

# Worldwide Prevalence of a Lingual Canal in Mandibular Premolars: A Multicenter Cross-sectional Study with Meta-analysis



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## ABSTRACT

**Introduction:** The presence of multiple root canals is an important morphologic aspect of mandibular premolars. This study aimed to perform a worldwide analysis on the prevalence of a lingual canal in mandibular premolars and to evaluate its influence on patients' demographics in 23 countries using cone-beam computed tomographic images. **Methods:** Observers from 23 countries were instructed to evaluate cone-beam computed tomographic images of 300 first and 300 second premolars (13,800 teeth) regarding the presence of a lingual canal, canal configuration, and data related to patients' ethnicity, age, and sex following a standardized screening methodology. Intra- and interrater evaluations were performed using the Cohen kappa test and intraclass correlation coefficient. Proportion and odds ratio forest plots were calculated in order to compare groups. Statistical significance was set at 5%. **Results:** Both kappa and intraclass correlation coefficient values were above 0.60, and the percentage of agreement was 94.9% (first premolar) and 97.8% (second premolar). A significant statistical difference was observed between the worldwide proportion of a lingual canal in mandibular first (23.8%; range, 12.0%–32.7%) and second (5.3%; range, 1.0%–15.3%) premolars ( $P < .05$ ). Asians and patients over 60 years old were associated with the lowest proportions of a lingual canal ( $P < .05$ ), whereas Africans and younger groups were associated with the highest proportions ( $P < .05$ ). The prevalence of a lingual canal in males (27.9%) was higher than females (20.0%) for the first premolar only ( $P < .05$ ). Males were associated with 1.533 and 1.597 higher odds of presenting a lingual root canal in the first and second premolars, respectively. **Conclusions:** The worldwide proportion of a lingual root canal was 23.6% and 5.3% for the first and second premolars, respectively. Ethnicity, geographic region, age, and sex had an influence on the outcomes. (*J Endod* 2021;47:1253–1264.)

## KEY WORDS

Anatomy; cone-beam computed tomography; mandibular premolar; meta-analysis; multicenter; prevalence study

In mandibular premolars, several morphologic variations of the root and root canals have been reported in the literature including the presence of radicular grooves, C-shaped configuration<sup>1</sup>, furcation canals<sup>2</sup>, apical ramification<sup>3</sup>, 3-rooted morphology<sup>2</sup>, and double canals<sup>4</sup>. Double canals are usually classified as a Vertucci type V configuration<sup>3</sup> and refer to the presence of a second root canal positioned on the lingual side; they are more likely to be noticed in first premolars<sup>5</sup>. The orifice of the lingual canal usually has a sharp entry angle and is located at the middle (69%) or apical (31%) thirds<sup>5</sup>, which may contribute to it going unnoticed clinically<sup>5</sup>. The relatively high prevalence of this additional canal in mandibular premolars is possibly 1 of the most relevant anatomic features in this group of teeth considering that missed or untreated root canals appeared to have an adverse effect on endodontic outcomes<sup>6</sup>. In the last decade, the root canal configuration of mandibular premolars has been addressed not only in laboratory studies using high-resolution micro-computed tomographic technology<sup>3–5</sup> but also through *in vivo* prevalence

## SIGNIFICANCE

Knowing the worldwide prevalence of a mandibular premolar lingual root canal and the demographic factors that may influence its proportions may help to anticipate possible technical difficulties in root canal treatment. Its prevalence was 23.6% and 5.3% for first and second premolars, respectively. Ethnicity, geographic region, age, and sex had an influence on the results.

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studies using cone-beam computed tomographic (CBCT) imaging<sup>7-9</sup>. A recent systematic review using CBCT assessment found 7 studies from 6 countries reporting the prevalence of the lingual canal in the mandibular first premolar and 5 studies from 4 countries on the second premolar<sup>3</sup>. Although additional data from different populations were published after this review<sup>10-12</sup>, the worldwide prevalence and impact of the lingual canal in mandibular premolars remain unknown in most geographic regions. Moreover, there are no studies evaluating its influence on demographic factors, such as sex, age, or ethnicity, as reported with other anatomic features<sup>13</sup>. Therefore, the aim of the present study was to perform an *in vivo* worldwide analysis regarding the prevalence of a lingual root canal in mandibular premolars and its relationship to patient demographics (ethnicity, age, and sex) using CBCT images. The null hypotheses tested were that there were no differences in the prevalence of the lingual canal in mandibular premolars considering

- (1) geographic regions,
- (2) ethnicity,
- (3) age, and
- (4) sex.

## MATERIALS AND METHODS

### Research Protocol and Sample Size Calculation

This study followed a previous publication that described the preferred reporting items for epidemiologic cross-sectional studies on root and root canal anatomy using CBCT technology<sup>14</sup> and received the previous approval of an ethics committee. The presence of a lingual root canal (the primary outcome) and the canal configuration (the secondary outcome) of mandibular first and second premolars was assessed by 23 specialists in endodontics from 23 different geographic regions using preexisting CBCT images. Before the analysis, all observers were provided simultaneously with written guidelines containing a detailed description of the assessment methodology, a tutorial video explaining step-by-step the screening process of the CBCT data sets for both primary and secondary outcomes, bibliographic references, and group deadlines. The sample size for this study was calculated based on the results of a previous publication that compared 2 specific geographic region groups and used similar methodology<sup>15</sup>. For the primary outcome, considering a power of 80% and an alpha-type error of 0.05, the final sample sizes for the mandibular first and second premolars were 287 (effect size of 8.9) and 233 (effect

size of 4.3), respectively. In order to counterbalance that no sample size calculation was performed for the comparison of the other geographic regions, the number of teeth per group was increased to 300.

### Sample Selection and Data Acquisition

The population in this study included a convenience sample made up of patients attending private practices from 23 different geographic regions. Demographic (ethnicity, age, and sex) and quantitative data were acquired by assessing preexisting CBCT databases containing at least 1 mandibular premolar. CBCT data sets were reviewed consecutively according to their numeric or alphabetic chart order until the sample size for each tooth group ( $n = 300$ ) was reached. Any type of CBCT scanner or field of view was acceptable as long as the voxel size was equal or less than 200  $\mu\text{m}$ ; more than 1 scanner was allowed in each region if the assessment was conducted by the same observer (Table 1). The exclusion criteria were as follows: teeth with previous root canal treatment, root resorption, or incomplete root formation; uncertainty regarding tooth numbering; absence of demographic information; or visualization compromised by imaging artifacts.

