

## Cone-beam Computed Tomography Analysis of the Root Canal Morphology of Mandibular Incisors Using Two Classification Systems in a Spanish Subpopulation: A Cross-Sectional Study

 Silvia HERRERO-HERNÁNDEZ,<sup>1</sup>  Óliver Valencia De PABLO,<sup>2</sup>  Manuel BRAVO,<sup>3</sup>  
 Antonio CONDE,<sup>2</sup>  Roberto ESTEVEZ,<sup>2</sup>  Yoseif HADDAD,<sup>4</sup>  Nansi LÓPEZ-VALVERDE,<sup>5</sup>  
 Giampiero ROSSI-FEDELE<sup>6</sup>

<sup>1</sup>Department of Surgery, University of Salamanca, Instituto de Investigación Biomédica de Salamanca (IBSAL), Salamanca, Spain

<sup>2</sup>Postgraduate Program in Endodontics, European University of Madrid, Madrid, Spain

<sup>3</sup>Department of Preventive and Community Dentistry, University of Granada, Facultad de Odontología, Granada, Spain

<sup>4</sup>Private Practice, Ontario, Canada

<sup>5</sup>Department of Medicine and Medical Specialties, Universidad Alcalá de Henares, Faculty of Health Sciences, Madrid, Spain

<sup>6</sup>Adelaide Dental School, University of Adelaide, Adelaide, Australia

### ABSTRACT

**Objective:** This study evaluated the root and canal morphology in permanent mandibular incisors teeth using cone-beam computer tomography imaging in a Spanish subpopulation, and compared these findings with ipsilateral (similarity) and contralateral (symmetry) incisors. In addition, the position of canal splitting was measured.

**Methods:** A total of 229 datasets comprising four mandibular teeth each (n=916 incisors) were analysed using Vertucci and Ahmed et al. classifications, and, the similarity and symmetry were calculated. The distance from the cemento-enamel junction (CEJ), and the most coronal canal divergence was measured (if present). The role of sex was also assessed. The Cochran Q Test, LOGIS PROC in SUDAAN, Chi-square, and Kappa were used for the different comparisons. A p-value of less than 0.05 was considered significant.

**Results:** All incisors were single-rooted and no significant differences regarding root canal morphology were found according to the sex of the subjects included in the database. The most common morphology was Vertucci type I/Ahmed et al. <sup>1</sup>MI<sup>1</sup> (65.3% for central and 66.8% for lateral incisors respectively), followed by type III/<sup>1</sup>MI<sup>1-2-1</sup> (31% for central and 30.6% for lateral incisors). 1.8% of the samples were considered as non-classifiable with Vertucci but were classified with codes using the Ahmed et al. system. Similarity values were 74.7% for the left side, and 74.2% for the right side, whereas symmetry values were 90% for central and 84.3% for lateral incisors. In the presence of divergences, the main (SD) distances from the CEJ were for type II/<sup>1</sup>MI<sup>1-2-1</sup> 3.8±0.8 (centrals) 4.0±0.7 mm (laterals); for type V/<sup>1</sup>MI<sup>1-2</sup> this value ranged between 6.0±1.8 and 5.5±1.5 mm, whereas values for <sup>1</sup>MI<sup>1-2-3-2-1</sup> were 1.8 and 2.1 mm. No significant differences were found when the position of the most coronal divergence was compared between lateral and central incisors for the different morphologies.

**Conclusion:** A high prevalence of Vertucci I/Ahmed et al. <sup>1</sup>MI<sup>1</sup> configuration was present in mandibular incisors from Spanish individuals. Similarity and symmetry were common, particularly for central incisors. The position of the coronal splitting of the canals varied according to the root canal morphology.

