CLINICAL RESEARCH

Worldwide Prevalence of Single-rooted with a Single Root Canal and Four-rooted Configurations in Maxillary Molars: A Multi-center Cross-sectional Study with Meta-analysis

Jorge N. R. Martins[*†‡] *"Worldwide Anatomy Research Group" (including all authors participating in the Worldwide Study), Marco A. Versiani*[§]

ABSTRACT

Introduction: To evaluate the prevalence of single root with a single root canal and four-root configurations in the maxillary first and second molars, and analyze how geographic region, ethnicity, sex, and age impact these outcomes. **Methods:** Researchers from 44 nations examined 26,400 maxillary molars using cone-beam computed tomography scans to gather data on the proportions of single roots with single canals and four-root configurations. All observers underwent prior calibration regarding the step-by-step assessment protocol and anatomical concepts to ensure consistent evaluations across all assessed locations. Tests were conducted to evaluate the intraobserver and interobserver reliability. Demographic data including ethnicity, gender, and age were collected for each participant. The potential impact of imaging voxel size and field-of-view on bias was also assessed. The primary results were depicted as odds ratios and untransformed proportion forest plots with 95% confidence intervals. Additionally, a meta-analysis was performed to compare various subgroups and identify sources of variation among them. Statistical significance was set at 5%. **Results:** The prevalence of single-rooted with a single canal and four-rooted configurations in the maxillary first molar was 0.16% and 0.28%, respectively, while in the maxillary second molar, it was 2.56% and 0.83%. Males tended to exhibit lower percentages of single roots with a single canal ($P < .05$) and higher percentages of four-rooted configurations ($P > .05$) in the second molar, whereas the African subgroup displayed lower proportions for both configurations. Additionally, in both teeth, single roots with a single canal were more prevalent among older patients. Voxel size and field-of-view did not significantly influence the results ($P > .05$). **Conclusions:** The proportions of single-rooted with a single canal and four-rooted configurations were low, and demographic factors such as geographic region, ethnicity, sex, and age may have influenced the outcomes for the maxillary second molar. *(J Endod 2024;■:1–19.)*

KEY WORDS

Anatomy; cone-beam computed tomography; endodontics; maxillary molars; prevalence study

SIGNIFICANCE

Maxillary molars are prone to anatomic variations. The proportion of single-rooted with a single canal and four-rooted configurations in the maxillary first molar was 0.16% and 0.28%, respectively, while in the maxillary second molar, it was 2.56% and 0.83%. Demographic factors may influence the prevalence of these morphologies for the maxillary second molar.

Studies examining the prevalence of root and root canal anatomy in endodontics should prioritize real-world data to establish real-world evidence[1], aiming to refine clinical treatment planning and improve treatment outcomes. Unlike laboratory studies or randomized clinical trials, which provide valuable insights under controlled conditions, real-world data and real-world evidence offer insights into the complexities and variabilities of clinical practice and patient outcomes in actual clinical settings[1,2].

From the *Faculdade de Medicina Dentária, Department of Endodontics, †Grupo de Investigação em Bioquimica e Biologia Oral, Unidade de Investigação em Ciências Orais e Biomédicas (UICOB), Faculdade de Medicina Dentária, and ‡Centro de Estudo de Medicina Dentária Baseada na Evidência (CEMDBE) - Cochrane Portugal, Faculdade de Medicina Dentária, Universidade de Lisboa, Lisbon, Portugal; and §Dental Specialty Center, Brazilian Military Police, Minas Gerais, Brazil

"Worldwide Anatomy Research Group" (including all authors participating in the Worldwide Study): Jorge N.R. Martins, DDS, MSc, PhD (Department of Endodontics, Faculdade de Medicina Dentária, Universidade de Lisboa, Lisbon, Portugal; Grupo de Investigação em Bioquimica e Biologia Oral, Unidade de Investigação em Ciências Orais e Biomédicas (UICOB), Faculdade de Medicina Dentária, Universidade de

Lisboa, Lisbon, Portugal; Centro de Estudo de Medicina Dentária Baseada na Evidência (CEMDBE) - Cochrane Portugal, Faculdade de Medicina Dentária, Universidade de Lisboa, Lisbon, Portugal; LIBPhys-FCT UID/FIS/04559/2013 (https://doi.org/10.54499/UIDB/04559/2020), Lisbon, Portugal); Pablo Ensinas, DDS, MSc (Private Practice, Salta, Argentina); Francis Chan, BDSc, DCD (The University of Melbourne, Melbourne, Australia); Narin Babayeva, DMD (Azerbaijan Medical University, Baku, Azerbaijan); Murilo von Zuben, DDS, MSc (Private Practice, Brussels, Belgium); Luiza Berti, DDS, MSc (Department of Radiology, Faculdade de Odontologia São Leopoldo Mandic, Campinas, Brazil); Ernest W.N. Lam, DMD, MSc, PhD, FRCD(C) (Faculty of Dentistry, University of Toronto, Toronto, Canada); Rodrigo Villanueva, DDS (Pontificia Universidad Católica de Chile, Santiago de Chile, Chile); Fan Pei, DDS (Department of Dentistry and Central Laboratory, Ninth People's Hospital of Suzhou, Soochow University, Suzhou, China); Catalina Mendez de la Espriella, DDS (Pontificia Universidad Javeriana – Centro de Investigaciones Odontologicas, Bogota, Colombia); Walter Vargas, DDS (Instituto de Estudios Avanzados en Odontologia Dr Yury Kuttler, San José, Costa Rica); Juan Carlos Izquierdo Camacho, DDS (Private Practice, Quito, Ecuador); Moataz-Bellah A.M. Alkhawas, DDS, MSc, PhD (Department of Endodontics, Al-Azhar University Faculty of Dental Medicine, Cairo, Egypt); Tiago Pimentel, DDS, MSc, MClinDent, MRD (King's College London, London, UK); Fábio Santiago, DDS, MSc (Private Practice, Paris, France); Hans Willi Herrmann, DDS (Private Practice, Bad Kreuznach, Germany); Antonis Chaniotis, DDS, MSc (Private Practice, Athens, Greece); Gergely Benyocs, DMD (Private Practice, Budapest, Hungary); Magnús F. Ragnarsson, DDS (Private Practice, Hafnarfjördur, Iceland); Jojo Kottoor, BDS, MDS (Department of Conservative Dentistry and Endodontics, Royal Dental College, Kerala, India); Avi Shemesh, DMD (Department of Endodontics, Israel Defense Forces Medical Corps, Tel Hashomer, Israel; Faculty of Dental Medicine, Hebrew University of Jerusalem, Jerusalem, Israel); Raffaella Castagnola, DDS, PhD (Dipartimento di Testa-Collo e organi di senso, Università Cattolica del Sacro Cuore, Rome, Italy); Sriteja Tummala, BDS (School of Dentistry, Faculty of Medical Sciences, The University of the West Indies, Kingston, Jamaica); Satoru Matsunaga, DDS, PhD (Department of Anatomy, Tokyo Dental College, Tokyo, Japan); Arina Maksimova, DDS, MD (Private Practice, Bishkek, Kyrgyzstan); Hani Ounsi, DDS, HDR, PhD (Department of Restorative Dentistry and Endodontics, Lebanese University, Beirut, Lebanon; Department of Medical Biotechnologies, Siena University, Siena, Italy); Abhishek Parolia, BDS, MDS, PhD (International Medical University School of Dentistry, Kuala Lumpur, Malaysia); Ruben Rosas Aguilar, MD (National Autonomus University of Mexico, León, Mexico); Olabisi H. Oderinu, BDS, MPH, MSc, MD, FMCDS (Department of Restorative Dentistry, Faculty of Dental Sciences, College of Medicine, University of Lagos, Lagos, Nigeria); Muhammad Rizwan Nazeer, BDS, FCPS (Private Practice, Karachi, Pakistan); Carlos Heilborn, DDS (Private Practice, Asunción, Paraguay); Christian Nole, DDS, MSc (Facultad de Medicina, Universidad Nacional Mayor de San Marcos, Lima, Peru); Sergiu Nicola, DDS (Private Practice, Bucharest, Romania); Elena Lipatova, DMD (Private Practice, Yekaterinburg, Russia); Hussam Alfawaz, BDS, MS, FRCD (King Saud University, College of Dentistry, Riyadh, Saudi Arabia); Hussein C. Seedat, BDS, MSc (Private Practice, Durban, South Africa); Seok Woo Chang, DDS, MSD, PhD (Kyung Hee University Dental School, Seoul, South Korea); Jose Antonio Gonzalez, DDS, MSc, PhD (Departamento de Endodoncia y Conservadora, Facultad de Odontología, Universitat Internacional de Catalunya, Barcelona, Spain); Zaher Altaki, DDS, MSc (Department of Endodontics, Damascus University, Damascus, Syria); Danuchit Banomyong, DDS, PhD (Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand); Ali Keles, DDS, PhD (Department of Endodontics, Bolu Abant İzzet Baysal University Faculty of Dentistry, Bolu, Turkey); Iliana Modyeievsky, DDS, MSc (Private Practice, Montevideo, Uruguay); Adam Monroe, DMD (Private Practice, Vista, USA); Carlos Boveda, DDS, PhD (Department of Endodontics, Faculty of Dentistry, Universidad Central de Venezuela, Caracas, Venezuela); Mohammed Turky, DDS, PhD (Department of Endodontics, Faculty of Dentistry, Minia University, Minia, Egypt; Department of Endodontics, Faculty of Dentistry, Sphinx University, Assiut, Egypt); Emmanuel J.N.L. Silva, DDS, MSc, PhD (Department of Endodontics, School of Dentistry, Grande Rio University (UNIGRANRIO), Rio de Janeiro, Rio de Janeiro, Brazil; Department of Endodontics, Fluminense Federal University, Niteroi, Rio de Janeiro, Brazil); Michael Solomonov, DMD (Department of Endodontics, Israel Defense Forces Medical Corps, Tel Hashomer, Israel; Faculty of Dental Medicine, Hebrew University of Jerusalem, Jerusalem, Israel); Joe Ben Itzhak, DMD (Department of Endodontics, Israel Defense Forces Medical Corps, Tel Hashomer, Israel); Marco A. Versiani, DDS, MSc, PhD (Dental Specialty Center, Brazilian Military Police, Minas Gerais, Brazil).

Address requests for reprints to Dr Jorge N.R. Martins, Faculdade de Medicina Dentária da Universidade de Lisboa, Cidade Universitária, Lisboa 1649-003, Portugal.jnr_martins@yahoo.com.br
0099-2399/$ - see front matter

https://doi.org/10.1016/j.joen.2024.06.010

Real-world data and evidence are essential in advancing personalized medicine and evidence-based practice in the field of endodontics. By analyzing large datasets encompassing diverse patient populations, researchers can identify patient-specific factors influencing treatment outcomes, such as age, sex, ethnicity, systemic health conditions, and anatomical variations in root morphology[1,2]. This enables clinicians to choose treatment approaches to individual patient needs, optimizing treatment prognosis, and minimizing the risk of complications. Research using real-world data from large population samples should ideally be conducted on actual patients. In recent years, cone-beam computed tomography (CBCT) has emerged as a valuable imaging modality for assessing the complex root and root canal anatomy of teeth[1,3,4]. Its 3-dimensional visualization capabilities provide unparalleled insights into the internal structures of teeth, allowing for precise diagnosis and treatment planning[5].

The successful outcome of endodontic treatment relies upon a comprehensive understanding of the intricate root and root canal anatomy, especially in complex teeth like maxillary molars[6]. Traditionally, these teeth have been described as having 3 roots designated due to their anatomical position as mesiobuccal, distobuccal, and palatal root, usually exhibiting four root canals. Nonetheless, several studies and case reports have highlighted the presence of diverse anatomical variations in maxillary molars, leading to a wide range of root and canal configurations. For instance, rare cases of single-rooted with a single canal[7,8] or four separate roots[9,10] have also been documented. Despite their clinical significance, the prevalence and characteristics of these less common anatomies remain inadequately documented, with only a few studies available in specific regions of the globe[7–9]. While the single-rooted configuration of maxillary molars has often been overlooked in scientific literature, with the majority of studies being case reports[11,12], some attempts have been made to establish the prevalence of four-rooted configurations using conventional radiographs[13,14] and CBCT[9].