### CBCT Imaging Assessment

To evaluate the CBCT images, the axial, coronal, and sagittal planes of each premolar root were aligned to the vertical and horizontal marking lines of the software. Then, each premolar was classified according to its type (first or second premolar), the number of roots (apical split was not considered a multirouted configuration), and the presence of a lingual canal (primary outcome). Additionally, as a secondary outcome, each tooth was classified as having a single canal, 2 independent canals (from the pulp chamber to the apex), 2 confluent canals (2 separate canals leaving the chamber but merging to form a single canal at the apex), or more than 2 canals. For these analyses, observers were allowed to change some visualization settings, such as filters or noise reduction, to improve imaging assessment. In case of doubt, they were asked to consult the main researcher (J.M.) to reach a consensus. All data were recorded in a standard Excel (Microsoft, Redmond, WA) sheet and further screened by the main researcher for nonconformities. Observers were blinded to the other outcomes to avoid any influence bias on their results.

**TABLE 1** - Geographic Location and Cone-beam Computed Tomographic (CBCT) Characteristics of Each Sample

Region	City	Continent	CBCT database	Observer	CBCT Model	CBCT Brand	CBCT Voxel Size	CBCT FOV	Visualization software	Date of CBCT examination acquisition	Patients excluded (reasons)
Australia	Melbourne	Oceania	Private clinic	P.P.	Accuitomo 80	Morita, Kyoto, Japan	160 $\mu$ m	Small	Morita 3D (Morita)	June 2015–April 2018	No exclusions
Belgium	Brussels	Europe	Private clinic	M.Z.	Newtom Giano	Newtom, Verona, Italy	150 $\mu$ m	Small/large	NNT (Newtom)	September 2016–August 2019	6 (artifacts)
Brazil	Campinas	America	University clinic	L.S.	i-CAT	i-CAT, Hatfield, UK	200 $\mu$ m	Large	iCATvision (iCat)	January 2017–March 2019	5 (artifacts)
China	Suzhou	Asia	University clinic	Y.Z.	Kavo 3D eXame	Kavo Sybron, Biberach an der Riss, Germany	200 $\mu$ m	Large	eXame vision (Kavo)	August 2018–August 2019	9 (incomplete root formation)
Costa Rica	San Jose	America	Private clinic	W.V.	X Mind Trium	Acteon, Merignac, France	75 $\mu$ m	Large	X Mind Trium (Acteon)	August 2017–September 2019	15 (artifacts)
Egypt	Cairo	Africa	Private clinic	M.A.	Promax 3D	Planmeca, Helsinki, Finland	75 $\mu$ m/150 $\mu$ m	Small/large	Romexis (Planmeca)	January 2014–August 2019	17 (artifacts)
England	London	Europe	Imaging center	D.F.	Accuitomo 170	Morita	80 $\mu$ m	Small	One Volume Viewer (Morita)	Jan 2016 to Sept 2019	No exclusions
France	Paris	Europe	Private clinic	F.S.	CS9000 Orthophos SL	Carestream, Atlanta, GA	76 $\mu$ m/150 $\mu$ m	Small/large	CS 3D imaging (Carestream)	January 2017–August 2019	5 (artifacts)
Greece	Athens	Europe	Imaging center	A.C.	Newtom VGI	Newtom	150 $\mu$ m	Large	Sidexis (Sirona)	January 2015–August 2019	2 (artifacts)
Iceland	Hafnarfjörður	Europe	Private clinic	M.R.	Promax 3D i-CAT	Planmeca, i-CAT	200 $\mu$ m/200 $\mu$ m	Small/large	NNT (Newtom)	March 2014–August 2019	7 (artifacts)
India	Kochi	Asia	Private clinic	J.K.	Newtom VGI	Newtom	75 $\mu$ m/150 $\mu$ m	Small/large	Romexis (Planmeca) iCATvision (iCat)	August 2017–February 2019	15 (artifacts, incomplete root formation)
Italy	Rome	Europe	Private clinic	G.P.	Toshiba Asteion	LBN Medical, Aalborg, Denmark	200 $\mu$ m	Large	NNT (Newtom)	May 2016–August 2019	15 (artifacts)
Kuwait	Salmiya	Asia	Private clinic	H.O.	Promax 3D	Planmeca	160 $\mu$ m	Large	Romexis (Planmeca)	January 2011–August 2019	15 (artifacts)
Mexico	Léon	America	Private clinic	R.R.A.	OP 300 Maxio	Kavo, Charlotte, NC	85 $\mu$ m	Small	OnDemand (Cybermed)	May 2015–August 2019	3 (artifacts and cut images)
New Zealand	Tauranga	Oceania	Private clinic	I.C.	Hyperion X9 Orthophos XG3D	MyRay, Imola, Italy	80 $\mu$ m/160 $\mu$ m	Small/large	Romexis (Planmeca)	May 2018–September 2019	No exclusions
Peru	Lima	America	Imaging center	C.N.	Point 3D Combi 500S	Sirona, Charlotte, NC	200 $\mu$ m	Large	Sidexis (Sirona)	Jan 2019 to Aug 2019	13 (artifacts)
Portugal	Lisbon	Europe	Private clinic	J.M.	Promax 3D	Planmeca	200 $\mu$ m	Large	Realscan (Pointnix)	Jan 2019 to Aug 2019	13 (artifacts)
Saudi Arabia	Riyadh	Asia	University clinic	H.A.	Promax 3D	Planmeca	200 $\mu$ m	Large	Romexis (Planmeca)	May 2015 to Aug 2019	59 (artifacts)
South Africa	Durban	Africa	Private clinic	H.S.	CS8100	Carestream, Atlanta, USA	150 $\mu$ m	Large	CS 3D imaging (Carestream)	Jan 2019 to Sep 2019	15 (artifacts)
Spain	Barcelona	Europe	Private clinic	J.G.	CS8100 Promax 3D	CarestreamPlanmeca	150 $\mu$ m/200 $\mu$ m	Small/large	CS 3D imaging (Carestream)	March 2014–August 2019	25 (artifacts)
Syria	Damascus	Asia	Imaging center	Z.A.	Scanora 3D	Soredex, Tuusula, Finland	200 $\mu$ m	Large	Romexis (Planmeca)	February 2016–December 2018	7 (artifacts)
United States	San Diego	America	Private clinic	A.M.	CS9000	Carestream	76 $\mu$ m	Small	Scanora 3D (Soredex)	February 2016–December 2018	7 (artifacts)
Venezuela	Caracas	America	Private clinic	C.B.	CS9000	Carestream	76 $\mu$ m	Small	CS 3D imaging (Carestream)	June 2018–January 2019	5 (artifacts)
									KDIS (Carestream)	April 2010–August 2019	6 (artifacts)

FOV, field of view.

