**	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	470	4.45	0	-	94	20.00	281	59.79	92	19.57	3	0.64	0	-
Americas	1667	15.78	0	-	118	7.08	1002	60.11	526	31.55	18	1.08	3	0.18
Asia	7515	71.15	6	0.08	518	6.89	4693	62.45	2223	29.58	72	0.96	3	0.04
Europe	910	8.62	0	-	68	7.47	739	81.21	103	11.32	0	-	0	-
Oceania	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Sub- To-tal	10562	17.49*	6	0.06	798	7.56	6715	63.58	2944	27.87	93	0.88	6	0.06
2nd Lower Molar	**Total of Molars**		**1 Canal**		**2 Canals**		**3 Canals**		**4 Canals**		**5 Canals**		**6 Canal**	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	758	7.40	11	1.45	147	19.39	512	67.55	78	10.29	10	1.32	0	-
Americas	1417	13.83	10	0.71	301	21.24	1049	74.03	57	4.02	0	-	0	-
Asia	7155	69.83	309	4.32	1833	25.62	4692	65.58	316	4.42	5	0.07	0	-
Europe	917	8.95	9	0.98	366	39.91	517	56.38	24	2.62	1	0.11	0	-
Oceania	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Sub- To-tal	10247	16.96*	339	3.31	2647	25.83	6770	66.07	475	4.64	16	0.16	0	-
3th Lower Molar	**Total of Molars**		**1 Canal**		**2 Canals**		**3 Canals**		**4 Canals**		**5 Canals**		**6 Canal**	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Africa	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Americas	144	11.81	5	3.47	25	17.36	83	57.64	25	17.36	5	3.47	1	0.69
Asia	1075	88.19	36	3.35	461	42.88	474	44.09	103	9.58	1	0.09	0	-
Europe	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Oceania	0	-	0	-	0	-	0	-	0	-	0	-	0	-
Sub- To-tal	1219	2.02*	41	3.36	486	39.87	557	45.69	128	10.50	6	0,49	1	0.08
Total	**60402**	**100**	**678**	**1.12**	**7160**	**11.85**	**35087**	**58.09**	**16735**	**27.71**	**711**	**1.18**	**31**	**0.05**

RESULTS

Calibration among the authors who reviewed the articles included in the study was excellent in all cases. The search yielded 2,917 articles distributed across PubMed (1,086), Scopus (1,240), and WOS (559). An additional 32 articles were retrieved from Research Rabbit (Figure 1).

After removing duplicates and excluding articles that did not meet the inclusion criteria, 272 reports were evaluated for eligibility. Out of these, 149 articles were excluded because they did not define the number of root canals per tooth, 8 were not available in full text, 18 were not relevant to the research topic, and 4 were excluded due to being other types of articles as per the exclusion criteria (Figure 1). After screening, 93 reports were included in this study and are listed in Table 1.

These articles provided information on 95 sample records of molars from various countries, where the number of canals per tooth could be determined. This was because the studies by Martins *et al.*,[15] and Peiris *et al.*,[16] examined populations from different countries.

Only one study was written in Spanish, while the remaining studies were published in English. The Journal of Endodontics was the most frequently represented journal, accounting for 19.35% of the reports. There were no significant trends in terms of author frequency (Table 1). Sensitivity analysis of the studies was deemed unnecessary, as only 10.75% of the studies were classified as having low measurement quality. Articles from 1971 to 2023 were included in the review. The year 2022 had the highest number of publications, with 12 articles, followed by 2020 with 9 articles. Both 2021 and 2023 had 8 articles each (Table 1 and Figure 2).

Data were extracted from 60,402 molars across all dental groups (Figure 3). China had the highest representation, contributing 23.88% of the total molars. This was followed by Saudi Arabia, South Korea, India, and Iran, contributing 7.94%, 7.37%, 7.21%, and 7.03%, respectively. On the other end of the spectrum, Ireland had the lowest contribution with only three molars. Poland, Lithuania, and New Zealand followed, with contributions of 0.13%, 0.10%, and 0.03%, respectively (Table 2).

Upper first molars were the most represented dental group, comprising 33.18% of the total data. Upper and lower third molars had the lowest representation, at 1.77% and 2.02%, respectively (Table 2 and Figure 4). Among upper first molars, China contributed the most (30.21%), while Ireland contributed the least (0.01%) (Table 2 and Figure 4). Upper second molars accounted for 28.58% of the total, with China contributing 30.01% and Japan the least at 0.31% (Table 2 and Figure 4).
For upper third molars, data came from Jordan (63.64%), the U.S. (15.70%), India (9.35%), Poland (7.29%), and China (4.02%) (Table 2 and Figure 4).

Lower first molars represented 17.49% of the data, with South Korea contributing the most (18.36%) and Lithuania the least (0.59%) (Table 2 and Figure 4). Lower second molars made up 16.96% of the sample, with China having the highest contribution (18.96%) and Thailand the lowest (0.59%) (Table 2 and Figure 4). For lower third molars, data were from Jordan

(58.16%), Pakistan (15.83%), Thailand (14.19%), and the U.S. (11.81%) (Table 2 and Figure 4).

Data from the studies indicate that on the African continent, the first and second upper molars typically have three root canals (45.62% and 41.31%, respectively), as do the first and second lower molars (59.79% and 67.55%). No data were reported for upper and lower third molars (Table 3). In America, 56.66% of upper first molars have four root canals. Other molars mainly have three root canals: 53.12% in the second upper molar, 60.12% in the third upper molar, 60.11% in the first lower molar, 67.55% in the second lower molar, and 57.64% in the third lower molar (Table 3). In Asia, most molars have three root canals: 54.69% in the first upper molar, 58.24% in the second upper molar, 51.09% in the upper third molar, 62.45% in the lower first molar, and 65.58% in the lower second molar. Lower third molars predominantly have three root canals, though 42.88% have two (Table 3). In Europe, all molars typically have three root canals, except for lower third molars, which lack data. Prevalence rates are 61.82% for the first upper molar, 55.22% for the second upper molar, 53.85% for the upper third molar, 81.21% for the lower first molar, and 56.38% for the lower second molar (Table 3). In Oceania, 65% of upper first molars have six root canals, based on the study data (Table 3).