Given the significant clinical implications associated with single-rooted maxillary molars with a single root canal and four-rooted configurations, which demand careful examination and adjusted therapeutic approaches–including potential modifications to treatment protocols and challenges in canal negotiation and obturation[11,15]–it is essential to develop a comprehensive understanding of their global prevalence and characteristics for informed clinical decision-making. Despite previous anatomical studies on maxillary molars, some using CBCT imaging as analytical tool[7,9], comprehensive investigations into the prevalence of single-rooted with a single root canal and four-rooted maxillary molars remain scarce. The present research aims to address this gap in the literature and offer valuable insights into the epidemiology of these anatomical variations. By systematically analyzing a diverse sample of maxillary molars

from various geographic regions, this study seeks to elucidate the global prevalence of single-rooted with a single root canal and four-rooted maxillary molars, while examining potential influences of geographic region, ethnicity, sex, and age on the occurrence of such configurations. The null hypothesis to be tested is that demographic factors do not affect the prevalence of these morphologies in maxillary first and second molars.

MATERIALS AND METHODS

Research Protocol and Methodology Validation

The research protocol for this cross-sectional study, conducted across multiple centers, received approval from the ethics committee of the University of Lisbon Faculty of Dental Medicine (registered as CE-FMDUL202239). All CBCT scans used in this study were pre-existing and not obtained specifically for this research. Patient identities remained confidential and were not accessed or disclosed. Furthermore, the imaging procedures adhered to the guidelines outlined by the American Association of Endodontists[16], and the report followed the preferred reporting items guidelines for epidemiologic cross-sectional studies on root and root canal anatomy using CBCT[17]. A team of 44 experienced observers, comprising scholars and specialized endodontists from 44 countries across 5 continents, conducted a global examination of the anatomy of maxillary first and second molars. The primary objective was to determine the prevalence of single roots with a single root canal and four-rooted configurations in both maxillary molars. To ensure consistency among observers, comprehensive written instructions covering research objectives, relevant scientific literature, target outcomes, examples of CBCT scan images depicting the anatomies of interest, definitions of relevant anatomical features, CBCT screening procedures, and individual and group schedules and deadlines were provided to all. Additionally, a tutorial video illustrating the step-by-step screening process for analyzing 3-dimensional volumes was distributed to the entire research team. The study coordinator (J.M.) compiled the supporting material, which underwent preliminary evaluation by 2 external reviewers (M.A.V. and J.B.I.), who were not involved as field observers. This step aimed to ensure a consensus-based scientific validation of the research goals and methodology. The supplementary material was then used for the simultaneous training of all 44 field observers at the beginning of the research timeline. No additional field observers were recruited once the initial training was completed. The 2 external reviewers consistently monitored the progress to ensure the fulfillment of both individual and collective deadlines and objectives.

Sample Size Calculation

To test the null hypothesis, a sample size calculation was based on preliminary evaluations involving 35 maxillary first molars and 35 maxillary second molars from all 44 regions examined. The 2 countries with the most significant differences between them for each main outcome in the preliminary assessment were identified and compared. Considering a statistical power of 80% and a confidence level (CI) of 95%, along with effect sizes of 0.33% (Argentina and Ecuador) for single root with single root canal and 0.67% (Australia and Ecuador) for 4-rooted configurations prevalence on the first molar, and 2.67% (Belgium and Azerbaijan) for single root with single root canal and 1.0% (Chile and Pakistan) for 4-rooted configurations prevalence on the second molar, the final sample size was determined to be 2371, 1164, 287, and 778 teeth for each outcome. Given the limited clinical significance of potential statistical differences with such large sample numbers, the study focused on the outcome of greatest clinical relevance (maxillary second molar single root with single root canal morphology) and established a final sample size of 300 teeth per group.

Assessment Methodology

In each geographic area, a single field observer was assigned the task of using multiple CBCT scanners capable of capturing scan volumes with both small and large field-of-view (FOV), ensuring that voxel sizes were 200 μm or smaller. Each observer was responsible for examining consecutive CBCT volumes from their regional databases, either numerically or alphabetically, until data on 300 specimens of maxillary first molars and 300 specimens of maxillary second molars were documented. The representativeness of the local subpopulation sample was ensured by selecting patients from those attending health centers in each region. Although patient identities were kept confidential, demographic details such as age and gender (male/female) were recorded for each tooth. Subjects lacking demographic information were excluded from the study. Additionally, teeth exhibiting root resorption, incomplete root development, prior root canal treatment, root decay, irreparable damage (such as root fractures), numbering ambiguity, and compromised image clarity due to artifacts were also excluded.

Table 1 offers a comprehensive summary of the data sources, CBCT machine specifications, and the rationale for exclusions in each region. The CBCT imaging screening process started by aligning the long axis of the analyzed molar with the reference lines in the visualization software. Following this alignment, anatomical assessment was conducted on the coronal, sagittal, and axial planes, guided by the supplementary materials provided during the initial calibration of the observer team. Field observers had the flexibility to adjust CBCT volume settings, such as applying specific filters or employing image noise reduction tools, to enhance anatomical clarity. To minimize individual bias, all 44 observers remained unaware of each other's findings. Each included molar was documented with tooth numbering using the Universal Numbering System, indicating the presence or absence of a single root with a single root canal configuration (yes/no) (Fig. 1), and the presence or absence of a 4-rooted morphology (yes/no) (Fig. 2). Furthermore, the ethnic group(s) of each patient were also documented for each specimen. It is important to note that the ethnic groups of patients attending the health center unit may not necessarily represent the most common ethnicities in the country. Observers were instructed to reach out to the study coordinator if any uncertainties arose during interpretation, ensuring a final consensus. Data were meticulously recorded using a standardized Excel template (Microsoft Office v15.0.5537, Redmond, WA, USA) to facilitate the identification of any inconsistencies. Any discrepancies identified during cross-checking were communicated to participants for review and correction. The outcomes of the dataset cross-checking process are summarized in Supplemental Table S1.

Reliability Measurements

Prior to the final data collection, 3 individual and 2 group assessments were conducted to enhance the reliability of the present research findings. Intrarater reliability was assessed by comparing 2 evaluations of the same 35 maxillary second molars (11.7% of the global sample) from the local dataset, conducted by each participant within a 1-month timeframe. The focus was on identifying both single roots with a single root canal and 4-rooted configurations. Cohen's kappa score was utilized to calculate each participant's individual reliability. For inter-rater reliability, all participants assessed 18 maxillary second molars from the same 15 CBCT volumes (none of them part of any regional dataset) to identify the morphologies of

TABLE 1 - Geographic Location, Cone-beam Computed Tomography Volume Characteristics, Exclusion Ratio, and Dates of Imaging Acquisition

Country	Location	Continent	Dataset source	Observer ID	CBCT model (brand, city, country)	Visualization software (Brand)	CBCT FOV	CBCT settings (μm, kV, mA)	Teeth exclusion ratio (reasons)	Date of CBCT imaging acquisition
Argentina	Salta	Americas	I/P	P.E.	CS 8100 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	L	75, 60–80, 2–15	2.4% (Edentulous, RCT)	2021–2022
Australia	Melbourne	Oceania	I	F.C.	Accuitomo 80 (Morita, Kyoto, Japan) i-CAT FLX (i-CAT, Hatfield, England)	InteleViewer (InteleRad, Montreal, Canada)	S	80–160, 86–90, 6–8 200, 120, 5	8.9% (Artefacts, RCT, open apex, resorptions, unclear number)	2011–2022
Azerbaijan	Baku	Asia	A	N.B.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	S/L	200, 90, 5–6	1.3% (Artefacts, RCT, unclear number)	2016–2022
Belgium	Brussels	Europe	P	M.Z.	Newtom Giano (Newtom, Verona, Italy)	NNT (Newtom)	S/L	150, 90, 4	0.3% (Artefacts, unclear number)	2016–2022
Brazil	Campinas	Americas	P	L.B.	i-CAT FLX (i-CAT, Hatfield, England)	i-CAT Vision (i-CAT)	L	200, 90, 5	0.6% (Artefacts)	2017–2022
Canada	Toronto	Americas	I/P	E.L.	CS 9300 (Carestream, Atlanta, USA)	Invivo (Anatomage, Santa Clara, USA)	S	90, 84, 5	—	2010–2020
Chile	Santiago do Chile	Americas	I	R.V.	CS 8100 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	L	150, 82, 5	15.4% (Artefacts, edentulous, RCT, open apex)	2016–2022
China	Suzhou	Asia	A	F.P.	Kavo 3D eXame (Kavo Sybron, Munich, Germany)	eXame vision (Kavo)	L	200, 120, 4	0.3% (Artefacts, edentulous, RCT)	2017–2022
Colombia	Bogota	Americas	I/P	C.E.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	S	75, 90, 14	—	2017–2022
Costa Rica	San Jose	Americas	P	W.V.	X Mind Trium (Acteon, Merignac, France)	X Mind Trium (Acteon)	L	200, 85–90, 8	—	2022
Ecuador	Quito	Americas	P	J.C.	Scanora 3Dx (Soredex, Helsinki, Finland)	On demand (Soredex)	L	150-200, 90, 6	2.4% (Artefacts)	2022
Egypt	Cairo	Africa	P	M.B.A.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	L	150, 90, 12	14.5% (Artefacts, RCT, open apex)	2017–2022
England	London	Europe	P	T.P.	CS 8100 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	S/L	75–150, 90, 3–6	2.1% (Artefacts, edentulous)	2019–2022
France	Paris	Europe	P	F.S.	Orthophos SL (Dentsply, Ballaigues, Switzerland)	Sidexis 4 (Dentsply)	S/L	160, 85, 6	0.5% (Artefacts)	2020–2022
Germany	Bab Kreuznach	Europe	P	H.H.	X800 (Morita, Kyoto, Japan) CS 9300 (Carestream, Atlanta, USA) Kavo OP 3D Pro (Kavo Sybron, Munich, Germany)	i-Dixel (Morita) CS 3D Imaging (Carestream) OnDemand 3D (Kavo)	S/L	80, 100, 7 90, 84–90, 5–8 85, 90, 6	—	2012–2022

(*continued on next page*)