## Observer Reliability

Intra- and interrater evaluations were performed before the assessment of the selected CBCT databases. The intrarater reliability was assessed between 2 subsequent repeated records (1-month interval) taken by the observers (first and second evaluations) on the analysis of 10% of randomly selected teeth ( $n = 30$  premolars) regarding the presence of a lingual canal (primary outcome) acquired from their own CBCT databases. The Cohen kappa test was used to measure the reliability of each observer. For interrater analysis, all observers evaluated the same 10 CBCT large field of view data sets (not included in the final analysis) containing 18 mandibular premolars from each group ( $n = 36$ ) regarding the presence of a lingual canal according to the data assessment protocol during the same time window. The interrater reliability was measured by both the intraclass correlation coefficient (ICC) and the percentage of agreement. Additionally, these results obtained from each observer were compared with a consensus classification reached by 2 experienced external evaluators using the Cohen kappa test. If the ICC and kappa values were below 0.60 for the primary outcome in the intra- and/or interrater evaluations, the observer was asked to review the research protocol and to repeat the evaluation.

## Statistical Analysis

Considering the multicenter nature of the present study, a meta-analysis was conducted based on a random effects model<sup>16</sup>. Data were analyzed using OpenMeta[Analyst] v. 10.10 software (<http://www.cebm.brown.edu/openmeta/>), and the results for the primary outcome (the presence of a lingual canal) were presented as forest plots displaying the odds ratio and untransformed proportions with a 95% confidence interval (CI). Meta-regression was used to understand the possible sources of heterogeneity. Statistical significance was set at  $P < .05$ .

## RESULTS

Supplemental Table S1 (available online at [www.jendodon.com](http://www.jendodon.com)) shows that all intra- and interrater kappa values were above 0.60, whereas the ICC and percentage of agreement values were 0.988 and 94.9% (first premolar) and 0.991 and 97.8% (second premolar). Imaging voxel size meta-regression showed an almost constant proportion of a lingual root canal when comparing results using different voxel sizes (between 75 and 200  $\mu\text{m}$ ) for both premolars (Supplemental Fig. S1 is available online at [www.jendodon.com](http://www.jendodon.com)). Considering the omnibus  $P$  values for the first (0.224) and

second (0.091) premolars, the heterogeneity of the results could not be explained by the image voxel size. Tables 2 and 3 summarize the demographic characteristics of the patients and the root canal configuration of 13,800 mandibular premolars (6900 teeth from each group) from more than 4270 patients. Overall, the worldwide proportion of a lingual canal in the mandibular premolar was 23.8% (95% CI, 21.1%–26.2%), varying from 12.0% (95% CI, 8.3%–15.7% [Australia]) to 32.7% (95% CI, 27.4%–38.0% [Egypt]), whereas a global percentage of 5.3% (95% CI, 4.1%–6.5%) was observed in the second premolars with proportions ranging from 1.0% (95% CI, 0.0%–2.1% [China]) to 15.3% (95% CI, 11.3%–19.4% [Syria]) (Fig. 1; Supplemental Fig. S2 is available online at [www.jendodon.com](http://www.jendodon.com)). The difference in the worldwide proportion of lingual canals observed in the first and second premolar teeth was considered statistically significant ( $P < .05$ ; Supplemental Fig. S2 is available online at [www.jendodon.com](http://www.jendodon.com)).

Data analysis from geographic regions showed that Oceania (16.2% [95% CI, 7.7%–24.7%]) and East Asia (17.3% [95% CI, 13.0%–21.6%]) had the lowest proportions of lingual canals in mandibular first premolars, whereas the highest was observed in Africa (28.4% [95% CI, 20.3%–36.6%]); however, no differences were noted among regions ( $P > .05$ , Fig. 2). For the second premolar, the differences were significant ( $P < .05$ ), with the lowest proportions found in East Asia (1.0% [95% CI, 0.0%–2.1%]) and Oceania (3.8% [95% CI, 1.3%–6.4%]) and the highest percentages ( $>6\%$ ) in Europe, Africa, and West Asia (Fig. 2). Regarding ethnicity, some mixed groups (Brazil, Kuwait, New Zealand, and South Africa) were excluded from the analysis because of their ethnic diversity. Asians showed the lowest proportions of a lingual canal for both groups of teeth compared with the other ethnic groups ( $P < .05$ , Fig. 3). Older patients ( $>60$  years old) also presented lower proportions compared with younger groups, but a statistical significance was only reached for the first premolar ( $P < .05$ ; Supplemental Fig. S3 is available online at [www.jendodon.com](http://www.jendodon.com)). In male patients, the prevalence of a lingual canal in the first premolars was 27.9% (95% CI, 24.3%–31.5%), whereas in females it was 20.0% (95% CI, 17.9%–22.1%; Fig. 4). The proportion difference between sexes was considered statistically significant for both premolars ( $P < .05$ , Fig. 4). Moreover, males were associated with significantly higher odds of presenting a lingual canal in both first (1.533 [95% CI, 1.329–1.768]) and second (1.597 [95% CI, 1.287–1.982]) premolars ( $P < .05$ ;

Supplemental Fig. S4 is available online at [www.jendodon.com](http://www.jendodon.com)).