**Keywords:** Ahmed, anatomy, cone-beam computed tomography, ethnicity, incisors, root canal, Vertucci

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#### Address for correspondence:

Giampiero Rossi-Fedele  
Adelaide Dental School, University of Adelaide, Adelaide, Australia  
E-mail: giampiero.rossi-fedele@adelaide.edu.au

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## HIGHLIGHTS

- One-third of mandibular incisors presented with morphologies different from Vertucci I/ Ahmed et al.' MI'.
- The root canal morphology of seventeen (1.8% of the sample) mandibular incisors within the Spanish subpopulation studied was unclassifiable using Vertucci's system, but were classified using Ahmed et al. classification.
- Ipsilateral and contralateral incisors may help to predict the morphology of the other mandibular incisors
- The position of the most coronal root canal splitting in regards to the CEJ varies according to the morphology.

## INTRODUCTION

Recent systematic reviews have reiterated the significant variability in root canal morphology globally when cone-beam computed tomography (CBCT) is used for assessment, including in mandibular incisors (1, 2). Studies based on clinical datasets demonstrated the differences in the number of canals and their configuration associated with the geographic location and ethnic backgrounds. The prevalence of two canals in mandibular incisors ranges between 2.7% and 45% (3–7).

An *a priori* understanding of root canal morphology, including the number of canals, is crucial for endodontic treatment, since missed canals are usually associated with persisting periapical lesions (8), and the need for additional treatments (9). Although available evidence suggests that the morphology of mandibular incisors is highly variable (3–7), endodontic case assessment tools consider these teeth to be of low difficulty, except in the presence of additional factors that would increase the difficulty level (10). Interestingly, one endodontic case assessment tool factors in the number of canals expected to be present in the tooth being considered for treatment, which may not be predictable based on two-dimensional imaging (11). It is worth noting that root canal morphology is of interest in subjects outside clinical dentistry such as anthropology (12).

There is limited evidence assessing root canal morphology and possible associations of mandibular incisors using CBCT when compared with other tooth types from Europe (1, 2). In addition, to the best of knowledge, there are no studies applying the system to classify root and root canal morphology proposed by Ahmed et al. (13) in this continent for this specific tooth type. Furthermore, mandibular incisors have not been previously assessed in the Spanish population. Though the Vertucci classification (14) has been used widely, the Ahmed et al. (13) classification has been purported to describe the root and canal morphology more accurately and practically (15), as allows to characterize all canal configurations and tooth anomalies (16). Similarly, the level of canal splitting has attracted attention due to its outstanding clinical relevance as it would support canal location when required (15, 17).

Therefore, the aim of the present study was three-fold; first, to assess the root canal morphology of mandibular incisors using Vertucci (14) and Ahmed et al. (13) classification systems (condition) based on available CBCT datasets in a Spanish subpopulation (context and subpopulation); second, to compare the morphology of central *versus* ipsilateral lateral incisors (*similarity*), and to compare central and lateral incisors *versus*

their contralateral tooth (*symmetry*); and third, to investigate the distance between the cemento-enamel junction (CEJ) and the most coronal canal splitting (if present).

## MATERIALS AND METHODS

The study was carried out and the current document was prepared following the "Preferred Reported items for Cross-Sectional Studies on Root and Canal anatomy using CBCT technology" (1) and Preferred Reporting items for root and canal anatomy in the human dentition (PROUD 2000) (2) guidelines. The present research was conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version 2013) and Ethical approval was granted by the University of Salamanca (20.10.2020-508).

### Sample Size Calculation

Sample size calculation indicated that datasets from 103 patients were required to compare the morphology of central *versus* lateral incisors plus the mandibular quadrants with 80% power and 5% level of significance, and a 15% difference in prevalence in the outcomes in question. Nonetheless, the final minimum sample size was increased to 154 (103×1.5) to account for the sample set including pairs of teeth from the same subject.

### Participants

For the selection process, a convenience sample of CBCT datasets from 285 subjects (165 female and 120 male) was included. The datasets were originally acquired in private practice in Salamanca (Spain) for reasons not related to the present study (e.g. implant surgery, orthodontic treatment, impacted teeth) from January 2020 to December 2021.

Inclusion criteria were as follows: subject age above 18 years; teeth with mature roots and with the outline of the root canal(s) visible on the datasets. Exclusion criteria were as follows: subjects with missing mandibular incisor(s); teeth with calcified canals, resorptive defects; developmental abnormalities, previous endodontic or restorative treatment and presence of implants in the anterior mandible; dataset not allowing complete visualization of all mandibular incisors. After applying all the inclusion and exclusion criteria, datasets from 229 patients were available, thus allowing an increased statistical power for the present study (Fig. 1).