TABLE 1 - Continued

Country	Location	Continent	Dataset source	Observer ID	CBCT model (brand, city, country)	Visualization software (Brand)	CBCT FOV	CBCT settings (μm, kV, mA)	Teeth exclusion ratio (reasons)	Date of CBCT imaging acquisition
Greece	Athens	Europe	I	A.C.	Newtom VGI (Newtom, Verona, Italy)	NNT (Newtom)	L	150, 110, 8	—	2022
Hungary	Budapest	Europe	P	G.B.	Promax 3D (Planmeca, Helsinki, Finland) CS 9300 (Carestream, Atlanta, USA) Vatech Green (Vatech, Gyeonggi-do, Korea)	Romexis (Planmeca) CS 3D Imaging (Carestream) Vatech MAR (Vatech)	L	200, 84, 15 200, 60–90, 2–15 200, 6–99, 9–16	—	2018–2022
Iceland	Hafnarfjördur	Europe	P	M.R.	i-CAT FLX (i-CAT, Hatfield, England)	i-CAT Vision (i-CAT)	L	200, 120, 4	0.8% (Artefacts, RCT)	2017–2021
India	Palakkad	Asia	P	J.K.	Newtom Giano (Newtom, Verona, Italy)	NNT (Newtom)	S/L	150, 90, 4–9	1.0% (Artefacts, edentulous, open apex)	2018–2022
Israel	Jerusalem	Asia	A	A.S.	Alioth (Asahi Roentgen, Kyoto, Japan)	RadiAnt Dicom Viewer (Medixant, Pozlan, Poland)	L	155, 85, 6	1.0% (Artefacts)	2018–2020
Italy	Rome	Europe	I	R.C.	Accuitomo 170 (Morita, Kyoto, Japan)	i-Dixel (Morita)	S	200, 88, 8	—	2021–2022
Jamaica	Kingston	Americas	P	S.T.	OP 300 (Kavo, Charlotte, USA)	Invivo (Anatomage, Santa Clara, USA)	L	85, 57–90, 4–16	1.3% (Artefacts, edentulous)	2021–2022
Japan	Tokyo	Asia	A	S.M.	Accuitomo F17 (Morita, Kyoto, Japan)	Infinitt Pacs (Infinitt Medical, Phillipsburg, USA)	S/L	80, 90, 7	0.1% (Artefacts)	2018–2022
Kuwait	Salmiya	Asia	P	H.O.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	S/L	150, 90, 10	10.0% (Artefacts, edentulous, RCT)	2018–2022
Kyrgyzstan	Bishkek	Asia	P	Ar.M.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	S/L	75–150, 90, 8–10	1.3% (Artefacts, edentulous, open apex)	2022
Malaysia	Kuala Lumpur	Asia	A	A.P.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	S/L	200, 60–120, 1–14	—	2019–2022
Mexico	León	Americas	I/P	R.A.	OP 300 (Kavo, Charlotte, USA) Promax 3D (Planmeca, Helsinki, Finland)	OnDemand 3D (Kavo) Romexis (Planmeca)	S/L	75–200, 85–120, 8–12	1.6% (Artefacts, edentulous)	2016–2022
Nigeria	Lagos	Africa	P/A	O.O.	CS 8100 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	S	150, 90, 3	0.1% (Artefacts, fractured teeth)	2018–2022
Pakistan	Karachi	Asia	P	M.N.	Promax 3D (Planmeca, Helsinki, Finland) CS 9600 (Carestream, Atlanta, USA)	Romexis (Planmeca) CS 3D Imaging (Carestream)	L	180–200, 85–90, 4–6	1.4% (Artefacts)	2018–2021
Paraguay	Asunción	Americas	I	C.H.	Imax 3D (Owandy, Beaubourg, France)	CS 3D Imaging (Carestream)	L	170, 84, 5	5.8% (Artefacts, RCT)	2019–2022

(*continued on next page*)

TABLE 1 - Continued

Country	Location	Continent	Dataset source	Observer ID	CBCT model (brand, city, country)	Visualization software (Brand)	CBCT FOV	CBCT settings (μm, kV, mA)	Teeth exclusion ratio (reasons)	Date of CBCT imaging acquisition
Peru	Lima	Americas	I	C.N.	OP 300 (Kavo, Charlotte, USA)	OnDemand 3D (Kavo)	L	200, 57–90, 4–16	0.1% (Artefacts)	2021
Portugal	Lisbon	Europe	P	J.M.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	L	200, 84, 15	1.9% (Artefacts, edentulous, RCT)	2019–2022
Romania	Bucharest	Europe	P	S.N.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	L	200, 85, 12	—	2022
Russia	Yekaterinburg	Asia	P	E.L.	CB 500 (Gendex, Hatfield, England)	i-CAT Vision (i-CAT)	S/L	200, 120, 3–8	10.8% (Artefacts, edentulous, RCT)	2021–2022
Saudi Arabia	Riyadh	Asia	A	H.A.	Promax 3D (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	L	200, 84, 15	—	2022
South Africa	Durban	Africa	P	H.S.	CS 8100 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	S/L	75–150, 90, 3	0.3% (Artefacts)	2017–2022
South Korea	Seoul	Asia	A	S.C.	Alphard 300 (Asahi Roentgen Ind, Kyoto, Japan)	Zetta PACS Viewer (Asahi)	L	200, 60–100, 2-15	—	2018–2022
Spain	Barcelona	Europe	P	J.G.	CS 8100 (Carestream, Atlanta, USA) Promax 3D (Planmeca, Helsinki, Finland)	InteleViewer (InteleRad, Montreal, Canada)	L	150–200, 84–90, 4–6	1.6% (Artefacts)	2016–2022
Syria	Damascus	Asia	P	Z.A.	Viso G5 (Planmeca, Helsinki, Finland)	Romexis (Planmeca)	L	200, 60–120, 1–16	1.6% (Edentulous)	2018–2022
Thailand	Bangkok	Asia	A	D.B.	Accuitomo 170 (Morita, Kyoto, Japan)	OneVolumeViewer (Morita)	S	125, 90, 5	2.9% (Artefacts, open apex, RCT)	2021–2022
Turkey	Istanbul	Europe	A	A.K.	5G XL (Newtom, Verona, Italy)	(Newtom, Verona, Italy)	S/L	100–200, 110, 3–6	2.7% (Artefacts, RCT, open apex)	2019–2022
Uruguay	Montevideo	Americas	I	I.M.	Tropypan (Trophy, Atlanta, USA) CS 9000 (Carestream, Atlanta, USA)	Trophy Imaging (Trophy) CS 3D Imaging (Carestream)	S/L	100–150, 70–90, 3–10	6.6% (Artefacts, open apex, RCT, resorption)	2020–2022
USA	Vista	Americas	P	Ad.M.	CS 9000 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	S	76, 80–85, 10	0.1% (Artefacts)	2022
Venezuela	Caracas	Americas	P	C.B.	CS 9000 (Carestream, Atlanta, USA)	CS 3D Imaging (Carestream)	S	76, 60–90, 2–15	3.0% (Artefacts, open apex, resorption)	2012–2022

RCT, root canal treated.

TABLE 2 - Patient Demographics and Anatomical Characteristics of the Maxillary First Molar

	Demographics						Anatomic configuration	
Region	Sample size (patients)	Ethnic groups	Age (y) Mean ± SD [range]	Proportion of males	Proportion of females	Sample size (teeth)	Single conical root with single root canal	4-rooted configuration
Argentina	156	Mixed (Hispanic and American Natives)	46 ± 14 [22–76]	74 (47.4%)	82 (52.6%)	300	—	2 (0.7%)
Australia	297	Mixed (Asians and Caucasians)	54 ± 13 [15–84]	116 (39.1%)	181 (60.9%)	300	—	—
Azerbaijan	164	Mostly Caucasians	43 ± 13 [14–70]	86 (52.4%)	78 (47.6%)	300	—	5 (1.7%)
Belgium	201	Mixed (Asians, Caucasians and Africans)	49 ± 15 [15–90]	78 (38.8%)	123 (61.2%)	300	—	1 (0.3%)
Brazil	154	Mixed (Caucasians (non-Hispanic) with Africans, American Natives and Asians)	40 ± 17 [13–85]	50 (32.5%)	104 (67.5%)	300	5 (1.7%)	2 (0.7%)
Canada	141	Mixed (Caucasian, Asian, and African-Canadian)	35 ± 16 [11–74]	66 (46.8%)	75 (53.2%)	300	—	1 (0.3%)
Chile	172	Mostly Caucasians (Hispanic origin)	33 ± 15 [10–72]	72 (41.2%)	100 (58.1%)	300	—	—
China	300	Asians (Han ethnicity)	36 ± 11 [14–78]	140 (46.7%)	160 (53.3%)	300	—	—
Colombia	242	Mostly Caucasians (Hispanic origin)	49 ± 15 [18–86]	84 (34.7%)	158 (65.3%)	300	3 (1.0%)	—
Costa Rica	157	Mostly Caucasians (Hispanic origin)	33 ± 7 [18–49]	58 (36.9%)	99 (63.1%)	300	—	—
Ecuador	154	Mostly Caucasians (Hispanic origin)	50 ± 16 [14–83]	65 (42.2%)	89 (57.8%)	300	2 (0.7%)	6 (2.0%)
Egypt	186	Africans (Egyptians)	39 ± 12 [16–78]	71 (38.2%)	115 (61.8%)	300	—	—
England	210	Mostly Caucasians	62 ± 13 [19–91]	89 (42.4%)	121 (57.6%)	300	—	1 (0.3%)
France	199	Mostly Caucasians	44 ± 15 [11–86]	90 (45.2%)	109 (54.8%)	300	—	—
Germany	282	Caucasians	55 ± 13 [19–89]	123 (43.6%)	159 (56.4%)	300	—	2 (0.7%)
Greece	155	Caucasians	49 ± 16 [11–87]	74 (47.7%)	81 (52.3%)	300	—	—
Hungary	209	Mostly Caucasians	45 ± 13 [13–82]	95 (45.5%)	114 (54.5%)	300	1 (0.3%)	—
Iceland	300	Mostly Caucasians	32 ± 14 [16–76]	138 (46.0%)	162 (54.0%)	300	1 (0.3%)	—
India	300	Asians (Indian origin)	40 ± 9 [22–72]	140 (46.7%)	160 (53.3%)	300	1 (0.3%)	—
Israel	197	Mixed (Jewish, Arabs, and Africans)	36 ± 11 [15–64]	97 (49.2%)	100 (50.8%)	300	1 (0.3%)	1 (0.3%)
Italy	165	Mostly Caucasians	30 ± 13 [14–93]	72 (43.6%)	93 (56.4%)	300	—	—
Jamaica	160	Mixed (Africans, Asians, and Caucasians)	30 ± 9 [16–61]	44 (27.5%)	116 (72.5%)	300	—	—
Japan	300	Asians	53 ± 13 [20–87]	126 (42.0%)	174 (58.0%)	300	—	—
Kuwait	185	Mixed (Asians and Caucasians)	41 ± 14 [12–78]	77 (41.6%)	108 (58.4%)	300	—	—
Kyrgyzstan	178	Mostly Asians	37 ± 13 [10–77]	59 (33.1%)	119 (66.9%)	300	—	—
Malaysia	264	Mostly Asians	38 ± 14 [15–77]	117 (44.3%)	147 (55.7%)	300	—	—
Mexico	153	Mostly Caucasians (Hispanic origin)	43 ± 13 [17–73]	52 (34.0%)	101 (66.0%)	300	3 (1.0%)	7 (2.3%)
Nigeria	165	Africans	39 ± 15 [13–83]	78 (47.3%)	87 (52.7%)	300	—	—
Pakistan	172	Asians	34 ± 13 [15–65]	85 (49.4%)	87 (50.6%)	300	—	2 (0.7%)
Paraguay	177	Mostly Caucasians (Hispanic origin)	42 ± 15 [13–79]	75 (42.4%)	102 (57.6%)	300	—	—
Peru	162	Mixed (Hispanic origin and American Natives)	33 ± 14 [16–69]	63 (38.9%)	99 (61.1%)	300	—	—
Portugal	214	Mostly Caucasians	48 ± 13 [19–81]	70 (32.7%)	144 (67.3%)	300	—	—
Romania	205	Mostly Caucasians	36 ± 12 [12–75]	83 (40.5%)	122 (59.5%)	300	3 (1.0%)	2 (0.7%)
Russia	156	Mixed (Russians, Ukrainians, Tatars, Bashkirs, Jews, Belarusians, and Kazakh)	32 ± 11 [12–73]	59 (37.8%)	97 (62.2%)	300	—	—

(*continued on next page*)

TABLE 2 - Continued

Region	Sample size (patients)	Demographics				Sample size (teeth)	Anatomic configuration	
		Ethnic groups	Age (y) Mean ± SD [range]	Proportion of males	Proportion of females		Single conical root with single root canal	4-rooted configuration
Saudi Arabia	175	Mostly Arabs	35 ± 13 [14–74]	78 (44.6%)	97 (55.4%)	300	—	—
South Africa	169	Mixed (Asians of Indian origin, Caucasians, and Africans)	45 ± 17 [11–81]	83 (49.1%)	86 (50.9%)	300	—	1 (0.3%)
South Korea	300	Asians	34 ± 14 [12–84]	163 (54.3%)	137 (45.7%)	300	—	—
Spain	155	Caucasians	40 ± 14 [15–87]	73 (47.1%)	82 (52.9%)	300	—	—
Syria	151	Arabs	41 ± 14 [16–74]	68 (45.0%)	83 (55.0%)	300	—	—
Thailand	229	Asians	42 ± 18 [12–81]	79 (34.5%)	150 (65.5%)	300	—	—
Turkey	183	Mostly Caucasians	32 ± 12 [14–68]	68 (37.2%)	115 (62.8%)	300	—	3 (1.0%)
Uruguay	206	Mixed (Hispanic origin and Africans)	45 ± 15 [11–78]	85 (41.3%)	121 (58.7%)	300	—	—
USA	292	Mostly Caucasians	56 ± 17 [14–98]	134 (45.9%)	158 (54.1%)	300	2 (0.7%)	—
Venezuela	264	Mostly Caucasians (Hispanic origin)	47 ± 15 [15–85]	108 (40.9%)	156 (59.1%)	300	—	1 (0.3%)
Total	8956	Multiethnic	41 ± 13 [10–98]	3805 (42.5%)	5151 (57.5%)	13.200	22 (0.16%)	37 (0.28%)

SD, standard deviation.

interest. The entire group's reliability was calculated using the intraclass correlation coefficient and percentage of agreement. These scores were also individually compared to a consensus result from 2 external nonobserver reviewers using Cohen's kappa value, providing an additional measure of individual reliability. The minimum acceptable reliability threshold for both the intraclass correlation coefficient and Cohen's kappa score was set at 0.61, indicating substantial agreement[18]. If this threshold was not met, participants were invited to review the study protocol and conduct the assessments again. All reliability assessments were conducted by all 44 participants, following the pre-established CBCT imaging screening protocol.