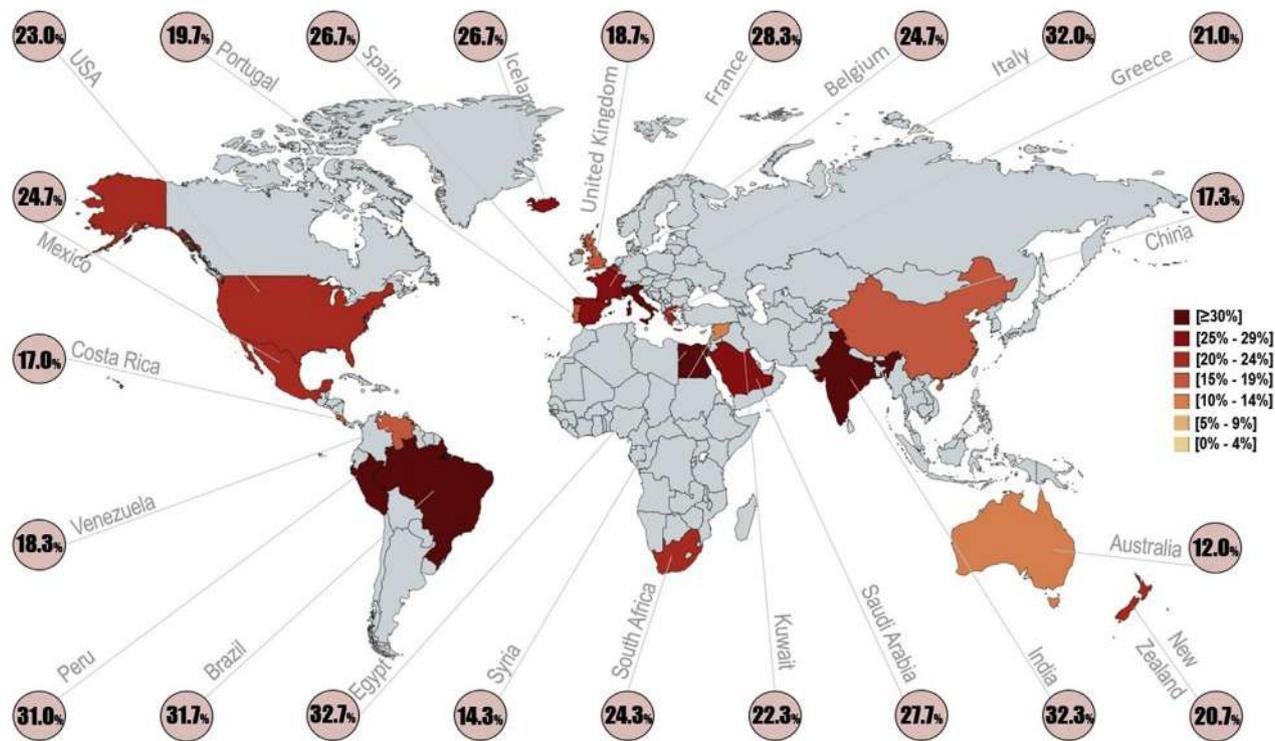
## DISCUSSION

In the present study, an *in vivo* worldwide analysis was performed to evaluate the prevalence of a lingual root canal in mandibular premolars and its relationship to patient demographics by assessing preexisting CBCT databases; thus, no patient was exposed to radiation for the purpose of this research. The multicenter nature of this study and the analytical tool used to access the root and root canal morphologies (CBCT imaging) allowed the evaluation of a large number of teeth ( $N = 13,800$  teeth) that could be distributed into subgroups according to their demographic characteristics while maintaining a high statistical power<sup>14</sup>. This methodological design also enabled exploration of this anatomic variation throughout the world (23 countries), including several geographic regions not assessed in any previous *in vivo* study with a low voxel size (Australia, Belgium, Costa Rica, France, Egypt, Greece, Iceland, India, Kuwait, Mexico, New Zealand, Peru, Saudi Arabia, South Africa, Spain, Syria, United Kingdom, United States, and Venezuela), providing new findings with high external validity. Overall, the mean worldwide prevalence of a lingual canal in the mandibular first premolar was 23.6% (Supplemental Fig. S2 is available online at [www.jendodon.com](http://www.jendodon.com)), a percentage quite similar to the ones reported in previous studies in different countries such as Brazil (19.1%)<sup>17</sup>, Italy (20.8%)<sup>10</sup>, South Korea (21.2%)<sup>11</sup>, Portugal (22.2%)<sup>18</sup>, Taiwan (26.6%)<sup>19</sup>, and Turkey (28.6%)<sup>20</sup>. It should be noted that previous studies on Chinese patients consistently reported lower percentages of this additional anatomy in mandibular premolars (13.2%<sup>9</sup>, 13.4%<sup>15</sup>, and 18.9%<sup>12</sup>) than the average, which is also in line with the outcome of the present investigation (17.3%). On the other hand, some regional analysis did not corroborate with the literature, and high percentages were noted (Brazil: 31.7% and Italy: 32.0%; Fig. 1). Similarly, a higher prevalence of multiple canals in mandibular first premolars was also reported in the German population (78.1%)<sup>7</sup>. However, authors considered apical ramifications as part of the main root canal system, which partially explains this dissimilarity. Regarding the mandibular second premolars, the mean worldwide prevalence of a lingual root canal was 5.3% (Supplemental Fig. S2 is available online at [www.jendodon.com](http://www.jendodon.com)), a significantly lower percentage when compared with first premolars but in agreement with previous investigations<sup>9,15,20</sup>. Again, the results of

**TABLE 2 - Patient Demographics and Root Canal System Configuration of the Mandibular First Premolar**

Region	Demographics					Root canal system configuration of the mandibular first premolar				
	Sample size (patients)	Ethnic groups	Average age, y (range)	Proportion of males, n (%)	Proportion of females, n (%)	Sample size (teeth)	Single canal, n (%)	2 independent canals (multiple exits), n (%)	2 confluent canals (single exit), n (%)	More than 2 canals, n (%)
Australia	234	Mostly Caucasians	55 (15–82)	83 (35.5)	151 (64.5)	300	264 (88.0)	30 (10.0)	6 (2.0)	—
Belgium	169	Mostly Caucasians	52 (17–84)	69 (40.8)	100 (59.2)	300	226 (75.3)	51 (17.0)	18 (6.0)	5 (1.7)
Brazil	162	Mixed (mainly Caucasians [non-Hispanic] with minorities from Africans, Native Americans, and Asians)	48 (16–93)	64 (39.5)	98 (60.5)	300	205 (68.7)	57 (18.7)	24 (8.0)	14 (4.6)
China	155	Asians	34 (14–71)	54 (34.8)	101 (65.2)	300	248 (82.7)	46 (15.3)	5 (1.7)	1 (0.3)
Costa Rica	156	Mostly Caucasians (Hispanic origin)	46 (21–79)	63 (40.4)	93 (59.6)	300	249 (83.0)	34 (11.3)	17 (5.7)	—
Egypt	222	Africans (Egyptians)	32 (14–75)	104 (46.8)	118 (53.2)	300	202 (67.3)	43 (14.3)	53 (17.7)	2 (0.7)
England	152	Mostly Caucasians	56 (15–93)	65 (42.8)	87 (57.2)	300	244 (81.3)	46 (15.3)	2 (0.7)	8 (2.7)
France	160	Mostly Caucasians	43 (16–79)	69 (43.1)	91 (56.9)	300	215 (71.7)	68 (22.7)	15 (5.0)	2 (0.6)
Greece	166	Caucasians	47 (18–82)	81 (48.8)	85 (51.2)	300	237 (79.0)	45 (15.0)	8 (2.7)	10 (3.3)
Iceland	300	Mostly Caucasians	36 (15–81)	126 (42.0)	174 (58.0)	300	220 (73.3)	49 (16.4)	27 (9.0)	4 (1.3)
India	158	South Indians (Dravidians)	42 (14–76)	79 (50.0)	79 (50.0)	300	203 (67.7)	86 (28.7)	10 (3.3)	1 (0.3)
Italy	156	Mostly Caucasians	42 (17–74)	72 (46.2)	84 (53.8)	300	204 (68.0)	50 (16.7)	46 (15.3)	—
Kuwait	191	Mixed (Caucasians and Asians)	40 (15–79)	77 (40.3)	114 (59.7)	300	233 (77.7)	53 (17.7)	13 (4.3)	1 (0.3)
Mexico	233	Caucasians (Hispanic origin)	46 (19–78)	62 (26.6)	171 (73.4)	300	226 (75.3)	51 (17.0)	23 (7.7)	—
New Zealand	161	Mixed (mainly Caucasians with minorities of Dravidians [India], Asians, and Maori)	54 (14–82)	83 (51.6%)	78 (48.4%)	300	238 (79.3%)	27 (9.0)	35 (11.7)	—
Peru	151	Mostly Native Americans (South American Amerindians)	41 (16–84)	69 (45.7)	82 (54.3)	300	207 (69.0)	61 (20.3)	32 (10.7)	—
Portugal	168	Mostly Caucasians	52 (19–86)	67 (39.9)	101 (60.1)	300	241 (80.3)	39 (13.0)	18 (6.0)	2 (0.7)
Saudi Arabia	168	Mostly Arabs	37 (18–82)	82 (48.8)	86 (51.2)	300	217 (72.3)	51 (17.0)	29 (9.7)	3 (1.0)
South Africa	169	Mixed (Asians [Indian origin] and Caucasians, with a minority of indigenous Africans)	47 (15–92)	86 (50.9)	83 (49.1)	300	227 (75.7)	40 (13.3)	31 (10.3)	2 (0.7)
Spain	153	Mostly Caucasians	42 (17–82)	74 (48.4)	79 (51.6)	300	220 (73.4)	16 (5.3)	57 (19.0)	7 (2.3)
Syria	154	Mostly Arabs	30 (16–51)	73 (47.4)	81 (52.6)	300	257 (85.7)	31 (10.3)	12 (4.0)	—
United States	275	Mostly Caucasians	55 (17–93)	123 (44.7)	152 (55.3)	300	231 (77.0)	49 (16.3)	20 (6.7)	—
Venezuela	261	Mostly Caucasians (Hispanic origin)	48 (15–86)	112 (42.9)	149 (57.1)	300	245 (81.6)	26 (8.7)	29 (9.7)	—
Total	4274		45 (14–93)	1837 (43.0)	2437 (57.0)	6900	5259 (76.2)	1049 (15.2)	530 (7.7)	62 (0.9)