### Image Acquisition and Evaluation

Datasets were acquired using a CS 8100 3D CBCT scanner (Carestream Dental, Rochester, NY, USA). The scanning setting was as follows: tube voltage 84 kV; tube current 4 mA; field of view of 8×9 cm; time of exposure 15 s; the voxel size was 150 μm. Datasets were reconstructed and visualized using the CS 3D

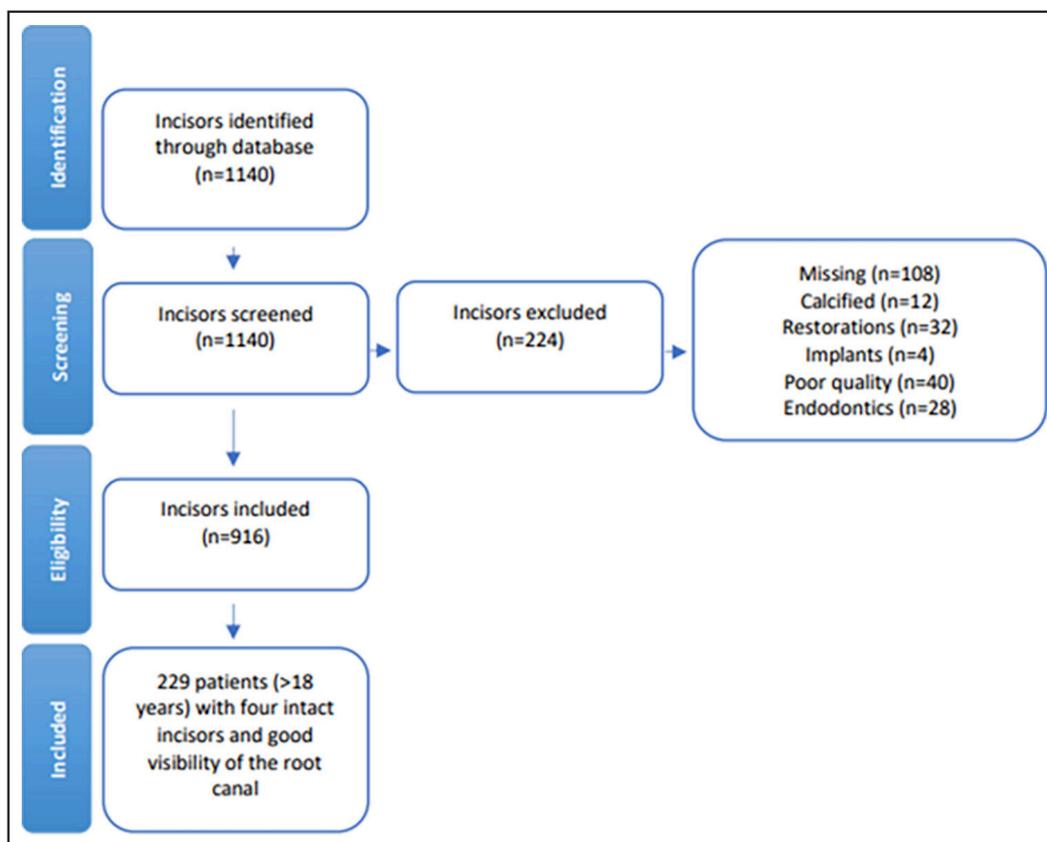


Figure 1. Flowchart of the cone-beam computed tomography dataset selection process



Figure 2. Representative images of Vertucci's (14) and Ahmed et al. (13) morphology configurations, based on sagittal sections of CBCT datasets. A: type I/MI<sup>1</sup>; B: type II/MI<sup>1-2-1</sup>; C: type III/MI<sup>1-2</sup>; D: Type VNC/MI<sup>1-2-1-2-1</sup>  
CBCT: Cone-beam computed tomography