DISCUSSION

These findings hold profound implications for both the educational landscape of dentistry and the global practice of clinical endodontics. In dental education, the variability in root canal morphology highlighted by this research underscores the need to em-phasize adaptability and critical thinking in curriculum design. Dental students must be trained not only in standard anatomical norms but also in recognizing and managing deviations that may arise due to genetic, ethnic, or geographical factors. Furthermore, this variability calls for the incorporation of advanced imaging techniques, such as cone-beam computed tomography (CBCT), into routine diagnostics as a core component of training programs.

Clinically, the diversity in root canal configu-rations stresses the importance of tailored treatment strategies that account for patient-specific anatomical nuances. On a global scale, this variability suggests the need for regio-nally adapted clinical guidelines and a more inclusive database of anatomical studies that reflects the diversity of patient popula-tions worldwide. Bridging the gap between research findings and practical applications, the field can achieve improved treatment outcomes and a deeper understanding of the evolutionary and cultural influences shaping dental anatomy.

Study sensitivity analysis is a procedure that helps researchers gauge the effectiveness of the results and guide readers on the accuracy of the information collected. In a study by Franka Marušić *et al.*,[104] they report that only 52% of the articles reported on quality thresholds for sensitivity analysis. In contrast, Ho *et al.*,[105] reported that only 0.9% of the articles evaluated had high methodological quality. These findings emphasize the importance of conducting rigorous evaluations of the quality of systematic review reports to ensure the reliability of the extracted data. In our study, a small group of included articles received a low sensitivity and accuracy evaluation, corresponding to articles published at a time when high-fidelity imaging equipment such as tomographs did not yet exist. The present research, within its limitations, provides evidence to support the reliability of the findings from the included studies. Ethnicity reveals significant anatomical variations in the teeth, as evidenced by the findings of several investigations. There is relevant variability in the number of root and root canal configurations dating from different historical periods, suggesting that genetics influences morphological diversity[7,106]

In addition, odontometric analyses have shown that East and Southeast Asians share dental similarities with sub-Saharan Africans, which places them at the center of a wide range of dental characteristics[107] On the other hand, research on African-American populations has shown the impact of mixing, derivation, and localized gene flow on dental morphology, which demonstrates the complex relationship of sociohistorical factors when studying anatomical characteristics.[108]
All these studies highlight the intricate correspondence between ethnic origins and dental anatomical variations and shed light on the diverse patterns observed in different population groups around the world.[7,109] This background derives the complexity of establishing anatomical patterns by considering populations of different continents, although a general view is helpful in visualizing an overview of these times.

Latin Americans show intermediate frequencies of dental features compared to those of Native Americans, Europeans and Africans[110] This is due to the mass exodus from the European and African continents centuries ago, which evidently had a direct impact on the anatomical characteristics of today's inhabitants. In the present study, the American population had divergent characteristics with the European and African populations[111] in terms of the maxillary first molar, but homogeneous samples were not recovered from these last two continents, as in the case of the Asian continent. The rest of the molar groups had similar typologies, although the study by Delgado *et al.*,[110] shows that dental characteristics provide a low predictive power of individual genetic ancestry. These findings underscore the importance of taking ethnicity into account when assessing anatomical variations in the permanent molar canals.

Naseri *et al.*,[112] analyzed studies from Iran and stated that although most maxillary first molars have three roots, the studies included in this research demonstrated a high frequency of two or more ducts in the mesiobuccal root. In the current study, the results concurred in a similar manner, and although the first maxillary molars with three canals prevailed, the second highest prevalence found in the studies was that of molars with four root canals. These results indicate that the variability between three and four canals in clinical practice can be frequently found according to geographical context or globally. This was demonstrated by a systematic review by Barbhai *et al.*,[113] who found that 68.2% of the first maxillary molars had a second mesiobuccal canal.

A systematic review by Valencia de Pablo *et al.*,[114] attempted to analyze the published literature related to root anatomy and configuration of the root canal system of the mandibular permanent first molar. In relation to the number of canals in this dental group, they determined that of 18 studies that included 4745 teeth, 61.3% had three canals, 35.7% 4 canals and about 1% had five canals. These results are almost identical to those obtained in the present study, and it is worth noting that they included reports with the same geographical diversity as this study. Valencia de Pablo *et al.*,[114] suggest that the number of roots of the mandibular first molar is directly related to the ethnicity of the population studied. The presence of a third root is more common in the Native American, Eskimos, and Chinese populations, suggesting a genetic component. Another systematic review by AL-Rammahi *et al.,*[115] observed the presence of a medial mesial canal in some studies, with a variable prevalence, which implies that the alterations of the normal anatomy of the mandibular first molar conform more to an anatomical pattern of three canals, as classically expressed in the academic literature. In addition, in distal roots, the study found a conduit that corresponded to the most common configuration. These results coincide with the prevalence of mandibular first molars in the three canals in the present study, although it is essential to consider the anatomical variability of this molar group to obtain successful endodontic treatment.

Although the research by Mashyakhy *et al.,*[116] was exclusive to studies that included mandibular teeth from Saudi Arabian populations, it was found that the first mandibular molars had three and four canals with a higher prevalence (58.7% and 40.6%, respectively). In the present study, the results were convergent with those of Mashyakhy *et al.,*[116] even when these characteristics were specified in the continent to which that nation belongs.

In the study by Joshi *et al.,*[117] the mandibular second molars had three roots. In their systematic review, most mesial roots had two canals (70.4%) and most distal roots had a single canal (77%). Mashyakhy *et al.,*[116] found similar results in their systematic review research exclusively for population studies in Saudi Arabia.

The present research had similar global and individual results for each continent on the prevalence of mandibular second molars with three canals, although in all the studies that studied this molar group there were cases of teeth that had two canals with a not so low prevalence. This fact warns that the anatomy of the root canals in the second molars of the mandible is variable and complex.

Limited research on the root and root canal morphology of third molars faces important implications for dental practice and the understanding of craniofacial morphology. Studies have shown that third molars have an unpredictable anatomy, with new canal configurations that had not been previously described in the literature, which highlights the need for further research[4] In addition, craniofacial morphology has been related to the impaction of the third molars[118] and their agenesis[119] which exposes the importance of taking into account other facial parameters in treatment decisions.