## Prevalence of a lingual canal in the mandibular first premolar



## Prevalence of a lingual canal in the mandibular second premolar

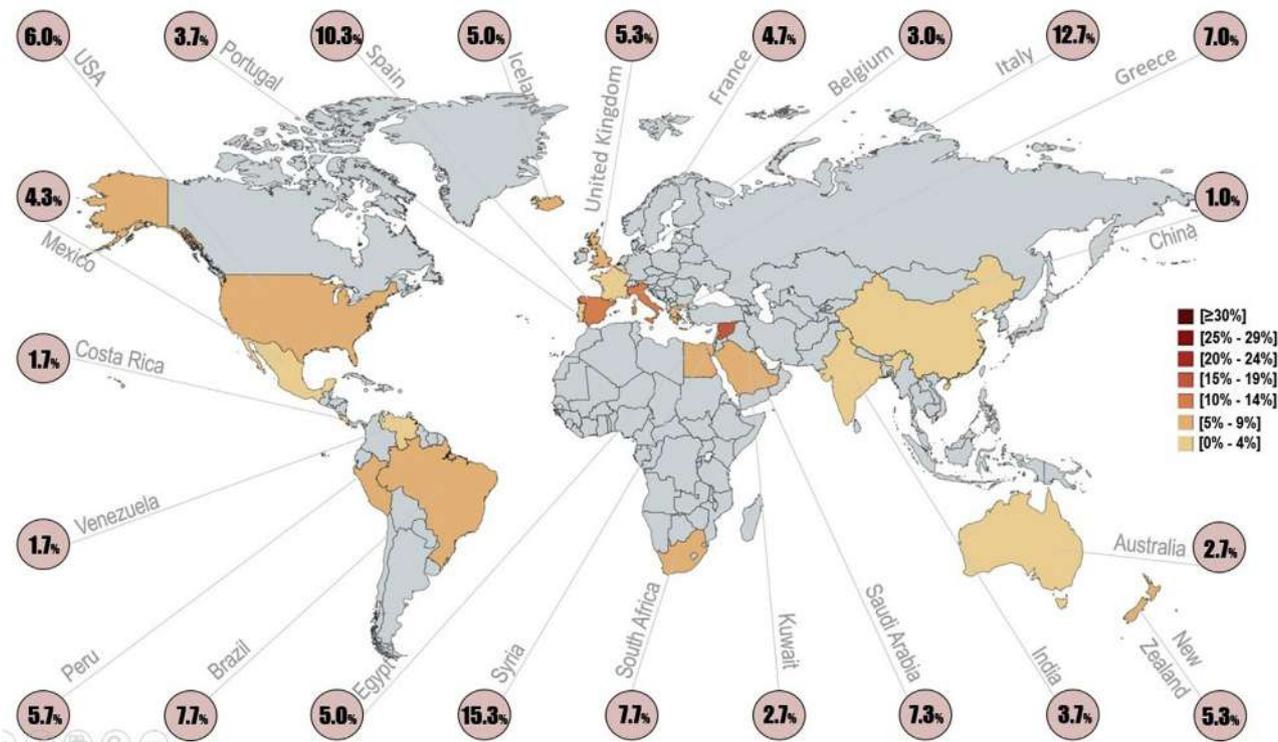


FIGURE 1 – Geographic lingual root canal prevalence on the mandibular first (top) and second premolar (bottom).