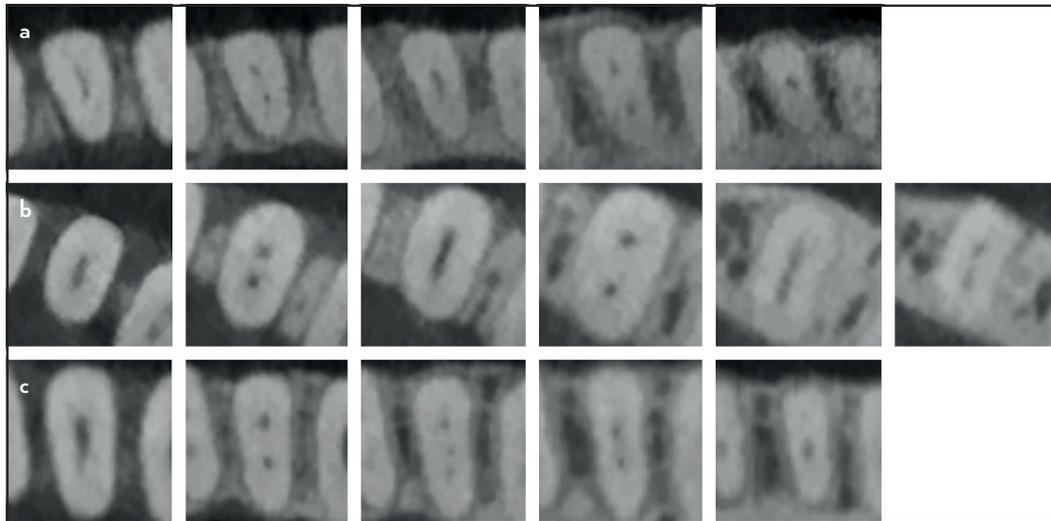
imaging software. Axial, sagittal, and coronal planes were analysed. The number of roots, their morphology according to Vertucci classification (14), and supplemental configurations (Figs. 2, 3), were assessed according to the subject gender, plus *similarity* comparison "central versus lateral" and *symmetry* comparisons "left versus right" of the previous outcome measures were assessed. In parallel, root and canal morphologies were assessed based using the Ahmed et al. (13) system. In brief, this system encompasses the tooth number, the number of roots and their configuration, and, finally, the root canal configuration (13) (Fig. 2). Finally, the perpendicular distance between the CEJ and the first bifurcation was measured in roots with multiple canals, as previously described (17).

### Calibration and Assessment

Datasets were assessed by three experienced endodontists previously calibrated using 30 datasets, with interobserver agreement (*kappa statistics*) values ranging between 0.60 and 0.73 (depending on the assessors compared and the outcome measures), with a strength of agreement "moderate" or "substantial" (18). Two endodontists assessed the datasets contemporarily and any disagreement was solved with the help of the third endodontist until a decision was obtained by consensus.

### Statistical Analysis

SPSS-Windows 21.0 (IBM Corp. Armonk, NY, USA) was used when the unit of analysis was the patient; SUDAAN 7.0 (RTI,



**Figure 3.** Representative images of morphology configurations not classifiable based on Vertucci types. (a) <sup>1</sup>MI<sup>2-1-2-1</sup>. (b) Type <sup>1</sup>MI<sup>1-2-1-2-1-2</sup>. (c) <sup>1</sup>MI<sup>1-2-3-2-1</sup>

RTP, NC, USA) was used when the unit was the tooth, to adjust for clustering. Confidence Interval Analysis (CIA) was used to calculate exact confidence intervals for percentages. Statistical tests and software are listed in the footnotes of the tables (results section). In all comparisons, a p-value of less than 0.05 was considered significant.

**RESULTS**

After the selection process, the sample size was 229 datasets (132 female and 97 male subjects), with a total of 916 incisors. All teeth were single-rooted and no significant differences were found based on sex (Table 1). The most common morphology was Vertucci type I/ Ahmed et al. <sup>1</sup>MI<sup>1</sup> (65.3% for central and 66.8% for lateral incisors respectively, followed by Vertucci type III/ Ahmed et al. <sup>1</sup>MI<sup>1-2-1</sup> (31% for central and 30.6% for lateral incisors), as well as configurations not listed originally by Vertucci were also evident (n=17; 1.8% of the total sample) (Table 1). Figures 2 and 3 illustrate various morphologies found in the datasets.