The study by Morita *et al.,*[120] encourages understanding the metameric variation in human molars through a detailed morphological analysis that can provide information on the evolution and development of teeth. Perhaps applied to this dental group it can allow a better understanding of its dental morphology and its evolutionary implications. The findings of this study suggest that the internal anatomy of permanent molars, particularly the number of root canals, presents significant variations globally. These variations have important implications in clinical practice, as they can influence endodontic treatment planning, the likelihood of treatment success, and the management of complications. More research is needed to understand the causes of these variations and develop more precise treatment strategies for different populations.

One of the limitations of this study is the uneven distribution of data across continents, despite a sufficiently large sample size to generalize the findings. There was a notable lack of studies from North America, Africa, and

Europe, leading to a lack of homogeneity in the dataset. However, the study successfully identified patterns in the number of root canals for each molar group across the represented geographical regions.

Future research directions in this area should focus on systematizing the collection of new, comprehensive studies to further analyze the total anatomical variations of root canals in posterior teeth. There is a need for studies that map out clinically relevant characteristics of root canal anatomy, which will be valuable for clinicians performing endodontic treatments.

CONCLUSION

This study identifies significant geographical variations in root canal anatomy of permanent molars, revealing distinct patterns across regions.

- In Africa, first and second upper and lower molars predominantly have three root canals.
- In America, upper first molars frequently have four canals.
- In Asia, most molars have three canals, with lower third molars often having two or three.
- In Europe, upper and lower molars generally have three canals, except lower third molars.
- In Oceania, upper first molars often have six canals.

Despite some data limitations, these findings demonstrate the need for more standardized, comprehensive research to enhance clinical practices and global understanding of molar anatomy.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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Does not apply

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AUTHORS' CONTRIBUTIONS

Alain M. Chaple Gil: Conceptualization, Methodology, Software, Supervision, Validation, Data curation, Investigation, Analysis, Writing - Original draft preparation, Display, Drafting - Revision and editin

Meylin Santiesteban-Velázquez: Data curation, Investigation, Analysis, Research, Display, Writing - Original draft preparation, Drafting - Revision and editing.

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REFERENCES

1. Ahmed HMA, Musale PK, El Shahawy OI, Dummer PMH. Application of a new system for classifying tooth, root and canal morphology in the primary dentition. Int Endod J. 2020;53(1):27-35. doi: 10.1111/iej.13199. Epub 2019 Oct 1. PMID: 31390075.
2. Ahmed HMA, Ibrahim N, Mohamad NS, Nambiar P, Muhammad RF, Yusoff M, Dummer PMH. Application of a new system for classifying root and canal anatomy in studies involving micro-computed tomography and cone beam computed tomography: Explanation and elaboration. Int Endod J. 202;54(7):1056-1082. doi: 10.1111/iej.13486. Epub 2021 Apr 18. PMID: 33527452.
3. Ahmed HMA, Versiani MA, De-Deus G, Dummer PMH. A new system for classifying root and root canal morphology. Int Endod J. 2017;50(8):761-770. doi: 10.1111/iej.12685. Epub 2016 Oct 17. Erratum in: Int Endod J. 2018;51(10):1184. doi: 10.1111/iej.12993. PMID: 27578418.
4. Al-Qudah AA, Bani Younis HAB, Awawdeh LA, Daud A. Root and canal morphology of third molar teeth. Sci Rep. 2023;13(1):6901. doi: 10.1038/s41598-023-34134-7. PMID: 37106025; PMCID: PMC10140078.
5. Ahmed HM. Anatomical challenges, electronic working length determination and current developments in root canal preparation of primary molar teeth. Int Endod J. 2013;46(11):1011-22. doi: 10.1111/iej.12134. Epub 2013 May 25. PMID: 23711096.
6. Tomaszewska IM, Leszczyński B, Wróbel A, Gładysz T, Duncan HF. A micro-computed tomographic (micro-CT) analysis of the root canal morphology of maxillary third molar teeth. Ann Anat. 2018;215:83-92. doi: 10.1016/j.aanat.2017.09.003. Epub 2017 Sep 24. PMID: 28954209.
7. Przesmycka A, Jędrychowska-Dańska K, Masłowska A, Witas H, Regulski P, Tomczyk J. Root and root canal diversity in human permanent maxillary first premolars and upper/lower first molars from a 14th-17th and 18th-19th century Radom population. Arch Oral Biol. 2020;110:104603. doi: 10.1016/j.archoralbio.2019.104603. Epub 2019 Nov 5. PMID: 31835191.
8. Martos J, Jardim Silva L, Lourenço Morel L, Hisse Gomes G, Gomes e Silva Leonardo N. Primeiro molar inferior permanente com radix entomolaris: relato de caso de uma ocorrência incomum. Relato de Caso. Endodontics 2023;13(2):10320.
9. Mathew T, Shetty A, Hegde MN, Babu B, Shetty KS. Study of the morphology of MB2 canals in maxillary first molars using CBCT. Indian J Public Health Res Dev. 2018;9(5):359-362.
10. Shetty A, Bhat R, Babu B, Hegde MN, Shetty C, Shetty P, Latha Senthilkumar P. Occurrence and Morphology of MB2 Canals in Maxillary First Molars in an Indian Subpopulation: A Cone Beam Computed Tomography Study. Journal of Health and Allied Sciences Nu (JHASNU). 2022;12(2):101-105. doi: 10.1055/s-0041-1736268
11. Betancourt P, Fuentes R, Aracena Rojas S, Cantín M, Navarro Cáceres P. Prevalencia del segundo canal en la raíz mesiovestibular de los primeros molares maxilares mediante tomografía computarizada de haz de cono. Av Odontoestomatología. 2013;29:31-36.
12. Al-Jumeily D, Balchin A, Bishop L, Ferrebe A, Simkhada P. Internationalisation: cui bono? Innovations in Practice. 2018;12(1):17-20.
13. Fragouli E. Internationalizing the Curriculum. IJHEM 2020;06(02):18-30.
14. Martins JNR; Worldwide Anatomy Research Group; Versiani MA. Worldwide Anatomic Characteris tics of the Mandibular Canine-A Multicenter Cross-Sectional Study with Meta-Analysis. J Endod. 2024;50(4):456-471. doi: 10.1016/j.joen.2024.01.016. Epub 2024 Jan 26. PMID: 38280512.
15. Martins JNR, Gu Y, Marques D, Francisco H, Caramês J. Differences on the Root and Root Canal Morphologies between Asian and White Ethnic Groups Analyzed by Cone-beam Computed Tomography. J Endod. 2018;44(7):1096-1104. doi: 10.1016/j.joen.2018.04.001. PMID: 29861062.
16. Peiris R. Root and canal morphology of human permanent teeth in a Sri Lankan and Japanese population. Anthropological Science 2008;116(2):123-133. doi: 10.1537/ase.070723
17. Rosaline H, Kanagasabai A, Shaji A, Bose S, Saeralaathan S, Ganesh A. Analysis of root and canal morphologies of maxillary second molars in a South Indian population using cone-beam computed tomography: A retrospective study. Endodontology 2021;33(3):133-138. doi: 10.4103/endo.endo_93_21
18. Aydin H. Analysis of root and canal morphology of fused and separate rooted maxillary molar teeth in Turkish population. Niger J Clin Pract. 2021;24(3):435-442. doi: 10.4103/njcp.njcp_316_20. PMID: 33723120.
19. Kim Y, Lee SJ, Woo J. Morphology of maxillary first and second molars analyzed by cone-beam computed tomography in a korean population: variations in the number of roots and canals and the incidence of fusion. J Endod. 2012;38(8):1063-8. doi: 10.1016/j.joen.2012.04.025. Epub 2012 Jun 20. PMID: 22794206.