Statistical Analysis

A meta-analysis was performed using a random-effects model (OpenMeta [Analyst] v.10.10 software) (Basagana, 2018) to ascertain the prevalence of single roots with a single root canal and 4-rooted configurations in both maxillary first and second molars taking advantage of the multicenter nature of the present research. The analysis was presented using proportions along with 95% CI forest plots and odds ratios. Metaregression was employed to explore potential sources of heterogeneity. Statistical significance was defined at the 5% level.

RESULTS

Studied Population

A total of 26,400 maxillary teeth, evenly distributed into 2 groups of 13,200 each, underwent screening. For the maxillary first molar, data were collected from 8,956 individuals, with 42.5% males and 57.5% females, and an average age of 41 years (Table 2). Regarding the maxillary second molar, information was gathered from 8,794 patients, with 42.6% males and 57.4% females, and a mean age of 41 years (Table 3).

Single Root with a Single Root Canal Morphology

Globally, the prevalence of a single root with a single root canal morphology in the maxillary first molar was found to be 0.16% (95% CI, 0.1%–0.3%). This varied across regions, with no findings reported in most regions, but reaching 1.7% (95% CI, 0.2%–3.10%) in Brazil (Fig. 1). Meta-analysis results indicated no significant differences in prevalence across different global regions (Supplemental Figure S1) or ethnic groups (Supplemental Figure S2), with all subgroups showing proportions around 0.20% ($P > .05$). Similarly, no significant differences were observed

TABLE 3 - Patient Demographics and Anatomical Characteristics of the Maxillary Second Molar

	Demographics						Anatomic configuration	
Region	Sample size (patients)	Ethnic groups	Age (y) Mean ± SD [range]	Proportion of males	Proportion of females	Sample size (teeth)	Single conical root with single root canal	4-rooted configuration
Argentina	164	Mixed (Hispanic and American Natives)	47 ± 14 [22–76]	77 (47.0%)	87 (53.0%)	300	6 (2.0%)	—
Australia	297	Mixed (Asians and Caucasians)	53 ± 13 [17–83]	114 (38.4%)	183 (61.6%)	300	8 (2.7%)	6 (2.0%)
Azerbaijan	163	Mostly Caucasians	43 ± 13 [14–70]	84 (51.5%)	79 (48.5%)	300	13 (4.3%)	7 (2.3%)
Belgium	185	Mixed (Asians, Caucasians and Africans)	51 ± 14 [16–93]	75 (40.5%)	110 (59.5%)	300	1 (0.3%)	2 (0.7%)
Brazil	153	Mixed (Caucasians (non-Hispanic) with Africans, American Natives and Asians)	40 ± 17 [13–85]	48 (31.4%)	105 (68.6%)	300	9 (3.0%)	4 (1.3%)
Canada	141	Mixed (Caucasian, Asian, and African-Canadian)	36 ± 16 [11–74]	66 (46.8%)	75 (53.2%)	300	4 (1.3%)	1 (0.3%)
Chile	166	Mostly Caucasians (Hispanic origin)	34 ± 15 [11–72]	80 (48.2%)	86 (51.8%)	300	8 (2.7%)	1 (0.3%)
China	300	Asians (Han ethnicity)	36 ± 11 [14–78]	140 (46.7%)	160 (53.3%)	300	9 (3.0%)	—
Colombia	245	Mostly Caucasians (Hispanic origin)	49 ± 14 [16–80]	90 (36.7%)	155 (63.3%)	300	20 (6.7%)	2 (0.7%)
Costa Rica	153	Mostly Caucasians (Hispanic origin)	33 ± 7 [18–49]	55 (35.9%)	98 (64.1%)	300	13 (4.3%)	2 (0.7%)
Ecuador	150	Mostly Caucasians (Hispanic origin)	50 ± 15 [19–83]	62 (41.3%)	88 (58.7%)	300	18 (6.0%)	2 (0.7%)
Egypt	187	Africans (Egyptians)	40 ± 13 [16–82]	69 (36.9%)	118 (63.1%)	300	3 (1.0%)	1 (0.3%)
England	205	Mostly Caucasians	61 ± 13 [19–91]	85 (41.5%)	120 (58.5%)	300	1 (0.3%)	3 (1.0%)
France	183	Mostly Caucasians	45 ± 14 [13–86]	86 (47.0%)	97 (53.0%)	300	2 (0.7%)	3 (1.0%)
Germany	281	Caucasians	55 ± 12 [22–90]	125 (44.5%)	156 (55.5%)	300	3 (1.0%)	8 (2.7%)
Greece	156	Caucasians	48 ± 16 [11–76]	79 (50.6%)	77 (49.4%)	300	9 (3.0%)	6 (2.0%)
Hungary	196	Mostly Caucasians	46 ± 13 [13–81]	79 (40.3%)	117 (59.7%)	300	9 (3.0%)	2 (0.7%)
Iceland	300	Mostly Caucasians	33 ± 14 [16–76]	139 (46.3%)	161 (53.7%)	300	3 (1.0%)	4 (1.3%)
India	300	Asians (Indian origin)	40 ± 9 [22–72]	140 (46.7%)	160 (53.3%)	300	16 (5.3%)	2 (0.7%)
Israel	199	Mixed (Jewish, Arabs, and Africans)	36 ± 11 [15–64]	98 (49.2%)	101 (50.8%)	300	6 (2.0%)	—
Italy	159	Mostly Caucasians	30 ± 13 [14–71]	67 (42.1%)	92 (57.9%)	300	2 (0.7%)	—
Jamaica	160	Mixed (Africans, Asians, and Caucasians)	30 ± 9 [16–61]	44 (27.5%)	116 (72.5%)	300	—	1 (0.3%)
Japan	300	Asians	53 ± 13 [20–87]	126 (42.0%)	174 (58.0%)	300	21 (7.0%)	6 (2.0%)
Kuwait	183	Mixed (Asians and Caucasians)	41 ± 14 [12–78]	77 (42.1%)	106 (57.9%)	300	2 (0.7%)	4 (1.3%)
Kyrgyzstan	161	Mostly Asians	37 ± 13 [14–76]	54 (33.5%)	107 (66.5%)	300	3 (1.0%)	1 (0.3%)
Malaysia	264	Mostly Asians	38 ± 14 [15–77]	116 (43.9%)	148 (56.1%)	300	—	3 (1.0%)
Mexico	155	Mostly Caucasians (Hispanic origin)	43 ± 13 [17–76]	52 (33.5%)	103 (66.5%)	300	7 (2.3%)	1 (0.3%)
Nigeria	164	Africans	40 ± 15 [13–83]	77 (47.0%)	87 (53.0%)	300	2 (0.7%)	—
Pakistan	168	Asians	34 ± 12 [16–65]	78 (46.4%)	90 (53.6%)	300	5 (1.7%)	9 (3.0%)
Paraguay	170	Mostly Caucasians (Hispanic origin)	44 ± 15 [13–81]	74 (43.5%)	96 (56.5%)	300	—	1 (0.3%)
Peru	155	Mixed (Hispanic origin and American Natives)	32 ± 14 [16–69]	57 (36.8%)	98 (63.2%)	300	19 (6.3%)	1 (0.3%)
Portugal	189	Mostly Caucasians	50 ± 12 [19–86]	63 (33.3%)	126 (66.7%)	300	6 (2.0%)	2 (0.7%)
Romania	197	Mostly Caucasians	40 ± 12 [12–86]	80 (40.6%)	117 (59.4%)	300	20 (6.7%)	5 (1.7%)
Russia	154	Mixed (Russians, Ukrainians, Tatars, Bashkirs, Jews, Belarusians, and Kazakh)	32 ± 11 [12–73]	57 (37.0%)	97 (63.0%)	300	9 (3.0%)	—

(*continued on next page*)

TABLE 3 - Continued

Region	Sample size (patients)	Demographics					Anatomic configuration	
		Ethnic groups	Age (y) Mean ± SD [range]	Proportion of males	Proportion of females	Sample size (teeth)	Single conical root with single root canal	4-rooted configuration
Saudi Arabia	165	Mostly Arabs	36 ± 13 [16–74]	75 (45.5%)	90 (54.5%)	300	3 (1.0%)	4 (1.3%)
South Africa	169	Mixed (Asians of Indian origin, Caucasians, and Africans)	45 ± 17 [11–81]	90 (53.3%)	79 (46.7%)	300	5 (1.7%)	2 (0.7%)
South Korea	300	Asians	34 ± 14 [12–84]	163 (54.3%)	137 (45.7%)	300	—	—
Spain	156	Caucasians	40 ± 14 [15–87]	73 (46.8%)	83 (53.2%)	300	19 (6.3%)	2 (0.7%)
Syria	151	Arabs	41 ± 14 [16–74]	68 (45.0%)	83 (55.0%)	300	15 (5.0%)	—
Thailand	221	Asians	44 ± 18 [12–82]	71 (32.1%)	150 (67.9%)	300	10 (3.3%)	3 (1.0%)
Turkey	181	Mostly Caucasians	32 ± 12 [14–68]	60 (33.1%)	121 (66.9%)	300	4 (1.3%)	5 (1.7%)
Uruguay	184	Mixed (Hispanic origin and Africans)	46 ± 14 [12–79]	73 (39.7%)	111 (60.3%)	300	20 (6.7%)	1 (0.3%)
USA	298	Mostly Caucasians	55 ± 16 [16–94]	137 (46.0%)	161 (54.0%)	300	2 (0.7%)	1 (0.3%)
Venezuela	266	Mostly Caucasians (Hispanic origin)	47 ± 14 [16–85]	117 (44.0%)	149 (56.0%)	300	2 (0.7%)	2 (0.7%)
Total	8794	Multiethnic	41 ± 13 [11–94]	3740 (42.6%)	5054 (57.4%)	13.200	338 (2.56%)	109 (0.83%)

SD, standard deviation.

between sexes ($P > .05$) (Supplemental Figure S3). Although males exhibited a slightly higher likelihood of this morphology, the odds ratio was 1.017 (95% CI, 0.591–1.751), which did not reach statistical significance ($P > .05$) (Supplemental Figure S4). Additionally, there were no significant differences observed between age groups (Fig. 3) or between the left and right sides (Supplemental Figure S5).