When comparing the Vertucci type of central *versus* lateral incisors in the same quadrant (similarity), this coincided in 74.7%

for the left side and 74.2% for the right side respectively, when all configurations were considered (Table 2). If single-canal roots are excluded from this analysis, the value is 65.8% for the left and 64.9% for the right sides.

When comparing the same teeth types in different quadrants (*symmetry*), the morphology coincided for 90% of the central incisors and 84.3% of the lateral incisors (Table 3). If Vertucci type I/ Ahmed et al. <sup>1</sup>MI<sup>1</sup> roots are excluded from this analysis, the value is 87.9% for the central incisors and 78.9% for lateral incisors.

The distance between the CEJ and the most coronal bifurcation varied according to the morphology and tooth type (Table 4). No significant differences were found when the position of the most coronal divergence was compared between lateral and central incisors with type II/<sup>1</sup>MI<sup>1-2-1</sup> morphology, having a mean (SD) as follows, 3.8±0.8 (centrals) 4.0±0.7 mm (laterals), or the other less frequent types (Table 4). For type V/<sup>1</sup>MI<sup>1-2</sup> values ranged between 6.0±1.8 and 5.5±1.5 mm, whereas values for <sup>1</sup>MI<sup>1-2-3-2-1</sup> were 1.8 and 2.1 mm.

**TABLE 1.** Vertucci (14) and Ahmed et al. (13) configuration of mandibular incisor teeth included in the study

	Left side				Right side				Global comparison p
	Central		Lateral		Central		Lateral		
	n	%	n	%	n	%	n	%	
Vertucci/Ahmed									
I/ <sup>1</sup> MI <sup>1</sup>	150	65.5	155	67.7	149	65.1	151	65.9	0.733 <sup>c</sup>
III/ <sup>1</sup> MI <sup>1-2-1</sup>	71	31.0	67	29.3	71	31.0	73	31.9	
V/ <sup>1</sup> MI <sup>1-2</sup>	3	1.3	3	1.3	4	1.7	2	0.9	
VNC/ <sup>1</sup> MI <sup>1-2-1-2-1</sup>	2	0.9	4	1.7	2	0.9	1	0.4	
VNC/ <sup>1</sup> MI <sup>1-2-1-2-1-2</sup>	2	0.9	-	-	2	0.9	2	0.9	
VNC/ <sup>1</sup> MI <sup>1-2-3-2-1</sup>	1	0.4	-	-	1	0.4	-	-	

<sup>c</sup>: Chi-square corrected for clustering (4 teeth) after collapsing the last four categories (i.e., V, and so on). With CROSSTAB procedure in SUDAAN 7.0. A p-value of less than 0.05 was considered significant VNC: Vertucci non-classifiable

**TABLE 2.** Morphological similarity of mandibular incisor teeth included in the study using Vertucci (14) and Ahmed et al. (13) classification