20. Rahman NA, Halim MS, Khamis MF, Ghani HA. Analysis of root and canal morphology of maxillary first and second molars among malay ethnic in the malaysian population with the aid of cone-beam computed tomography: A retrospective study. Eur J Gen Dent. 2020;9(2):84-89. doi: 10.4103/ejgd.ejgd_167_19
21. Algarni YA. Analysis of root canal anatomy and variation in morphology of maxillary first molar using various methods: An in vitro study. World J. Dent. 2019;10(4):291-294.
22. Mantovani VO, Gabriel AES, Silva RG, Savioli RN, Sousa-Neto MD, Cruz-Filho AM. Analysis of the mandibular molars root canals morphology. Study by computed tomography. Braz Dent J. 2022;33(5):1-8. doi: 10.1590/0103-6440202205105. PMID: 36287490; PMCID: PMC9645170.
23. Tian XM, Yang XW, Qian L, Wei B, Gong Y. Analysis of the Root and Canal Morphologies in Maxillary First and Second Molars in a Chinese Population Using Cone-beam Computed Tomography. J Endod. 2016;42(5):696-701. doi: 10.1016/j.joen.2016.01.017. Epub 2016 Mar 16. PMID: 26994598.
24. Stropko JJ. Canal morphology of maxillary molars: clinical observations of canal configurations. J Endod. 1999;25(6):446-50. doi: 10.1016/S0099-2399(99)80276-3. PMID: 10530248.
25. Donyavi Z, Shokri A, Khoshbin E, Khalili M, Faradmal J. Assessment of root canal morphology of maxillary and mandibular second molars in the Iranian population using CBCT. Dent Med Probl. 2019;56(1):45-51. doi: 10.17219/dmp/101783. PMID: 30951619.
26.Wang M, Gao Y, Deng Q, Gao Y, Song D, Huang D. Assessment of the coronal root canal morphology of permanent maxillary first molars using digital 3D-reconstruction technology based on micro-computed tomography data. J Dent Sci. 2023;18(2):586-593. doi: 10.1016/j.jds.2022.08.011. Epub 2022 Sep 9. PMID: 37021262; PMCID: PMC10068546.
27. Mirza MB, Gufran K, Alhabib O, Alafraa O, Alzahrani F, Abuelqomsan MS, Karobari MI, Alnajei A, Afroz MM, Akram SM, Heboyan A. CBCT based study to analyze and classify root canal morphology of maxillary molars - A retrospective study. Eur Rev Med Pharmacol Sci. 2022;26(18):6550-6560. doi: 10.26355/eurrev_202209_29753. PMID: 36196703.
28. Krishnamurthy NH, Athira P, Umapathy T, Balaji P, Jose S. A CBCT Study to Evaluate the Root and Canal Morphology of Permanent Maxillary First Molars in Children. Int J Clin Pediatr Dent. 2022;15(5):509-513. doi: 10.5005/jp-journals-10005-2441. PMCID: PMC9973102.
29. Almansour MI, Al-Zubaidi SM, Enizy AS, Madfa AA. Comprehensive evaluation of root and root canal morphology of mandibular second molars in a Saudi subpopulation evaluated by cone-beam computed tomography. BMC Oral Health. 2022;22(1):267. doi: 10.1186/s12903-022-02305-z. PMID: 35778729; PMCID: PMC9250273.
30. Al Shehadat S, Waheb S, Al Bayatti SW, Kheder W, Khalaf K, Murray CA. Cone Beam Computed Tomography Analysis of Root and Root Canal Morphology of First Permanent Lower Molars in a Middle East Subpopulation. J Int Soc Prev Community Dent. 2019;9(5):458-463. doi: 10.4103/jispcd.JISPCD_41_19. PMID: 31620378; PMCID: PMC6792317.
31. Madfa AA, Almansour MI, Al-Zubaidi SM, Alghurayes AH, AlDAkhayel SD, Alzoori FI, Alshammari TF, Aldakhil AM. Cone beam computed tomography analysis of the root and canal morphology of the maxillary second molars in a Hail province of the Saudi population. Heliyon. 2023;9(9):e19477. doi: 10.10 16/j.heliyon.2023.e19477. PMID: 37681163; PMCID: PMC10481312.
32. Celikten B, Orhan K, Aksoy U, Tufenkci P, Kalender A, Basmaci F, Dabaj P. Cone-beam CT evaluation of root canal morphology of maxillary and mandibular premolars in a Turkish Cypriot population. BDJ Open. 2016 Jan 29;2:15006. doi: 10.1038/bdjopen.2015.6. PMID: 29607060; PMCID: PMC5831013.
33. Celikten B, Tufenkci P, Aksoy U, Kalender A, Kermeoglu F, Dabaj P, Orhan K. Cone beam CT evaluation of mandibular molar root canal morphology in a Turkish Cypriot population. Clin Oral Investig. 2016;20(8):2221-2226. doi: 10.1007/s00784-016-1742-2. Epub 2016 Feb 6. PMID: 26850623.
34. Pérez-Heredia M, Ferrer-Luque CM, Bravo M, Castelo-Baz P, Ruíz-Piñón M, Baca P. Cone-beam Computed Tomographic Study of Root Anatomy and Canal Configuration of Molars in a Spanish Population. J Endod. 2017;43(9):1511-1516. doi: 10.1016/j.joen.2017.03.026. Epub 2017 Jul 20. PMID: 28735786.
35. Al-Sheeb F, Diab H, Al Obaid M, Diab A, Lari M, Mahmoud N. Cone-beam computed tomographic study of root morphology, canal configuration, and bilateral symmetry of mandibular first and second molars in a Qatari population. Saudi Endodontic Journal 2022;12(2):186-194.