**TABLE 3 - Patient Demographics and Root Canal System Configuration of the Mandibular Second Premolar**

Region	Demographics					Root canal system configuration of the mandibular second premolar				
	Sample size (patients)	Ethnic groups	Average age, y (range)	Proportion of males, n (%)	Proportion of females, n (%)	Sample size (teeth)	Single canal, n (%)	2 independent canals (multiple exits), n (%)	2 confluent canals (single exit), n (%)	More than 2 canals
Australia	247	Mostly Caucasians	55 (16–87)	80 (32.4)	167 (67.6)	300	292 (97.3)	8 (2.7)	—	—
Belgium	182	Mostly Caucasians	50 (17–84)	79 (43.4)	103 (56.6)	300	291 (97.0)	4 (1.3)	2 (0.7)	3 (1.0)
Brazil	165	Mixed (mainly Caucasians [non-Hispanic] with minorities from Africans, Native Americans, and Asians)	46 (16–92)	65 (39.4)	100 (60.6)	300	277 (92.3)	6 (2.0)	8 (2.7)	9 (3.0)
China	159	Asians	35 (16–71)	51 (32.1)	108 (67.9)	300	297 (99.0)	1 (0.3)	2 (0.7)	—
Costa Rica	163	Mostly Caucasians (Hispanic origin)	45 (21–79)	68 (41.7)	95 (58.3)	300	295 (98.4)	4 (1.3)	1 (0.3)	—
Egypt	217	Africans (Egyptians)	32 (16–69)	107 (49.3)	110 (50.7)	300	285 (95.0)	3 (1.0)	11 (3.7)	1 (0.3)
England	151	Mostly Caucasians	57 (16–93)	65 (43.0)	86 (57.0)	300	284 (94.6)	12 (4.0)	2 (0.7)	2 (0.7)
France	166	Mostly Caucasians	42 (16–79)	75 (45.2)	91 (54.8)	300	286 (95.3)	10 (3.3)	2 (0.7)	2 (0.7)
Greece	171	Caucasians	47 (18–82)	83 (48.5)	88 [51.5]	300	279 (93.0)	9 (3.0)	6 (2.0)	6 (2.0)
Iceland	300	Mostly Caucasians	36 (15–81)	126 (42.0)	174 (58.0)	300	285 (95.0)	6 (2.0)	6 (2.0)	3 (1.0)
India	158	South Indians (Dravidians)	41 (16–78)	77 (48.7)	81 (51.3)	300	289 (96.3)	11 (3.7)	—	—
Italy	157	Mostly Caucasians	42 (17–74)	75 (47.8)	82 (52.2)	300	262 (87.3)	22 (7.3)	16 (5.3)	—
Kuwait	192	Mixed (Caucasians and Asians)	41 (15–79)	76 (39.6)	116 (60.4)	300	292 (97.3)	5 (1.7)	3 (1.0)	—
Mexico	232	Caucasians (Hispanic origin)	46 (21–78)	91 (39.2)	141 (60.8)	300	287 (95.7)	4 (1.3)	9 (3.0)	—
New Zealand	165	Mixed (mainly Caucasians with minorities of Dravidians [India], Asians, and Maori)	54 (14–89)	86 (52.1)	79 (47.9)	300	284 (94.7)	11 (3.7)	5 (1.6)	—
Peru	155	Mostly Native Americans (South American Amerindians)	41 (17–84)	67 (43.2)	88 (56.8)	300	283 (94.4)	13 (4.3)	4 (1.3)	—
Portugal	181	Mostly Caucasians	51 (19–86)	71 (39.2)	110 (60.8)	300	289 (96.3)	6 (2.0)	5 (1.7)	—
Saudi Arabia	173	Mostly Arabs	37 (19–82)	85 (49.1)	88 (50.9)	300	278 (92.7)	10 (3.3)	8 (2.7)	4 (1.3)
South Africa	181	Mixed (Asians [Indian origin] and Caucasians, with a minority of indigenous Africans)	45 (15–78)	97 (53.6)	84 (46.4)	300	277 (92.3)	8 (2.7)	13 (4.3)	2 (0.7)
Spain	153	Mostly Caucasians	41 (17–82)	74 (48.4)	79 (51.6)	300	269 (89.7)	6 (2.0)	19 (6.3)	6 (2.0)
Syria	154	Mostly Arabs	30 (16–51)	73 (47.4)	81 (52.6)	300	254 (84.7)	33 (11.0)	13 (4.3)	—
United States	284	Mostly Caucasians	57 (17–93)	134 (47.2)	150 (52.8)	300	282 (94.0)	13 (4.3)	5 (1.7)	—
Venezuela	261	Mostly Caucasians (Hispanic origin)	46 (16–89)	111 (42.5)	150 (57.5)	300	295 (98.3)	3 (1.0)	2 (0.7)	—
Total	4367		44 (14–93)	1916 (43.9)	2451 (56.1)	6900	6512 (94.4)	208 (3.0)	142 (2.1)	38 (0.5)

mandibular second premolars from Asian patients were under the average (1.0%) (Fig. 1), confirming previous research in the Chinese population (0.4%<sup>15</sup> and 2.8%<sup>9</sup>).

In relation to patient demographics, analysis of the results showed significant differences (Figs. 2–4 and Supplemental Fig. S3 is available online at [www.jendodon.com](http://www.jendodon.com)); therefore, the null hypotheses were rejected. Geographic location and ethnicity (Figs. 2 and 3) are closely related factors, and their understanding pushes us back to the origin of human species and the early colonization of the world. Modern anthropological studies indicate that the human origins may be in Kenya in the African continent<sup>21</sup>. From there, the early humans moved north through the Levant corridor or east through the Horn of Africa, giving origin to the 3 main ethnic groups: Africans, Caucasians (northern Eurasian expansion), and Asian (eastern Asian expansion)<sup>21</sup>. This early human migration led to several differences observed among Caucasians, Africans, and Asians because their evolutions were made independently from each other for thousands of years during world colonization<sup>21</sup>. Their genome became an evolutionary result of genetic heritability and environmental influences<sup>22</sup> such as dietary modification<sup>23</sup>. As a result, it is likely that differences in the mandibular premolar phenotype, based on geographic region or ethnicity, may have existed for a long time.

Traditionally, anthropological studies focus on crown or external root morphology traits and landmarks and not on root canal configuration<sup>24</sup>. Comparative research evaluating anatomic landmarks of the mandibular premolar crowns concluded that some primitive hominid traits were preserved in *Homo erectus* located in the suburban area of

Beijing when compared with their ancestors, with divergences also being observed in comparison to European Pleistocene ancestral populations<sup>25</sup>. Overall, it has been stated that Africans are among the ones presenting the largest teeth, whereas Asians and Europeans have similar sizes<sup>26</sup>. Considering the reported influence of the external morphology on the internal root canal anatomy<sup>1</sup>, it has been proposed that the highest proportion of multiple canals in Africans and the lowest percentages on Asians may be related to teeth size, reflecting the evolutionary process of these 2 ethnic groups<sup>27</sup>. For instance, the lowest proportion of multiple canals in the mandibular premolars of Asian populations observed in the present study not only corroborates with previously published data<sup>9,12,15</sup> but is also consistent with results reported to other tooth groups, such as the second canal in the mesiobuccal root of maxillary molars<sup>27</sup> and the lingual canal in mandibular anterior teeth<sup>28</sup>.