Root canal configurations <sup>a</sup> Both incisors	Mandibular left incisors				Mandibular right incisors			
	n <sup>b</sup>	%	(95%-CI) <sup>c</sup>	kappa (95% CI) <sup>d</sup>	n	%	(95%-CI)	kappa (95% CI)
Configurations				0.47 (0.36–0.59)				0.45 (0.34–0.57)
Both type I ( <sup>1</sup> MI <sup>1</sup> )	127	55.5		0.50 (0.38–0.62)	123	53.7		0.48 (0.36–0.60)
Both type III ( <sup>1</sup> MI <sup>1-2-1</sup> )	43	18.8		0.46 (0.34–0.59)	44	19.2		0.43 (0.31–0.56)
Both type V ( <sup>1</sup> MI <sup>1-2</sup> )	1	0.4		NC <sup>e</sup>	1	0.4		NC
Both VNC ( <sup>1</sup> MI <sup>1-2-1-2-1-2</sup> )	–	–		–	2	0.9		NC
I/III ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2-1</sup> )	47	20.5		–	51	22.3		–
I/V ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2</sup> )	3	1.3		–	3	1.3		–
I/VNC ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1</sup> )	1	0.4		–	–	–		–
III/V ( <sup>1</sup> MI <sup>1-2-1</sup> / <sup>1</sup> MI <sup>1-2</sup> )	1	0.4		–	1	0.4		–
III/VNC ( <sup>1</sup> MI <sup>1-2-1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1</sup> )	3	1.3		–	3	1.3		–
III/VNC ( <sup>1</sup> MI <sup>1-2-1</sup> / <sup>1</sup> MI <sup>1-2-3-2-1</sup> )	1	0.4		–	1	0.4		–
VNC/VNC ( <sup>1</sup> MI <sup>1-2-1-2-1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1-2</sup> )	2	0.9		–	–	–		–
Same configuration	171	74.7	(69.0–80.3)		170	74.2	(68.6–79.9)	
Different configurations	58	25.3	(19.7–31.0)		59	25.8	(20.1–31.4)	

<sup>a</sup>: "Both" means a patient with both compared incisors having the same configuration; "/" is used to separate incisors with different configurations; <sup>b</sup>: Incisors pair; <sup>c</sup>: 95%-Confidence Interval, calculated with CIA v.1.0 statistical program; <sup>d</sup>: Kappa and 95% Confidence-Interval, calculated with SPSS-Windows 15.0, both global for each pair of compared incisors and some categories. Due to the limited sample size for some categories, categories for kappa calculation were collapsed; <sup>e</sup>: NC: Kappa non-calculable due to insufficient sample size. CI: Confidence interval

**TABLE 3.** Morphological symmetry of mandibular incisor teeth included in the study using Vertucci (14) and Ahmed et al. (13) classification

Root canal configurations <sup>a</sup> Side 1/Side 2	Central incisors				Lateral incisors			
	n <sup>b</sup>	%	(95%-CI) <sup>c</sup>	kappa (95% CI) <sup>d</sup>	n	%	(95%-CI)	kappa (95% CI)
Configurations				0.79 (0.71–0.87)				0.68 (0.58–0.78)
Both type I ( <sup>1</sup> MI <sup>1</sup> )	140	61.1		0.82 (0.74–0.90)	137	59.8		0.69 (0.58–0.79)
Both type III ( <sup>1</sup> MI <sup>1-2-1</sup> )	60	26.2		0.78 (0.69–0.86)	54	23.6		0.67 (0.57–0.78)
Both type V ( <sup>1</sup> MI <sup>1-2</sup> )	3	1.3		NC <sup>e</sup>	2	0.9		NC
Both VNC ( <sup>1</sup> MI <sup>1-2-1-2-1-2</sup> )	2	0.9		NC	–	–		NC
Both VNC ( <sup>1</sup> MI <sup>1-2-3-2-1</sup> )	18	7.9		NC	–	–		NC
I/III ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2-1</sup> )	18	7.9		–	30	13.1		–
I/V ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2</sup> )	1	0.4		–	1	0.4		–
I/VNC ( <sup>1</sup> MI <sup>1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1</sup> )	–	–		–	1	0.4		–
III/VNC ( <sup>1</sup> MI <sup>1-2-1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1</sup> )	4	1.7		–	2	0.9		–
VNC/VNC ( <sup>1</sup> MI <sup>1-2-1-2-1</sup> / <sup>1</sup> MI <sup>1-2-1-2-1-2</sup> )	–	–		–	2	0.9		–
Same configuration	206	90.0	(86.1–93.8)		193	84.3	(79.6–89.0)	
Different configurations	23	10.0	(6.1–13.9)		36	15.7	(11.0–20.4)	