36. Deng PU, Halim MS, Masudi SM, Al-Shehadat S, Ahmad B. Cone-beam computed tomography analysis on root and canal morphology of mandibular first permanent molar among multiracial population in East Coast Malaysian population. Eur J Dent 2018;12(3):410-416.
37. Zheng QH, Wang Y, Zhou XD, Wang QA, Zheng GN, Huang DM. A Cone-Beam Computed Tomography Study of Maxillary First Permanent Molar Root and Canal Morphology in a Chinese Population. Journal of Endodontics 2010;36(9):1480-1484.
38. Popovic M, Zivanovic S, Vucicevic T, Grujovic M, Papic M. Cone-beam computed tomography study of tooth root and canal morphology of permanent molars in a Serbian population. Vojnosanitetski Pregled 2020;77(5):470-478.
39. Fu Y, Deng Q, Xie Z, Sun J, Song D, Gao Y, Huang D. Coronal root canal morphology of permanent two-rooted mandibular first molars with novel 3D measurements. Int Endod J. 2020 Feb;53(2):167-175. doi: 10.1111/iej.13220. Epub 2019 Oct 6. PMID: 31519062.
40. Rios P, Arriagada C, Rosas C, Aracena D. Description of the Morphology of the Root Canal System of the Maxillary First Molar Using Cone-Beam Computed Tomography in a Chilean Population. Inter. J. Morphol. 2023;41(2):477-481. doi:10.4067/S0717-95022023000200477
41. Razumova S, Brago A, Khaskhanova L, Barakat H, Howijieh A. Evaluation of Anatomy and Root Canal Morphology of the Maxillary First Molar Using the Cone-Beam Computed Tomography among Residents of the Moscow Region. Contemp Clin Dent 2018;9:S133-s136.
42. Namdar P, Molania T, Hoshyari N, Lotfizadeh A, Alimohammadi M, Khojastehfar M, Kohsar AH. Evaluation of Root and Canal Morphology of Maxillary First and Second Molars by Cone Beam Computed Tomography in a Northern Iranian Population. J Res Dent Maxillofac Sci. 2023; 8(4): 265-273. doi: 10.52547/jrdms.8.4.265
43. Wang H, Ci BW, Yu HY, Qin W, Yan YX, Wu BL, Ma DD. Evaluation of root and canal morphology of maxillary molars in a southern chinese subpopulation: A cone-beam computed tomographic study. Int J Clin Exp Med. 2017;10(4):7030-7039.
44. Guo J, Vahidnia A, Sedghizadeh P, Enciso R. Evaluation of root and canal morphology of maxillary permanent first molars in a North American population by cone-beam computed tomography. J Endod. 2014;40(5):635-9. doi: 10.1016/j.joen.2014.02.002. Epub 2014 Mar 29. PMID: 24767556.
45. Al Mheiri E, Chaudhry J, Abdo S, El Abed R, Khamis AH, Jamal M. Evaluation of root and canal morphology of maxillary permanent first molars in an Emirati population; a cone-beam computed tomography study. BMC Oral Health 2020;20(1):274.
46. Ahmed G, Ahmed Mostafa G, Muhammad N, Mohamed Mokhtar N, Amr Ahmed B, Amr B, et al. Evaluation of Root and Canal Morphology of Maxillary Permanent Molars in an Egyptian Population by Cone-beam Computed Tomography. Journal of Endodontics 2017.
47. Alrahabi M, Sohail Zafar M. Evaluation of root canal morphology of maxillary molars using cone beam computed tomography. Pak J Med Sci 2015;31(2):426-430.
48. Reuben J, Velmurugan N, Kandaswamy D. The evaluation of root canal morphology of the mandibular first molar in an Indian population using spiral computed tomography scan: an in vitro study. J Endod 2008;34(2):212-215.
49. Dibaji F, Shariati R, Moghaddamzade B, Mohammadian F, Sooratgar A, Kharazifard M. Evaluation of the relationship between buccolingual width of mesiobuccal root and root canal morphology of maxillary first molars by cone-beam computed tomography. Dent Res J (Isfahan) 2022;19:5.
50. Wang Y, Zheng QH, Zhou XD, Tang L, Wang Q, Zheng GN, et al. Evaluation of the root and canal morphology of mandibular first permanent molars in a western Chinese population by cone-beam computed tomography. J Endod 2010;36(11):1786-1789.
51. Nikoloudaki GE, Kontogiannis TG, Kerezoudis NP. Evaluation of the Root and Canal Morphology of Maxillary Permanent Molars and the Incidence of the Second Mesiobuccal Root Canal in Greek Population Using Cone-beam Computed Tomography. Open Dent J 2015;9:267-272.
52. Caputo BV, Noro Filho GA, de Andrade Salgado DM, Moura-Netto C, Giovani EM, Costa C. Evaluation of the Root Canal Morphology of Molars by Using Cone-beam Computed Tomography in a Brazilian Population: Part I. J Endod 2016;42(11):1604-1607.
53. Pawar A, Thakur B, Machado R, Kwak SW, Kim HC. An In-Vivo cone-beam computed tomography analysis of root and canal morphology of maxillary first permanent molars in an Indian population. Indian J Dent Res 2021;32(1):104-109.
54. Monsarrat P, Arcaute B, Peters OA, Maury E, Telmon N, Georgelin-Gurgel M, et al. Interrelationships in the Variability of Root Canal Anatomy among the Permanent Teeth: A Full-Mouth Approach by Cone-Beam CT. PLoS One 2016;11(10):e0165329.