The root canal space can be understood as a dynamic system that changes over time due to pathologic or physiological events<sup>29</sup>. In the present study, older patients (> 60 years old) were associated with the lowest presence of a lingual canal in the first premolar (19.1%) (Supplemental Fig. S3 is available online at [www.jendodon.com](http://www.jendodon.com)), possibly as a consequence of physiological deposition of secondary dentin<sup>30</sup>. This narrowing process may reduce the root canal system to sizes that may become undetectable even through high-resolution CBCT imaging<sup>30</sup>. However, the present results are not in agreement with 2 previous findings<sup>10,20</sup> that reported no difference in the prevalence of additional canals in mandibular premolars due to aging. However, it is

important to note that the sample size in these studies comprised only a small number of mandibular first premolars ( $n = 97$  and  $n = 154$ , respectively), resulting in a reduced statistical power compared with our sample size ( $N = 6900$ ). Considering the analysis of sex, the low prevalence of multiple canals in 1 root observed in the female group in both mandibular premolars (Fig. 4 and Supplemental Fig. S4 is available online at [www.jendodon.com](http://www.jendodon.com)) corroborates the results reported for other tooth groups such as maxillary molars<sup>27</sup> and mandibular central incisors<sup>28</sup>. In fact, the percentage difference between males and females regarding the prevalence of a lingual canal in the mandibular first premolar (~8%) is not only statistically significant but also clinically relevant. Sexual dimorphism is well recognized in dental sciences. For instance, forensics use metric and nonmetric dental measurements to perform sex estimation<sup>31</sup>. Previous research in several populations reported males as having larger tooth sizes compared with females<sup>32</sup>, a characteristic that may be related to the influence of the X and Y chromosomes on growth, in which Y promotes crown dentin and enamel formation and X seems to limit enamel growth<sup>33</sup>. These morphologic differences may help to partially explain the lowest number of additional canals in the female group<sup>27</sup>.

The root canal system of mandibular premolars has been addressed using several *in vivo* and *ex vivo* methodological approaches using different analytical tools. Nowadays, micro-computed tomographic technology is considered the gold standard to evaluate root canal morphology. However, considering it is a laboratory tool, it is impractical and quite expensive to evaluate the influence of certain anatomic components on demographic

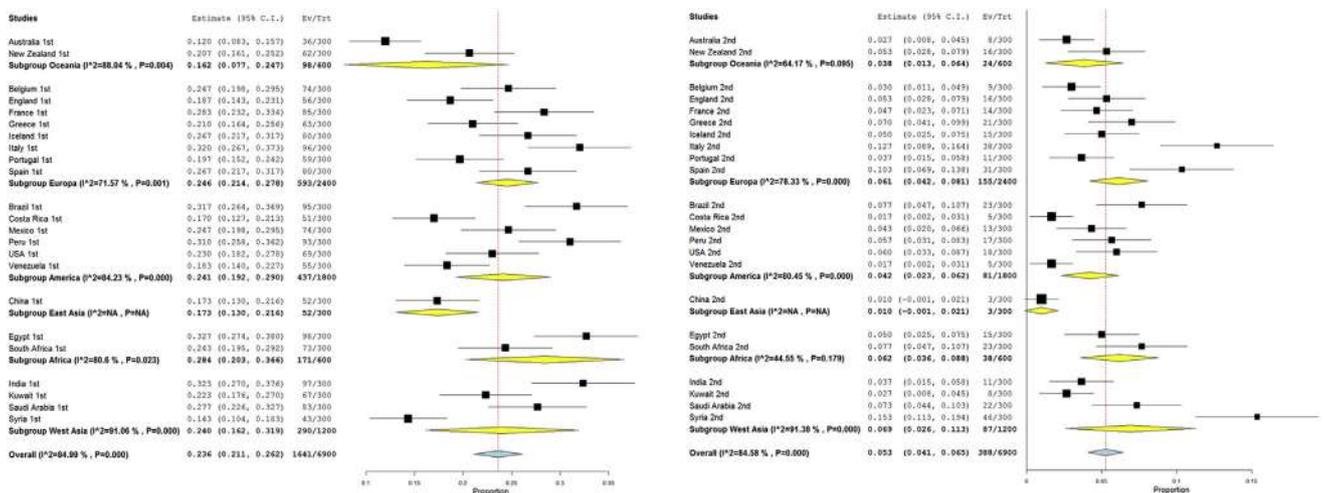
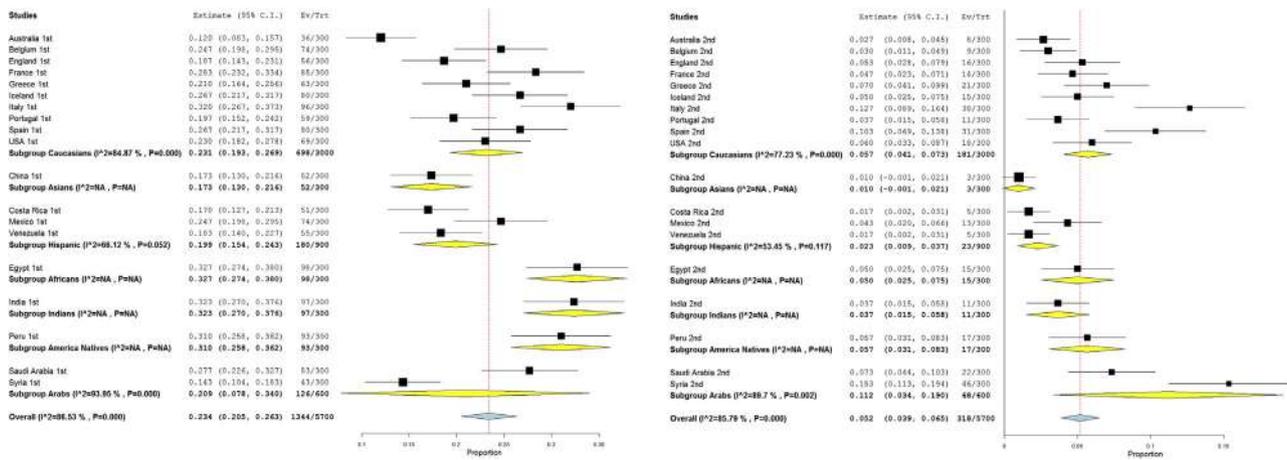


FIGURE 2 – A proportion forest plot regarding lingual root canal presence on the mandibular first (left) and second premolar (right) according to geographic region.