For the maxillary second molar, the global prevalence was estimated at 2.56% (95% CI, 1.6%–2.8%). This prevalence varied widely, from no findings reported in Jamaica, Malaysia, Paraguay, and South Korea to 7.0% (95% CI, 4.1%–9.9%) in Japan (Fig. 1). When comparing major subgroup regions, the meta-analysis revealed a significantly lower prevalence in the Africa subgroup (1.0% [95% CI, 0.3%–1.6%]) compared to the Americas (2.5% [95% CI, 1.6%–3.4%]) ($P < .05$) (Supplemental Figure S1). Similarly, the African ethnic group also exhibited a lower percentage (0.8% [95% CI, 0.1%–1.5%]) (Supplemental Figure S2). Males were less likely to present a single root with a single root canal, as evidenced by both a significantly lower odds ratio (0.701 [95% CI, 0.526–0.934]) and proportions compared to females ($P < .05$) (Figure 4 and Supplemental Figure S3). There was a trend of increasing prevalence of this anatomy with age, with older individuals showing significantly higher rates ($P < .05$) (Fig. 3). No difference was found when comparing sides ($P > .05$) (Supplemental Figure S5). Additionally, the prevalence of a single root with a single root canal was significantly higher in the maxillary second molar compared to the first molar ($P < .05$) (Supplemental Figure S6).

Four-rooted Morphology

The global prevalence of a 4-rooted configuration was found to be 0.28% (95% CI, 0.1%–0.3%) for the maxillary first molar, with Mexico exhibiting the highest prevalence (2.3% [95% CI, 0.6%–4.0%]) (Fig. 2). Similarly to the single root with a single root canal morphology, the meta-analysis did not find any statistically significant differences in the prevalence of 4-rooted configurations in the maxillary first molar when comparing subpopulations from different major geographic regions, ethnic groups, sexes (neither in proportions nor odds ratio), or sides ($P > .05$) (Supplemental Figures S1–S5). The worldwide prevalence of a 4-rooted configuration for the maxillary second molar was 0.83% (95% CI, 0.4%–0.9%), with Pakistan exhibiting the highest percentages (3.0% [95% CI, 1.1%–4.9%]) (Fig. 2). While the meta-analysis based on geographic regions

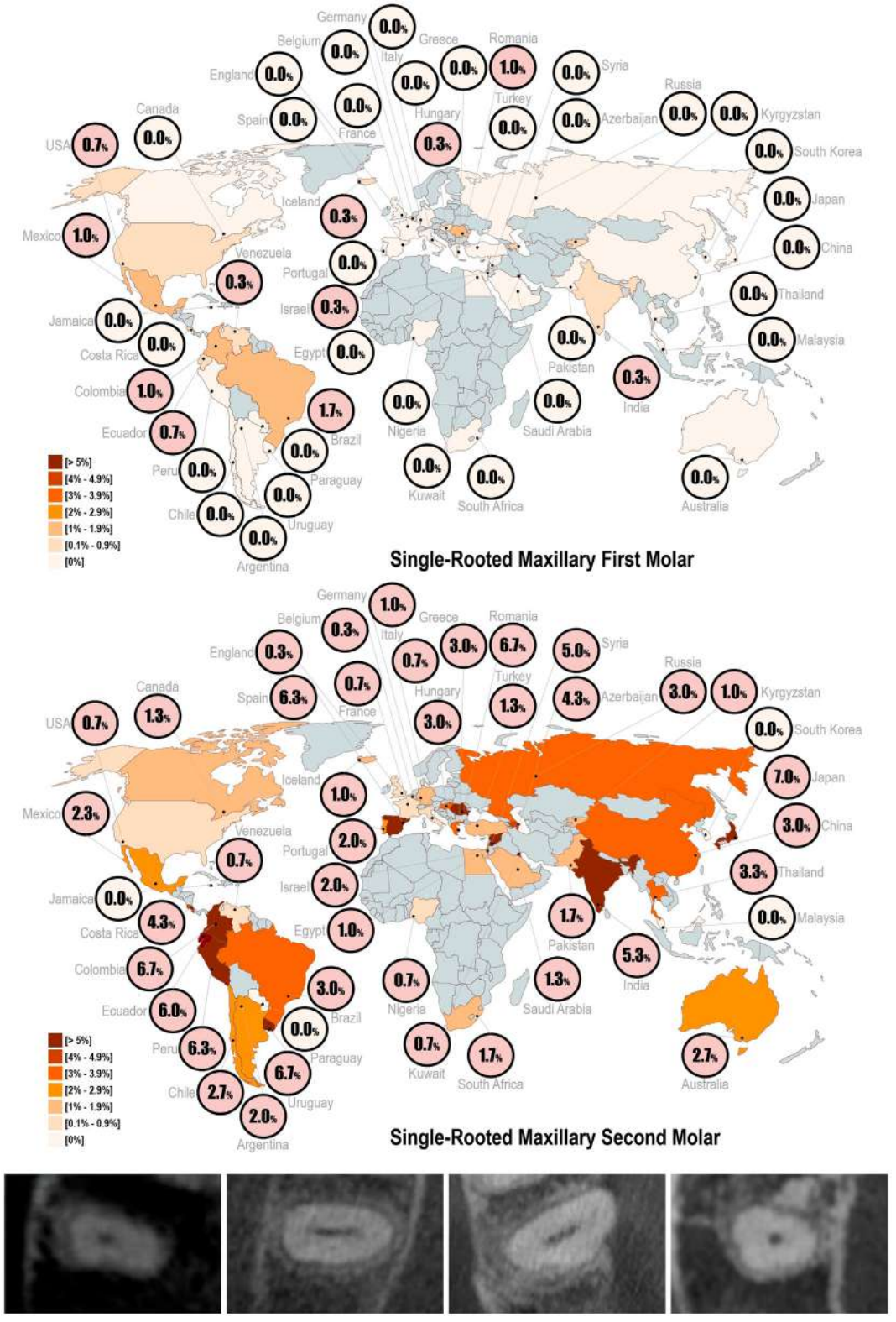

FIGURE 1 – Worldwide maps depicting the prevalence of the single root with single root canal configuration in both maxillary first (top) and second (middle) molars. For the first molar, the prevalences are uniformly low, with occasional minor variations in specific countries. In contrast, for the second molar, the African region shows the lowest percentages. Representative images of the screened teeth are shown at the bottom (from left to right: Peru, Syria, Chile, and Spain).

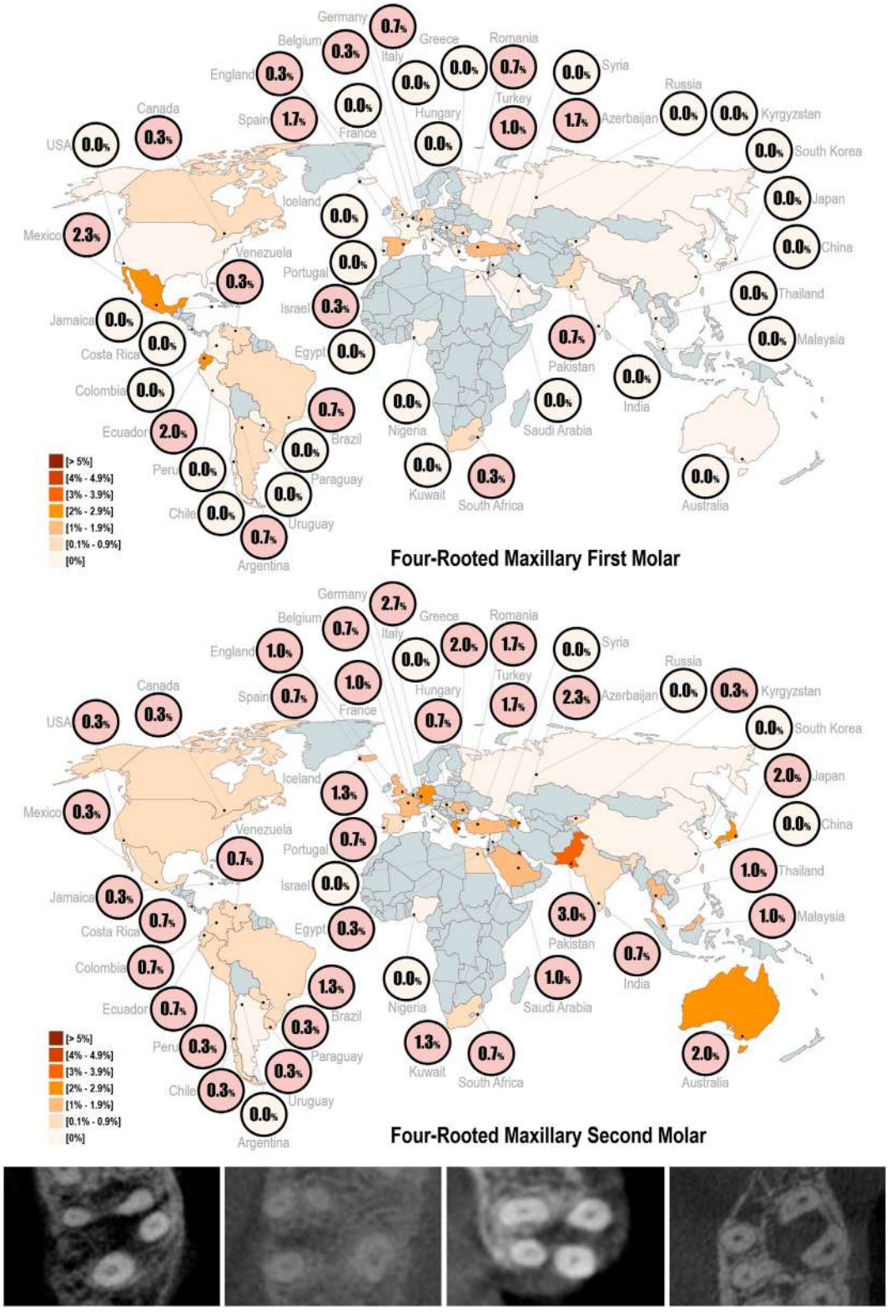

FIGURE 2 – Worldwide maps illustrating the prevalence of four-rooted configurations in both maxillary first (top) and second (middle) molars. The proportions for the first molar were consistently low with minor variations in specific countries. In contrast, for the second molar, Europe, South Asia, the Middle East, and Oceania exhibited higher percentages. Representative images of the analyzed teeth are displayed at the bottom (from left to right: Venezuela, United States, Portugal, and France).