55. McGuigan MB, Theodorakou C, Duncan HF, Davies J, Sengupta A, Horner K. An investigation into dose optimisation for imaging root canal anatomy using cone beam CT. Dentomaxillofac Radiol 2020;49(7):20200072.
56. Matsunaga S, Yamada M, Kasahara N, Noguchi T, Morita S, Kitamura K, et al. Japanese Maxillary First Molar Root Canal Morphology: An Ultrastructural Study Using Micro-Computed Tomography. Journal of Hard Tissue Biology 2022;31(2):109-114.
57. Ren HY, Kum KY, Zhao YS, Yoo YJ, Jeong JS, Perinpanayagam H, et al. Maxillary molar root and canal morphology of Neolithic and modern Chinese. Arch Oral Biol 2021;131:105272.
58. Zhang T, Zhao M, Hu Y. Maxillary Molar Root Canal Morphology Using Cone-Beam Computed Tomography: An Epidemiological Study from Shandong Province, China. International Journal of Morphology 2023;41(3):775-784.
59. Lee JH, Kim KD, Lee JK, Park W, Jeong JS, Lee Y, et al. Mesiobuccal root canal anatomy of Korean maxillary first and second molars by cone-beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011;111(6):785-791.
60. Verma P, Love RM. A Micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth. Int Endod J 2011;44(3):210-217.
61. Filpo-Perez C, Bramante CM, Villas-Boas MH, Húngaro Duarte MA, Versiani MA, Ordinola-Zapata R. Micro-computed tomographic analysis of the root canal morphology of the distal root of mandibular first molar. J Endod 2015;41(2):231-236.
62. Asijavičienė U, Drukteinis S, Suduiko A. Microcomputed tomography evaluation of the root canals morphology of the mandibular first molars. Stomatologija 2020;22(3):75-79.
63. Kim SY, Kim BS, Woo J, Kim Y. Morphology of mandibular first molars analyzed by cone-beam computed tomography in a Korean population: variations in the number of roots and canals. J Endod 2013;39(12):1516-1521.
64. Lyra CM, delai D, Pereira KCR, Pereira GM, Júnior BP, Oliveira CAP. Morphology ofmesiobuccal root canals of maxillary first molars: A comparison of CBCT scanning and cross-sectioning. Brazilian Dental Journal 2015;26(5):525-529.
65. Kenawi LMM, Althobaiti RF, Filimban DM, Alotaiby SDA, Alharbi MA, Kassar WM. Radiographic Investigation of Root Canal Morphology of Permanent Mandibular Molars in Makkah Population (Saudi Arabia) Using Cone-Beam Computed Tomography. Int J Dent 2022;2022:1535752.
66. Mohara NT, Coelho MS, de Queiroz NV, Borreau MLS, Nishioka MM, de Jesus Soares A, Frozoni M. Root Anatomy and Canal Configuration of Maxillary Molars in a Brazilian Subpopulation: A 125-μm Cone-Beam Computed Tomographic Study. Eur J Dent. 2019;13(1):82-87. doi: 10.1055/s-0039-1688736. Epub 2019 Jun 6. PMID: 31170761; PMCID: PMC6635971.
67. Xia Y, Qiao X, Huang YJ, Li YH, Zhou Z. Root Anatomy and Root Canal Morphology of Maxillary Second Permanent Molars in a Chongqing Population: A Cone-Beam Computed Tomography Study. Med Sci Monit. 2020 Aug 18;26:e922794. doi: 10.12659/MSM.922794. PMID: 32810082; PMCID: PMC7453757.
68. Atram J, Banga K, Gupta P, Pawar A. Root and canal anatomy of mandibular first molar teeth of an Indian population. Endodontology 2020;32(1):3-7. doi: 10.4103/endo.endo_71_19
69. Rwenyonyi CM, Kutesa A, Muwazi LM, Buwembo W. Root and canal morphology of mandibular first and second permanent molar teeth in a Ugandan population. Odontology. 2009; 97(2): 92-6. doi: 10.1007/s10266-009-0100-0. Epub 2009 Jul 29. PMID: 19639451.
70. Senan E, Alhadainy H, Madfa AA. Root and Canal Morphology of Mandibular Second Molars in a Yemeni Population: A Cone-beam Computed Tomography. Eur Endod J 2021;6(1):72-81.
71. Saber SM, Seoud MAE, Sadat SMAE, Nawar NN. Root and canal morphology of mandibular second molars in an Egyptian subpopulation: a cone-beam computed tomography study. BMC Oral Health. 2023;23(1):217. doi: 10.1186/s12903-023-02939-7. PMID: 37061674; PMCID: PMC10105946.
72. Neelakantan P, Subbarao C, Subbarao CV, Ravindranath M. Root and canal morphology of mandibular second molars in an Indian population. J Endod. 2010;36(8):1319-22. doi: 10.1016/j.joen.2010.04.001. Epub 2010 May 23. PMID: 20647088.
73. Ahmed HA, Abu-bakr NH, Yahia NA, Ibrahim YE. Root and canal morphology of permanent mandibular molars in a Sudanese population. Int Endod J 2007;40(10):766-771.
74. Gulabivala K, Opasanon A, Ng YL, Alavi A. Root and canal morphology of Thai mandibular molars. Int Endod J 2002;35(1):56-62.
75. Mashyakhy M, Gambarini G. Root and Root Canal Morphology Differences Between Genders: A Comprehensive in-vivo CBCT Study in a Saudi Population. Acta Stomatol Croat. 2019;53(3):213-246. doi: 10.15644/asc53/3/5. PMID: 31749454; PMCID: PMC6820446.