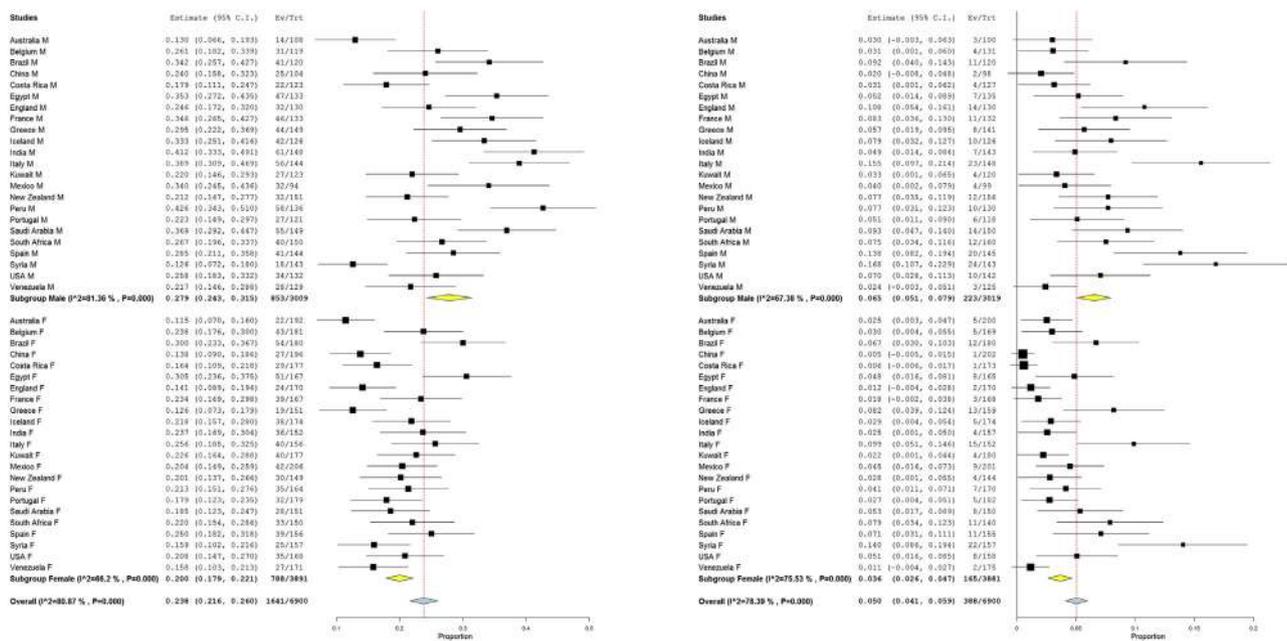
**FIGURE 3** – A forest plot with lingual canal proportions on the mandibular first (left) and second premolar (right) according to ethnicity. Four regions reporting mixed ethnicities were not included.

factors using large-sized groups. This is 1 of the main advantages of using non-destructive CBCT imaging because it allows the analysis of a large volume of data by assessing preexisting databases. On the other hand, the most relevant limitation of CBCT imaging is related to its limited spatial resolution, which has been considered inappropriate in identifying fine anatomic features<sup>34</sup>. In the present study, both primary and secondary outcomes were obtained by means of CBCT images and consisted in the analysis of the main root canal system configuration only, avoiding the assessment of smaller anatomic structures, such as lateral canals or apical deltas. Additionally, the main canal morphology was investigated in CBCT data sets from different

centers using voxel sizes between 75 and 200  $\mu\text{m}$ . This could be interpreted as a potential confounding factor, but this variable was excluded as a major source of bias in accordance with other meta-regression studies<sup>27,28</sup>.

One important limitation of multicenter studies is the difficulty to guarantee that all observers perform the data assessment using a standardized methodological approach. Aiming to minimize this potential bias, observers were chosen based on their large experience in the endodontic field, and the primary outcome was reduced to a dichotomous response (the presence/absence of a lingual root canal). In addition, intra- and interrater reliability measurements

were conducted to guarantee trustworthy results. Consequently, the methodological standardization for imaging assessment was validated in all centers of the 23 countries, allowing the meta-analysis statistical comparisons in order to explore possible heterogeneities and confounders, as previously done in similar studies<sup>16,35</sup>. Notwithstanding, as in any other cross-sectional study, the present evaluation was based on only 1 point in time. This may lead to some limitations when performing the interpretation of age results (eg, because factors not related to physiological aging, such as pathologic dentin deposition due to caries, restorative procedures, or periodontal problems, were not possible to be assessed).



**FIGURE 4** – A forest plot with lingual root canal prevalence comparison between sexes (male on top and female on bottom) on the mandibular first (left) and second premolar (right).

Further studies should continue exploring other geographic regions in order to collect more data with clinical and anthropological interest in order to analyze the influence of demographic factors on the root canal morphology.

## CONCLUSIONS

The mean prevalence of a lingual root canal in the mandibular first premolar (23.6%) was significantly higher than in the mandibular second premolar (5.3%). Demographic characteristics influenced the final outcomes. Asian ethnicity and older patients (> 60 years old) had the lowest prevalence of lingual canals in mandibular premolars, whereas the highest proportions and odds were observed in males for both teeth.

## CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

**Jorge N.R. Martins:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing - original draft, Supervision, Project administration.  
**Yuerong Zhang:** Methodology, Validation,

Investigation, Resources. **Murilo von Zuben:** Methodology, Validation, Investigation, Resources. **Walter Vargas:** Methodology, Validation, Investigation, Resources. **Hussein C. Seedat:** Methodology, Validation, Investigation, Resources. **Fábio Santiago:** Methodology, Validation, Investigation, Resources. **Ruben Rosas Aguilar:** Methodology, Validation, Investigation, Resources. **Magnús F. Ragnarsson:** Methodology, Validation, Investigation, Resources. **Gianluca Plotino:** Methodology, Validation, Investigation, Resources. **Peter Parashos:** Methodology, Validation, Investigation, Resources. **Hani F. Ounsi:** Methodology, Validation, Investigation, Resources. **Christian Nole:** Methodology, Validation, Investigation, Resources. **Adam Monroe:** Methodology, Validation, Investigation, Resources. **Jojo Kottoor:** Methodology, Validation, Investigation, Resources. **Jose Antonio Gonzalez:** Methodology, Validation, Investigation, Resources. **Daniel Flynn:** Methodology, Validation, Investigation, Resources. **Antonis Chaniotis:** Methodology, Validation, Investigation, Resources. **Imran Cassim:** Methodology, Validation, Investigation,

Resources. **Carlos Boveda:** Methodology, Validation, Investigation, Resources. **Luiza Berti:** Methodology, Validation, Investigation, Resources. **Zaher Altaki:** Methodology, Validation, Investigation, Resources. **Moataz-Bellah A.M. Alkhawas:** Methodology, Validation, Investigation, Resources. **Hussam Alfawaz:** Methodology, Validation, Investigation, Resources. **Emmanuel J.N. L. Silva:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision. **Marco Aurélio Versiani:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing, Supervision.

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*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](http://www.jendodon.com) (10.1016/j.joen.2021.04.021).

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