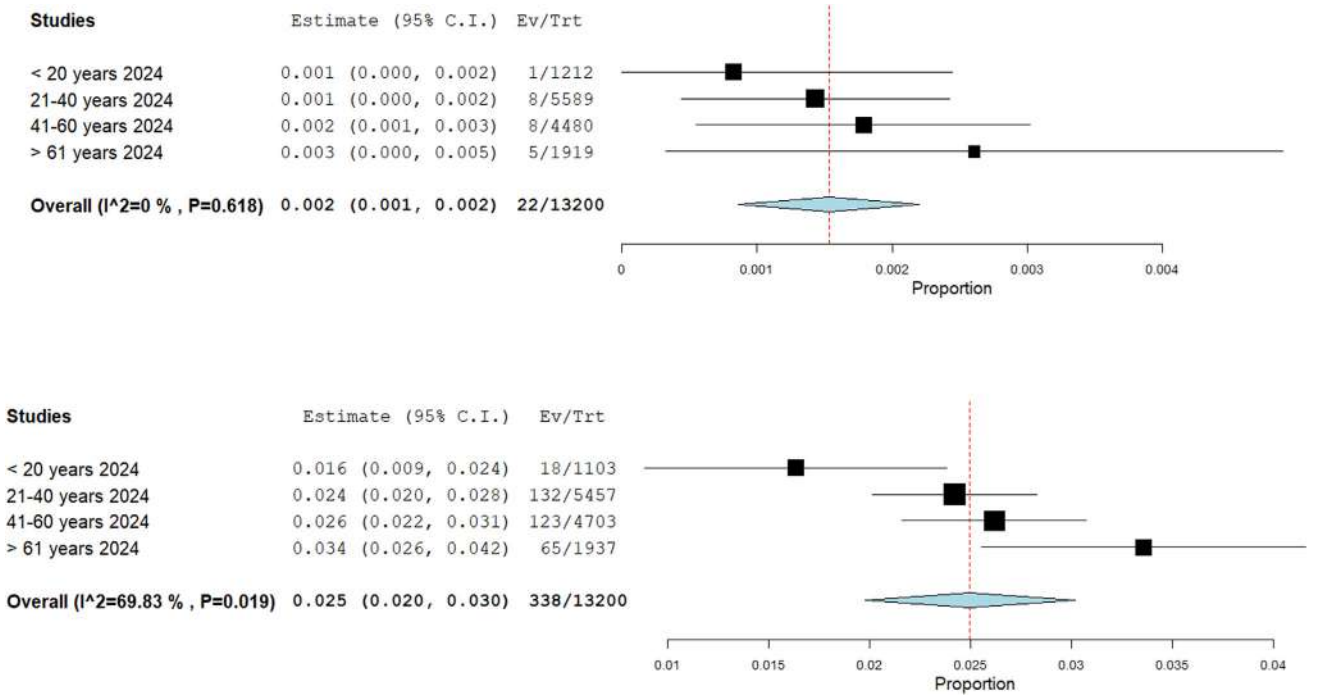

FIGURE 3 – Forest plot charts comparing the prevalence of single roots with a single root canal configuration in both maxillary first (top) and second (bottom) molars across different age groups. In each plot, the size of the black square corresponds to the weight of the region, the horizontal line represents the 95% confidence interval, and the blue diamond indicates the overall results. The graphs illustrate a tendency for the proportions to increase with age.

did not document any statistically significant differences, a noticeable trend towards higher percentages in Europe, South Asia, the Middle East, and Oceania was observed ($P > .05$) (Fig. 5). In terms of ethnic groups, Africans (0.2% [95% CI, 0.0%–0.6%]) showed a significantly lower prevalence compared to Caucasians (1.0% [95% CI, 0.6%–1.3%]) ($P < .05$) (Supplemental Figure S2). Although males had a higher prevalence of this morphology compared to females, the difference was not statistically significant ($P > .05$) (Supplemental Figure S3). However, males exhibited a nonsignificant but higher odds ratio of having a 4-rooted configuration compared to females (1.406 [95% CI, 0.957–2.065]) ($P > .05$) (Supplemental Figure S4). No differences were found when comparing left and right molars ($P > .05$) (Supplemental Figure S5). Once again, the maxillary second molar showed significantly higher proportions of 4-rooted morphologies compared to the first molar ($P < .05$) (Supplemental Figure S6).

Voxel Size and FOV

The metaregression analysis revealed that both voxel size and FOV were not significant sources of heterogeneity for either single roots with a single root canal (1st molar: Omnibus *P* values for voxel size of 0.894 and FOV of 0.983; 2nd molar: 0.699 and 0.308) or 4-rooted morphologies (1st molar: Omnibus *P* values for voxel size of 0.898 and FOV of 0.736; 2nd molar: 0.781 and 0.905) assessments.

Reliability Measurements Outcomes

External observer consensus and intrarater reliability tests for both morphologies demonstrated substantial agreement (0.61–0.80) among all observers. Inter-rater assessment revealed a high percentage of agreement (99.2%) with nearly perfect agreement (0.958) (Supplemental Table S1).

DISCUSSION

Studying anatomical differences in teeth between sexes is fundamental in forensic anthropology[19,20], aiding in determining biological sex from skeletal remains. Sexual dimorphism in dental features, including crown size, shape, and specific morphological traits, offers valuable clues for sex identification[19–21], invaluable in forensic contexts for reconstructing demographic profiles and resolving medicolegal cases. Additionally, understanding ethnic variations in tooth morphology is vital for elucidating population histories and migration patterns[22]. Anthropological studies have unveiled distinct dental characteristics among various ethnic groups, reflecting their evolutionary paths and adaptive responses to diverse environmental pressures[22–24]. By decoding these morphological signatures, researchers can reconstruct ancestral relationships, trace population movements, and glean insights into the colonization of continents and regions[22]. Beyond its forensic and evolutionary significance, understanding tooth anatomical differences holds profound implications for grasping cultural practices and dietary habits[1,25]. Dental anthropologists have documented how cultural behaviors, like chewing habits, dietary preferences, and dental modification practices, influence tooth morphology over generations[1]. For instance, the prevalence of dental wear patterns linked to specific food processing techniques or cultural rituals underscores the intricate interplay between biology and culture[26]. Thus, understanding tooth anatomical differences between sexes and ethnic groups transcends the domains of forensic science and evolutionary biology. It provides a glimpse into human diversity, revealing adaptive strategies, cultural practices, and historical trajectories that have shaped human evolution. Given the significance of anatomical variations concerning demographic factors and the lack of comprehensive literature on the prevalence of both single roots with a single canal and 4-

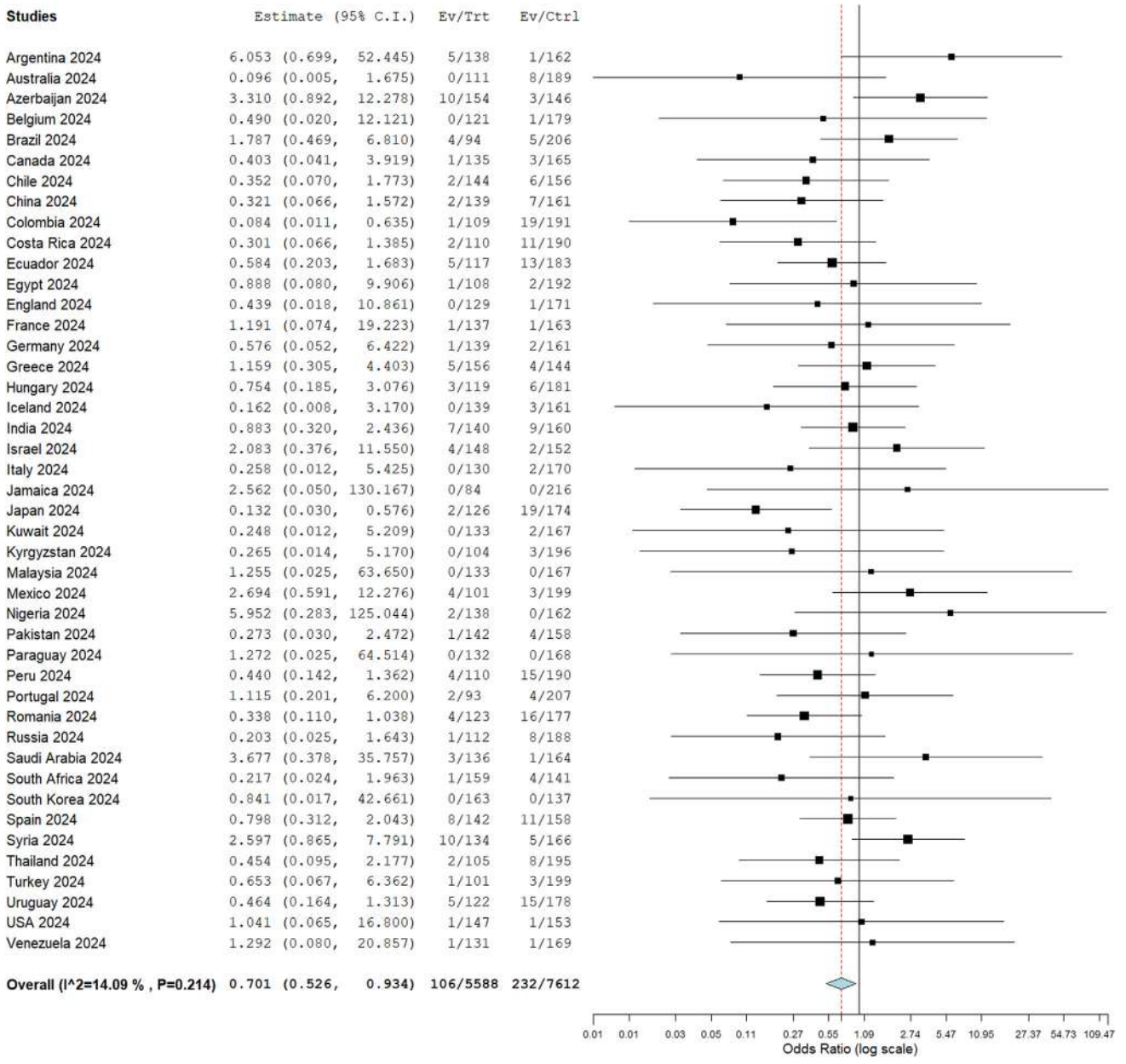

FIGURE 4 – Odds ratio forest plot for the prevalence of single roots with a single root canal configuration in the maxillary second molar, comparing male (Ev/Trt) and female (Ev/Ctrl) patients. The plot indicates that males have significantly lower odds of presenting this anatomy compared to females.

rooted configurations in maxillary molars, the present study aimed to analyze the global proportions of these 2 anatomies. Differences between geographic regions, sexes, and ethnic and age groups were identified, leading to the rejection of the null hypothesis.

Previous studies have indicated significant ethnic variations in mandibular molar morphology, particularly concerning the presence of a second distal root in the mandibular first molar and a single conical root in the second molar[27–30]. Prevalence studies have revealed higher incidences of a second distal root in the mandibular first molar among Asian populations, with rates of 25.6% in Taiwan, 22.3% in Korea, and 22.1% in China, contrasting with lower percentages observed in other regions such as 0.5% in Turkey and 0.8% in Spain[4,31]. Similarly, for the single conical root in the mandibular second molar, Korean subpopulations exhibited rates of 43.1%, while Spanish individuals showed 16.5%[4,28]. These morphologies have demonstrated percentages over 20% higher in Asia, leading to their characterization as specific ethnic traits.

In the current study, we examined potential morphological traits in maxillary molars, focusing on single roots with a single canal and 4-rooted configurations. Information on single roots with single canals is scarce, limited to a few prevalence studies[24–32] and case reports[11,15]. Conversely, more studies have reported single-rooted configurations in maxillary molars, with proportions ranging from 0.2% in China[33] to 2.1% in Spain[4] for the first molars, and from 1.6%[3] to 17.7%[34] in China for the second molars. Notably, maxillary molars exhibit a distinct root fusion pattern compared to mandibular molars[8], and single-rooted maxillary molars may manifest various other forms beyond a single root canal[8]. However, in this study, we targeted only single roots with a single canal due to its similarity to mandibular molar fusion and the limited information