76. Guo Q, Wang Q, Yang Y, Guo D. Root and root canal morphology of mandibular second permanent molars in the Gansu province population: A CBCT study. Aust Endod J. 2023;49 Suppl 1:27-32. doi: 10.1111/aej.12692. Epub 2022 Sep 20. PMID: 36125937.
77. Ahmad I, Azzeh M, Zwiri A, Abu Haija MA, Diab M. Root and root canal morphology of third molars in a Jordanian subpopulation. Saudi Endodontic Journal 2016;6(3):113-121.
78. Demirtaş Ö, Duman ŞB. Root canal anatomy of maxillary first molars in a Turkish population using cone-beam computed tomography. J. Dental Materials and Techniques, 2023; 12(4): 168-174. doi: 10.22038/jdmt.2023.70840.1557
79. Pawar AM, Pawar M, Kfir A, Singh S, Salve P, Thakur B, Neelakantan P. Root canal morphology and variations in mandibular second molar teeth of an Indian population: an in vivo cone-beam computed tomography analysis. Clin Oral Investig. 2017;21(9):2801-2809. doi: 10.1007/s00784-017-2082-6. Epub 2017 Mar 9. PMID: 28281013.
80. Gomez F, Brea G, Gomez-Sosa JF. Root canal morphology and variations in mandibular se-cond molars: an in vivo cone-beam compu-ted tomography analysis. BMC Oral Health. 2021; 21(1):424. doi: 10.1186/s12903-021-017877. PMID: 34470619; PMCID: PMC8411505.
81. Ceperuelo D, Lozano M, Duran-Sindreu F, Mercadé M. Root canal morphology of Chalco-lithic and early bronze age human populations of El Mirador Cave. Anat Rec. 2014;297(12):2342-2348.
82. Shahi S, Yavari HR, Rahimi S, Torkamani R. Root canal morphology of human mandibular first permanent molars in an Iranian population. J Dent Res Dent Clin Dent Prospects. 2008;2(1):20-3. doi: 10.5681/joddd.2008.004. Epub 2008 May 15. PMID: 23285325; PMCID: PMC 3533633.
83. Sidow SJ, West LA, Liewehr FR, Loushine RJ. Root canal morphology of human maxillary and man-dibular third molars. J Endod. 2000;26(11):675-8. doi: 10.1097/00004770-20001 1000-00011. PMID: 11469300.
84. Chourasia HR, Meshram GK, Warhadpande M, Dakshindas D. Root canal morphology of mandibular first permanent molars in an Indian population. Int J Dent 2012;2012:745152.
85. Sana U, Niazi IU, Din RS, Rasheed M, Haider I, Yousaf O. Root Canal Morphology of Mandibular First Permanent Molars in Pakistani Sub-population - An in vitro study. Pakistan Journal of Medical & Health Sciences 2021;15(6):1314-1316.
86. Naseri M, Ali Mozayeni M, Safi Y, Heidarnia M, Akbarzadeh Baghban A, Norouzi N. Root Canal Morphology of Maxillary Second Molars according to Age and Gender in a Selected Iranian Population: A Cone-Beam Computed Tomography Evaluation. Iran Endod J. 2018;13(3):373-380. doi: 10.22037/iej.v13i3.19278. PMID: 30083209; PMCID: PMC6064032.
87. Alamri HM, Mirza MB, Riyahi AM, Alharbi F, Aljarbou F. Root canal morphology of maxillary second molars in a Saudi sub-population: A cone beam computed tomography study. Saudi Dent J 2020;32(5):250-254.
88. Habiba Suleiman M, Habiba Suleiman M, Irene Kida M, Irene Kida M, Irene KM. Root canal morphology of native Tanzanian permanent mandibular molar teeth. The Pan African medical journal 2018.
89. Weng XL, Yu SB, Zhao SL, Wang HG, Mu T, Tang RY, Zhou XD. Root canal morphology of permanent maxillary teeth in the Han nationality in Chinese Guanzhong area: a new modified root canal staining technique. J Endod. 2009 May;35(5):651-6. doi: 10.1016/j.joen.2009.02.010. PMID: 19410077.
90. Pan JYY, Parolia A, Chuah SR, Bhatia S, Mutalik S, Pau A. Root canal morphology of permanent teeth in a Malaysian subpopulation using cone-beam computed tomography. BMC Oral Health 2019;19(1):14.
91. Singh S, Pawar M. Root canal morphology of South Asian Indian maxillary molar teeth. Eur J Dent 2015;9(1):133-144.
92. Skidmore AE, Bjorndal AM. Root canal morphology of the human mandibular first molar. Oral Surg Oral Med Oral Pathol 1971;32(5):778-784.
93. Walker RT. Root form and canal anatomy of mandibular first molars in a southern Chinese population. Endod Dent Traumatol. 1988;4(1):19-22. doi: 10.1111/j.1600-9657.1988.tb00287.x.
94. Walker RT. Root form and canal anatomy of mandibular second molars in a southern Chinese population. J Endod 1988;14(7):325-329.
95. Abarca J, Duran M, Parra D, Steinfort K, Zaror C, Monardes H. Root morphology of mandibular molars: a cone-beam computed tomography study. Folia Morphol (Warsz). 2020;79(2):327-332. doi: 10.5603/FM.a2019.0084. Epub 2019 Jul 19. PMID: 31322722.
96. Estrela C, Bueno MR, Couto GS, Rabelo LE, Alencar AH, Silva RG, Pécora JD, Sousa-Neto MD. Study of Root Canal Anatomy in Human Permanent Teeth in A Subpopulation of Brazil's Center Region Using Cone-Beam Computed Tomography - Part 1. Braz Dent J. 2015;26(5):530-6. doi: 10.1590/0103-6440201302448. PMID: 26647941.

97. Naseri M, Safi Y, Akbarzadeh Baghban A, Khayat A, Eftekhar L. Survey of Anatomy and Root Canal Morphology of Maxillary First Molars Regarding Age and Gender in an Iranian Population Using Cone-Beam Computed Tomography. Iran Endod J. 2016;11(4):298-303.

98. Plotino G, Tocci L, Grande NM, Testarelli L, Messineo D, Ciotti M, et al. Symmetry of root and root canal morphology of maxillary and mandibular molars in a white population: a cone-beam computed tomography study in vivo. J Endod. 2013;39(12):1545-1548.

99. Fu YJ, Gao Y, Gao YX, Tan XL, Zhang L, Huang DM. Three-dimensional analysis of coronal root canal morphology of 136 permanent mandibular first molars by micro-computed tomography. Journal of Dental Sciences. 2022;17(1):482-489.

100. Demirbuga S, Sekerci AE, Dinçer AN, Cayabatmaz M, Zorba YO. Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular first and second molars in Turkish individuals. Med Oral Patol Oral Cir Bucal. 2013;18(4):e737-744.

101. Zhang R, Wang H, Tian YY, Yu X, Hu T, Dummer PM. Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals. Int Endod J. 2011;44(11):990-9. doi: 10.1111/j.1365-2591.2011.01904.x. PMID: 21658074.

102. Khattak I, Khattak MA, Khattak YJ, Arbab S, Rashid M, Shah SA. Use of tooth clearing technique to determine root and canal morphology of permanent mandibular third molars in population of peshawar: an in vitro cross-sectional study. Khyber Med. University J. 2021;13(4):216-221.doi:10.35845/kmuj.2021.21653

103. Yang L, Han J, Wang Q, Wang Z, Yu X, Du Y. Variations of root and canal morphology of mandibular second molars in Chinese individuals: a cone-beam computed tomography study. BMC Oral Health. 2022;22(1):274. doi: 10.1186/s12903-022-02299-8. PMID: 35790917; PMCID: PMC9258086.

104. Marušić MF, Fidahić M, Cepeha CM, Farcaș LG, Tseke A, Puljak L. Methodological tools and sensitivity analysis for assessing quality or risk of bias used in systematic reviews published in the high-impact anesthesiology journals. BMC Medical Research Methodology 2020;20(1):121.

105. Ho L, Ke FYT, Wong CHL, Wu IXY, Cheung AKL, Mao C, Chung VCH. Low methodological quality of systematic reviews on acupuncture: a cross-sectional study. BMC Med Res Methodol. 2021 30;21(1):237. doi: 10.1186/s12874-021-01437-0. PMID: 34717563; PMCID: PMC8557536.

106. Wong BK, Leichter JW, Chandler NP, Cullinan MP, Holborow DW. Radiographic study of ethnic variation in alveolar bone height among New Zealand dental students. J Periodontol. 2007;78(6):1070-4. doi: 10.1902/jop.2007.060366. PMID: 17539721.

107. Hanihara T, Ishida H. Metric dental variation of major human populations. Am J Phys Anthropol. 2005;128(2):287-98. doi: 10.1002/ajpa.20080. PMID: 15838862.

108. Gross JM, Edgar HJH. Geographic and temporal diversity in dental morphology reflects a history of admixture, isolation, and drift in African Americans. Am J Phys Anthropol. 2021 Jun;175(2):497-505. doi: 10.1002/ajpa.24258. Epub 2021 Mar 11. PMID: 33704773.

109. Hanihara T. Morphological variation of major human populations based on nonmetric dental traits. Am J Phys Anthropol. 2008;136(2):169-82. doi: 10.1002/ajpa.20792. PMID: 18257017.

110. Delgado M, Ramírez LM, Adhikari K, Fuentes-Guajardo M, Zanolli C, Gonzalez-José R, Canizales S, Bortolini MC, Poletti G, Gallo C, Rothhammer F, Bedoya G, Ruiz-Linares A. Variation in dental morphology and inference of continental ancestry in admixed Latin Americans. Am J Phys Anthropol. 2019;168(3):438-447. doi: 10.1002/ajpa.23756. Epub 2018 Dec 24. PMID: 30582632.

111. Sperber GH, Moreau JL. Study of the number of roots and canals in Senegalese first permanent mandibular molars. Int Endod J. 1998;31(2):117-22. doi: 10.1046/j.1365-2591.1998.00126.x. PMID: 986 8938.

112. Naseri M, Kharazifard MJ, Hosseinpour S. Canal Configuration of Mesiobuccal Roots in Permanent Maxillary First Molars in Iranian Population: A Systematic Review. J Dent. 2016;13(6):438-447. PMID: 28243306; PMCID: PMC5318501.

113. Barbhai S, Shetty R, Joshi P, Mehta V, Mathur A, Sharma T, Chakraborty D, Porwal P, Meto A, Wahjuningrum DA, Luke AM, Pawar AM. Evaluation of Root Anatomy and Canal Configuration of Human Permanent Maxillary First Molar Using Cone-Beam Computed Tomography: A Systematic Review. Int J Environ Res Public Health. 2022; 19(16): 10160. doi: 10.3390/ijerph191610160. PMID: 36011794; PMCID: PMC9408299.

114. de Pablo ÓV, Estevez R, Péix Sánchez M, Heilborn C, Cohenca N. Root Anatomy and Canal Configuration of the Permanent Mandibular First Molar: A Systematic Review. Journal of Endodontics 2010;36(12):1919-1931.

115. Al-Rammahi HM, Chai WL, Nabhan MS, Ahmed HMA. Root and canal anatomy of mandibular first molars using micro-computed tomography: a systematic review. BMC Oral Health. 2023;23(1):339. doi: 10.1186/s12903-023-03036-5. PMID: 37248469; PMCID: PMC10228077.
116. Mashyakhy M, AlTuwaijri N, Alessa R, Alazzam N, Alotaibi B, Almutairi R, Alroomy R, Thota G, Melha AA, Alkahtany MF, Almadi KH, Chohan H, Tarrosh M, Mirza MB. Anatomical Evaluation of Root and Root Canal Morphology of Permanent Mandibular Dentition among the Saudi Arabian Population: A Systematic Review. Biomed Res Int. 2022;2022:2400314. doi:10.1155/2022/2400314. PMID: 35958809;
117. Joshi PS, Shetty R, Sarode GS, Mehta V, Chakraborty D. Root anatomy and canal configuration of human permanent mandibular second molar: A systematic review. J Conserv Dent 2021;24(4):298-306.
118. Kindler S, Ittermann T, Bülow R, Holtfreter B, Klausenitz C, Metelmann P, Mksoud M, Pink C, Seebauer C, Kocher T, Koppe T, Krey KF, Metelmann HR, Völzke H, Daboul A. Does craniofacial morphology affect third molars impaction? Results from a population-based study in northeastern Germany. PLoS One. 2019;14(11):e0225444. doi: 10.1371/journal.pone.0225444. PMID: 31756203; PMCID: PMC68 74347.
119. Huang Y, Yan Y, Cao J, Xie B, Xiao X, Luo M, Bai D, Han X. Obeservations on association between third molar agenesis and craniofacial morphology. J Orofac Orthop. 2017;78(6):504-510. English. doi: 10.1007/s00056-017-0109-x. Epub 2017 Oct 27. PMID: 29080079.
120. Morita W, Morimoto N, Ohshima H. Exploring metameric variation in human molars: a morphological study using morphometric mapping. J Anat. 2016;229(3):343-55. doi: 10.1111/joa.12482. Epub 2016 Apr 21. PMID: 27098351; PMCID: PMC4974549.