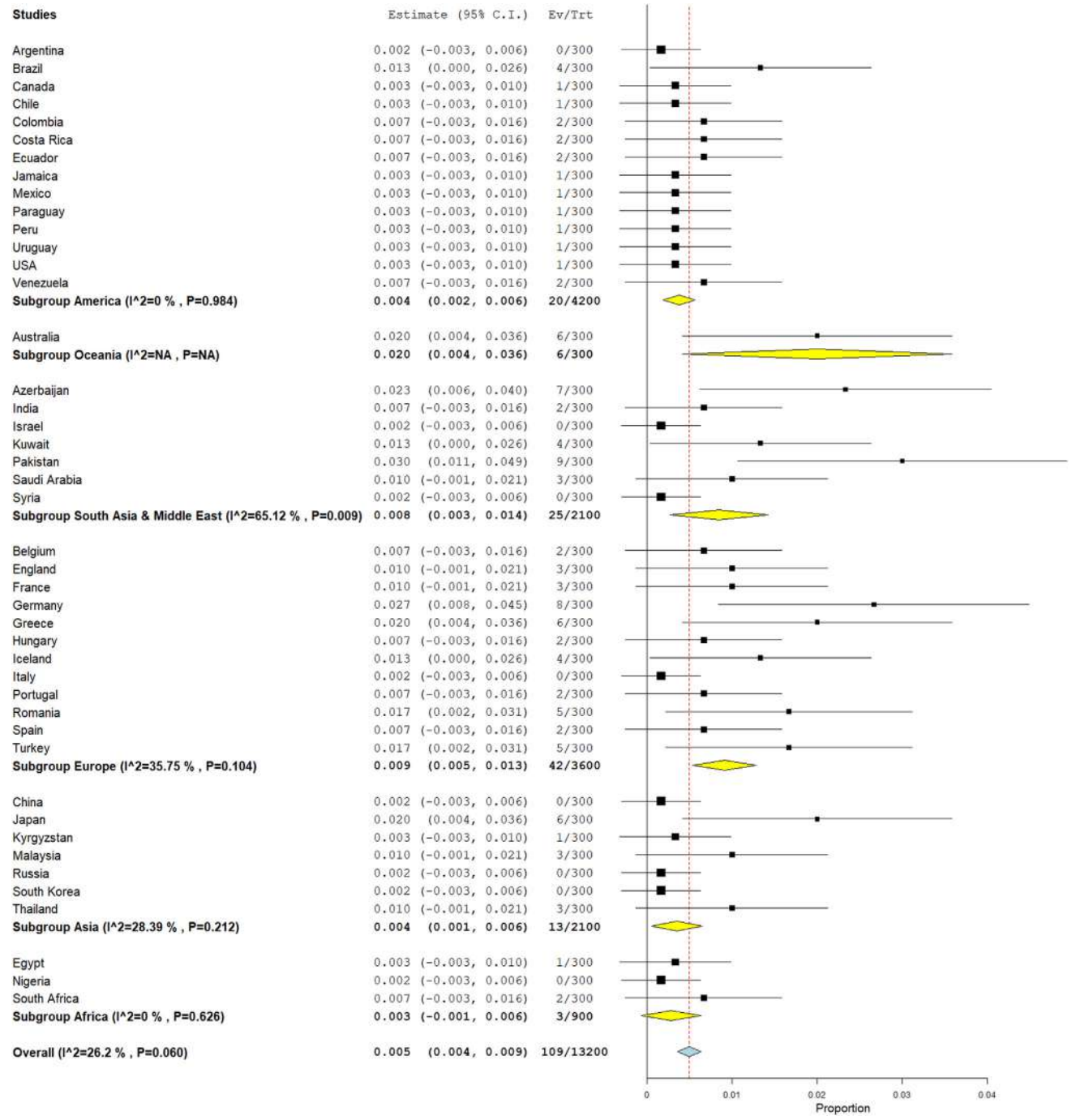

FIGURE 5 – Proportion forest plot chart displaying the prevalence of four-rooted configurations in the maxillary second molar across different geographic locations. Each black square represents the point estimate for a specific region, with its size indicating the weight of that region's data. The horizontal line crossing each square depicts the 95% confidence interval. The yellow diamond denotes the global results within each subgroup, while the blue diamond represents the overall results across all subgroups. While not statistically significant, the subgroups Europe, South Asia, Middle East, and Oceania exhibit a trend toward higher proportions.

available regarding its prevalence in worldwide populations. Previous studies have reported varying proportions of single-rooted configurations with a single root canal in maxillary first molars, ranging from 0% in Brazil[32] to 0.2% in China[33] and 0.8% in Iran[35]. While these studies offer insights into specific regions, they do not provide a comprehensive global perspective. However, they align with our current findings, indicating consistently low proportions across different geographic locations. Similarly, studies examining these morphologies in maxillary second molars have shown proportions of 1.9% in Brazil[32], 1.9%[36] and 2.0%[33] in China, and 3.3% in Taiwan[37]. While these findings are limited to specific areas, they support our observations, particularly regarding the 3% incidence in Brazil and China (Supplemental Figure S1). Notably, there is a lack of data from African countries, preventing direct comparison with our findings suggesting lower proportions in this region.

When considering 4-rooted configurations in maxillary molars, previous

studies, while not focusing primarily on this aspect, have provided data that allow for some prevalence insights. These reports have indicated findings of no 4-rooted configurations in multiple countries, along with proportions of 0.0% in multiple countries[4,38], 0.4% in Egypt, Iceland, and Spain[38], 0.2%[33] and 0.5%[39] in China, and 1.6% in Greece[38] for the maxillary first molar. These findings underscore the consistently low proportions observed across different geographic areas, suggesting a lack of significant differences between these locations. Similarly, for the second molar, proportions of 0.3%[33] and 0.8%[34] in China, 0.5% in Portugal[40], and 0.6% in Iran[41] have been reported, further supporting the low proportions observed in our study.

Previously published information regarding sexes and age groups is scarce. A study from China[34] reported higher percentages of maxillary second molar single root with single root canal configurations in both females and older patients, aligning with our present findings. However, this same study documented higher percentages of 4-rooted configurations in females (0.87%) compared to males (0.68%), contradicting our results. Nevertheless, the trend of males exhibiting a greater number of roots and root canals in their teeth, observed in our study and supported by previous research on various types of teeth[1,42], may be attributed to sexual dimorphism, given that males typically have larger teeth[21], possibly due to enhanced growth of enamel and dentin stimulated by the Y chromosome[43]. As for the age-related results, they may be linked to physiological and pathological calcification processes that tend to simplify anatomy and accessory microanatomy over time[44], potentially resulting in a clearer definition of the root canal system as a single conical canal in single roots. The lack of differences observed regarding sides, voxel sizes, and FOVs aligns with previous reports[1,42] and allowed us to exclude these variables as potential sources of bias.

The results for the maxillary first molar revealed notably low proportions of both single roots with a single canal (0.16%) and 4-rooted (0.28%) configurations (Table 1). Although the percentages were marginally higher for the maxillary second molar, they remained low at 2.56% and 0.83%, respectively (Table 2). These findings indicate that the traits observed in mandibular molars were not observed in maxillary molars. Despite the statistically significant differences observed across regions, sexes, and age groups, the percentages were so minimal that they might be considered clinically insignificant. However, even rare configurations can hold clinical significance for several reasons. Awareness of these variations can aid clinicians in diagnosing and treating patients more effectively, ensuring optimal care provision. Moreover, dental anomalies may sometimes mimic pathological conditions or complicate treatment planning. Familiarity with uncommon configurations can enhance both accurate diagnosis and treatment planning. Furthermore, comprehending anatomical anomalies or rare conditions enriches the dental literature and education, offering valuable insights for researchers exploring dental morphology, development, genetics, and evolutionary biology. Simultaneously, in forensic dentistry, even rare dental variations can be crucial for identifying individuals, as these dental conditions can serve as unique identifiers in forensic investigations. Dental anomalies and rare conditions also offer insights into the evolutionary history of humans, with the study of these variations helping researchers understand how dental traits have evolved, providing a deeper evolutionary perspective. Additionally, knowledge of these rare anatomical conditions enhances patient communication. Explaining rare conditions to patients can improve their understanding of their oral health and alleviate any concerns they may have about their dental anatomy by assuring them that their condition, although rare, is not necessarily abnormal or harmful. In summary, every dental anatomical variation, regardless of its rarity, contributes to the overall understanding of dental science and plays a significant role in patient care, research, education, and forensic investigations.

Given the limited coverage of geographic regions and low percentages reported in previous studies, a comprehensive assessment of both single-rooted configurations and 4-rooted configurations in maxillary molars requires 2 key study design features: extensive representation of geographic regions to identify potential ethnic-specific traits and a substantial sample size to enable robust statistical analysis, particularly for potentially low prevalence rates. The present research incorporated both of these study design characteristics, which can be viewed as significant strengths of the study. One challenge of conducting multicenter studies is ensuring consistency in the methodological approach among all observers. To address this potential bias, observers were carefully chosen based on their extensive experience in endodontics, and the primary outcome was simplified to a binary response (the presence or absence of a specific anatomy). Additionally, to minimize the potential variability related to different CBCT scanners, the voxel size was limited, and a specific step-by-step protocol was designed to make the assessment more dependent on the observer and less on the scanner itself. Furthermore, multiple assessments of both intrarater and inter-rater reliability were performed to ensure the reliability of the results. Consequently, methodological consistency in imaging assessment was confirmed across all centers in the 44 countries, allowing for statistical comparisons in meta-analysis to explore potential variations and confounding factors, consistent with previous studies of a similar nature[1,42,45,46]. Another limitation of the study was the classification of ethnic groups based on patients' profiles, a methodology consistent with previous publications[1,42]. It is essential to note that conducting genetic tests on the large number of individuals involved in the study would have been impractical. However, given the multiple reliability tests conducted and the large sample size, both internal and external validity may be considered high, allowing for a secure generalization of the results. Future studies should aim to explore additional morphologies and investigate more regions in Africa and Oceania, which were less represented in the present study, and a deeper understanding of the environmental and genetic factors influencing tooth morphology variations across different regions and populations would be welcome.

CONCLUSIONS

The prevalence of both single roots with a single root canal and 4-rooted configurations in maxillary molars was found to be low, with rates of 0.16% and 0.28% for the first molar, and 2.56% and 0.83% for the second molar, respectively. While no significant differences were observed among demographic groups for the first molar, notable variations emerged for the second molar. Specifically, males exhibited lower percentages of single roots with single root canals and higher rates of 4-rooted configurations compared to females. Regions in Africa tended to have lower proportions of both anatomies. Additionally, older individuals demonstrated a higher prevalence of single roots with a single canal for both teeth. Factors such as side, voxel size, and FOV did not influence the results.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Jorge N.R. Martins: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing – original draft. **Pablo Ensinas:** Methodology, Investigation, Resources, Writing – review & editing. **Francis**

Chan: Methodology, Investigation, Resources, Writing – review & editing. **Narin Babayeva:** Methodology, Investigation, Resources, Writing – review & editing. **Murilo von Zuben:** Methodology, Investigation, Resources, Writing – review & editing. **Luiza Berti:** Methodology, Investigation, Resources, Writing – review & editing. **Ernest W.N. Lam:** Methodology, Investigation, Resources, Writing – review & editing. **Rodrigo Villanueva:** Methodology, Investigation, Resources, Writing – review & editing. **Fan Pei:** Methodology, Investigation, Resources, Writing – review & editing. **Catalina Mendez de la Espriella:** Methodology, Investigation, Resources, Writing – review & editing. **Walter Vargas:** Methodology, Investigation, Resources, Writing – review & editing. **Juan Carlos Izquierdo Camacho:** Methodology, Investigation, Resources, Writing – review & editing. **Moataz-Bellah A.M. Alkhawas:** Methodology, Investigation, Resources, Writing – review & editing. **Tiago Pimentel:** Methodology, Investigation, Resources, Writing – review & editing. **Fábio Santiago:** Methodology, Investigation, Resources, Writing – review & editing. **Hans Willi Herrmann:** Methodology, Investigation, Resources, Writing – review & editing. **Antonis Chaniotis:** Methodology, Investigation, Resources, Writing – review & editing. **Gergely Benyocs:** Methodology, Investigation, Resources, Writing – review & editing. **Magnús F. Ragnarsson:** Methodology, Investigation, Resources, Writing – review & editing. **Jojo Kottoor:** Methodology, Investigation, Resources, Writing – review & editing. **Avi Shemesh:** Methodology, Investigation, Resources, Writing – review & editing. **Raffaella Castagnola:** Methodology, Investigation, Resources, Writing – review & editing. **Sriteja Tummala:** Methodology, Investigation, Resources, Writing – review & editing. **Satoru Matsunaga:** Methodology, Investigation, Resources, Writing – review & editing. **Arina Maksimova:** Methodology, Investigation, Resources, Writing – review & editing. **Hani Ounsi:** Methodology, Investigation, Resources, Writing – review & editing. **Abhishek Parolia:** Methodology, Investigation, Resources, Writing – review & editing. **Ruben Rosas Aguilar:** Methodology, Investigation, Resources, Writing – review & editing. **Olabisi H. Oderinu:** Methodology, Investigation, Resources, Writing – review & editing. **Muhammad Rizwan Nazeer:** Methodology, Investigation, Resources, Writing – review & editing. **Carlos Heilborn:** Methodology, Investigation, Resources, Writing – review & editing. **Christian Nole:** Methodology, Investigation, Resources, Writing – review & editing. **Sergiu Nicola:** Methodology, Investigation, Resources, Writing – review & editing. **Elena Lipatova:** Methodology, Investigation, Resources, Writing – review & editing. **Hussam Alfawaz:** Methodology, Investigation, Resources, Writing – review & editing. **Hussein C. Seedat:** Methodology, Investigation, Resources, Writing – review & editing. **Seok Woo Chang:** Methodology, Investigation, Resources, Writing – review & editing. **Jose Antonio Gonzalez:** Methodology, Investigation, Resources, Writing – review & editing. **Zaher Altaki:** Methodology, Investigation, Resources, Writing – review & editing. **Danuchit Banomyong:** Methodology, Investigation, Resources, Writing – review & editing. **Ali Keles:** Methodology, Investigation, Resources, Writing – review & editing. **Iliana Modyeievsky:** Methodology, Investigation, Resources, Writing – review & editing. **Adam Monroe:** Methodology, Investigation, Resources, Writing – review & editing. **Carlos Boveda:** Validation, Writing – original draft, Writing – review & editing. **Mohammed Turky:** Validation, Writing – original draft, Writing – review & editing. **Emmanuel J.N.L. Silva:** Validation, Writing – original draft, Writing – review & editing. **Michael Solomonov:** Validation, Supervision, Writing – review & editing. **Joe Ben Itzhak:** Conceptualization, Validation, Supervision, Writing – original draft, Writing – review & editing. **Marco A. Versiani:** Conceptualization, Validation, Supervision, Writing – Original draft preparation, Writing – Review and editing.

ACKNOWLEDGMENTS

The authors would like to acknowledge Yongchun Gu (Soochow University, China), Masashi Yamada (Tokyo Dental College, Japan), Masahiro Furusawa (Tokyo Dental College, Japan), Marcia Antúnez (Faculty of Health and Dentistry, Diego Portales University, Chile), András Mócz (private practitioner, Hungary), Uche Iheme (private practitioner, Nigeria), Amy Traore-Shumbusho (private practitioner, Nigeria), Yetunde Braithwaite (private practitioner, Nigeria), Javier De Lima (private practitioner, Uruguay), Guzman Pedreira (private practitioner, Uruguay), Sashi Nallapati (private practitioner, Jamaica), Alexander Soloshenko (private practitioner, Kyrgyzstan), and Tito Enrique Caballero Cruz (private practitioner, Peru) for their help on the development of this study. Additionally, the authors also thank College of Dentistry Research Center, King Saud University, for their support in conducting this project.

The authors deny any conflicts of interest related to this study.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found in the online version at www.jendodon.com (https://doi.org/10.1016/j.joen.2024.06.010).

REFERENCES

1. Martins JNR, , Worldwide Anatomy Research Group, Versiani MA. Worldwide assessment of the root and root canal characteristics of maxillary premolars – a multi-center cone-beam computed tomography cross-sectional study with meta-analysis. J Endod 2024;50:31–54.
2. Makady A, de Boer A, Hillege H, et al. What is real-world data? a review of definitions based on literature and stakeholder interviews. Value Health 2017;20:858–65.
3. Ghobashy AM, Nagy MM, Bayoumi AA. Evaluation of root and canal morphology of maxillary permanent molars in an Egyptian population by cone-beam computed tomography. J Endod 2017;43:1089–92.
4. Perez-Heredia M, Ferrer-Luque CM, Bravo M, et al. Cone-beam computed tomographic study of root anatomy and canal configuration of molars in a Spanish population. J Endod 2017;43:1511–6.

5. Patel S, Brown J, Pimentel T, et al. Cone beam computed tomography in endodontics - a review of the literature. Int Endod J 2019;52:1138–52.
6. Pereira B, Martins JNR, Baruwa AO, et al. Association between endodontically treated maxillary and mandibular molars with fused roots and periapical lesions: a cone-beam computed tomography cross-sectional study. J Endod 2020;46:771–7.
7. Martins JN, Mata A, Marques D, Carames J. Prevalence of root fusions and main root canal merging in human upper and lower molars: a cone-beam computed tomography *in vivo* study. J Endod 2016;42:900–8.
8. Zhang Q, Chen H, Fan B, et al. Root and root canal morphology in maxillary second molar with fused root from a native Chinese population. J Endod 2014;40:871–5.
9. Gu Y, Wang W, Ni L. Four-rooted permanent maxillary first and second molars in a Northwestern Chinese population. Arch Oral Biol 2015;60:811–7.
10. Versiani MA, Pecora JD, de Sousa-Neto MD. Root and root canal morphology of four-rooted maxillary second molars: a micro-computed tomography study. J Endod 2012;38:977–82.
11. Fava LR, Weinfeld I, Fabri FP, Pais CR. Four second molars with single roots and single canals in the same patient. Int Endod J 2000;33:138–42.
12. Ajeti N, Vula V, Apostolska S, et al. Maxillary second molar with single root and single canal - case report. Open J Stomatol 2015;5:47–52.
13. Libfeld H, Rotstein I. Incidence of four-rooted maxillary second molars: literature review and radiographic survey of 1,200 teeth. J Endod 1989;15:129–31.
14. Peikoff MD, Christie WH, Fogel HM. The maxillary second molar: variations in the number of roots and canals. Int Endod J 1996;29:365–9.
15. Shin SJ, Park JW, Lee JK, Hwang SW. Unusual root canal anatomy in maxillary second molars: two case reports. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:e61–5.
16. AAE and AAOMR joint position statement: use of cone beam computed tomography in endodontics 2015 update. Oral Surg Oral Med Oral Pathol Oral Radiol 2015;120:508–12.
17. Martins JNR, Kishen A, Marques D, et al. Preferred reporting items for epidemiologic cross-sectional studies on root and root canal anatomy using cone-beam computed tomographic technology: a systematized assessment. J Endod 2020;46:915–35.
18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159–74.
19. Capitaneanu C, Willems G, Thevissen P. A systematic review of odontological sex estimation methods. J Forensic Odontostomatol 2017;2:1–19.
20. Noss JF, Scott GR, Potter RH, et al. The influence of crown size dimorphism on sex differences in the carabelli trait and the canine distal accessory ridge in man. Arch Oral Biol 1983;28:527–30.
21. Lakhanpal M, Gupta N, Rao N, Vashisth S. Tooth dimension variations as a gender determinant in permanent maxillary teeth. J Sci Med Dent 2013;1:1014–9.
22. Hanihara T. Geographic structure of dental variation in the major human populations of the world. In: Scott R, Irish J, editors. Anthropological Perspectives on Tooth Morphology. Genetics, Evolution, Variation. 1st ed. New York, NY: Cambridge University Press; 2013. p. 479–509.
23. Martins JNR, , Worldwide Anatomy Research Group, Versiani MA. Worldwide prevalence of the lingual canal in mandibular incisors: a multicenter cross-sectional study with meta-analysis. J Endod 2023;49:819–35.
24. Yaacob H, Nambiar P, Naidu MD. Racial characteristics of human teeth with special emphasis on the mongoloid dentition. Malays J Pathol 1996;18:1–7.
25. Potter RH, Yu PL, Dahlberg AA, et al. Genetic studies of tooth size factors in Pima Indian families. Am J Hum Genet 1968;20:89–100.
26. Xing S, Zhou M, Liu W. Crown morphology and variation of the lower premolars of Zhoukoudian Homo erectus. Chin Sci Bull 2009;54:3905–15.
27. Martins JNR, Nole C, Ounsi HF, et al. Worldwide assessment of the mandibular first molar second distal root and root canal: a cross-sectional study with meta-analysis. J Endod 2022;48:223–33.
28. Park JB, Kim N, Park S, et al. Evaluation of root anatomy of permanent mandibular premolars and molars in a Korean population with cone-beam computed tomography. Eur J Dent 2013;7:94–101.

29. Tu MG, Huang HL, Hsue SS, et al. Detection of permanent three-rooted mandibular first molars by cone-beam computed tomography imaging in Taiwanese individuals. J Endod 2009;35:503–7.

30. Zhang X, Xiong S, Ma Y, et al. A cone-beam computed tomographic study on mandibular first molars in a Chinese subpopulation. PLoS One 2015;10:e0134919.

31. Nur BG, Ok E, Altunsoy M, et al. Evaluation of the root and canal morphology of mandibular permanent molars in a south-eastern Turkish population using cone-beam computed tomography. Eur J Dent 2014;8:154–9.

32. Silva EJ, Nejaim Y, Silva AI, et al. Evaluation of root canal configuration of maxillary molars in a Brazilian population using cone-beam computed tomographic imaging: an *in vivo* study. J Endod 2014;40:173–6.

33. Wang H, Ci B, Yu H, et al. 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;10:7030–9.

34. Wu D, Zhang G, Liang R, et al. Root and canal morphology of maxillary second molars by cone-beam computed tomography in a native Chinese population. J Int Med Res 2017;45:830–42.

35. Abed M, Kolahdouzn S, Hashemi S. Usage of cone-beam comouted tomography (CBCT) to evaluate root and canal morphology of maxillary first molar. Bull Env Pharmacol Life Sci 2013;2:19–23.

36. Zhang R, Yang H, Yu X, et al. Use of CBCT to identify the morphology of maxillary permanent molar teeth in a Chinese subpopulation. Int Endod J 2011;44:162–9.

37. Lin Y, Lin H, Chen C, Chen M. Evaluation of the root and canal systems of maxillary molars in Taiwanese patients: a cone beam computed tomography study. Biomed J 2017;40:232–8.

38. Martins JNR, Alkhawas MAM, Altaki Z, et al. Worldwide analyses of maxillary first molar second mesiobuccal prevalence: a multicenter cone-beam computed tomographic study. J Endod 2018;44:1641–9.

39. Jing YN, Ye X, Liu DG, et al. [Cone-beam computed tomography was used for study of root and canal morphology of maxillary first and second molars]. Beijing Da Xue Xue Bao Yi Xue Ban 2014;46:958–62.

40. Martins JNR, Gu Y, Marques D, et al. Differences on the root and root canal morphologies between Asian and white ethnic groups analyzed by cone-beam computed tomography. J Endod 2018;44:1096–104.

41. Khademi A, Zamani Naser A, Bahreinian Z, et al. Root morphology and canal configuration of first and second maxillary molars in a selected Iranian population: a cone-beam computed tomography evaluation. Iran Endod J 2017;12:288–92.

42. Martins JNR, Zhang Y, von Zuben M, et al. Worldwide prevalence of a lingual canal in mandibular premolars: a multicenter cross-sectional study with meta-analysis. J Endod 2021;47:1253–64.

43. Alvesalo L. The expression of human sex chromossome genes in oral and craniofacial growth. In: Scott GR, Irish J, editors. Anthropological Perspectives on Tooth Morphology. Genetics, Evolution, Variation. 1st ed. New York, NY: Cambridge University Press; 2013. p. 92–107.

44. Alak SG, Keles A, Keskin C, et al. Age-related changes in the morphology of the root canal system of mandibular first molars: a micro-CT study. Clin Oral Investig 2023;27:4667–75.

45. Basagana X, Pedersen M, Barrera-Gomez J, et al. Analysis of multicentre epidemiological studies: contrasting fixed or random effects modelling and meta-analysis. Int J Epidemiol 2018;47:1343–54.

46. Cesaroni G, Forastiere F, Stafoggia M, et al. Long term exposure to ambient air pollution and incidence of acute coronary events: prospective cohort study and meta-analysis in 11 European cohorts from the ESCAPE project. BMJ 2014;348:f7412.