<sup>a</sup>: "Both" means a patient with both incisors having the same root canal configuration; "/" is used to separate incisors with different configurations; <sup>b</sup>: Incisors pair; <sup>c</sup>: 95%-Confidence Interval, calculated with CIA v.1.0 statistical program; <sup>d</sup>: Kappa and 95% Confidence-Interval, calculated with SPSS-Windows 15.0, both global for each pair of compared incisors and for some categories. Due to the limited sample size for some categories, categories for kappa calculation were collapsed. <sup>e</sup>: NC: Kappa non-calculable due to insufficient sample size

## DISCUSSION

The results of the present study highlight the morphology of mandibular incisors in a Spanish subpopulation, with the majority of teeth assessed presenting a Vertucci type I/ Ahmed et al. /<sup>1</sup>MI<sup>1</sup> configuration, followed by types III/<sup>1</sup>MI<sup>1-2-1</sup>, V/<sup>1</sup>MI<sup>1-2</sup> and others not described by Vertucci (configuration type 1–2–1–2–1, 1–2–1–2–1–2, 1–2–3–2–1), which can be described using Ahmed et al. classification system. The latter configurations are clinically important as they reiterate the crucial role irrigation during root canal treatment of mandibular incisors (19). A relatively high de-

gree of *similarity* and *symmetry* was also found. These findings should improve the understanding of root canal morphology of maxillary incisors within the Spanish population and globally, when compared with other similar studies assessing other geographic regions and ethnic backgrounds. It is worth noting that the province of Salamanca has a relatively low gross immigration rate compared with the rest of the country (20).

The role of ethnicity in root canal morphology is corroborated by this study. A previous CBCT-based study using a database in

**TABLE 4.** Distance in mm (mean and standard deviation) between the CEJ and most coronal canal bifurcation of mandibular incisor teeth included in the study using Ahmed et al. (13) classification

Vertucci/Ahmed	Central		Lateral		p <sup>a</sup>
	n	Mean±SD	n	Mean±SD	
III/MI <sup>1-2-1</sup>	142	3.8±0.8	140	4.0±0.7	0.072
Others (low frequency)	17	4.0±1.9	12	3.9±1.9	0.752 <sup>b</sup>
V/MI <sup>1-2</sup>	7	5.8±1.2	5	5.7±1.4	
VNC/MI <sup>1-2-1-2-1</sup>	4	3.2±1.3	5	2.4±0.2	
VNC/MI <sup>1-2-1-2-1-2</sup>	4	2.7±1.2	2	2.9±1.0	
VNC/MI <sup>1-2-3-2-1</sup>	2	1.9±0.2	–	–	

<sup>a</sup>: With procedure DESCRIPT (t-test) in SUDAAN 7.0, to account for clustering, i.e., multiple incisors per patient, <sup>b</sup>: Please, note that p-values are calculated only after collapsing all low-frequency categories. CEJ: Cemento-enamel junction

Portugal, another European country that neighbours Spain, reported a Vertucci I/ Ahmed et al. MI<sup>1</sup> prevalence of 72.6% and 70.1% for mandibular and central incisors (3), similar to the findings of the present study. Another study on an European sub-population reported lower incidences of one canal, with 55% of central incisors and 57% of lateral incisors having a Vertucci I/ Ahmed et al. MI<sup>1</sup> configuration in Italy (4). Two studies on Belgian and German populations reported a prevalence of 61.5% and 77.4% of single canal configuration in central incisors and 59.7% and 75.7% for lateral incisors, respectively (21, 22).

Most of the studies that examined the root and canal anatomy of mandibular incisors were undertaken on Asian populations. The results from the present study are in contrast with those arising from Eastern Asia (i.e. China and Taiwan), with a much higher proportion of mandibular incisors with single canals, ranging from 84.4% (both types of incisors) to 99.6% (central incisors) (3, 5, 23, 24), particularly in central incisors (3, 19). Nonetheless, other studies from the same region reported about 75% prevalence of single canals in mandibular lateral incisors (25, 26). Regarding studies from Western Asia, a study from Saudi Arabia reported the presence of one canal in 73.7% of central incisors and 69.2% of laterals (6). Contradictory findings were reported in two studies based in different regions in Turkey, with one study based in the Mediterranean area reporting a prevalence of 52.4% of single canals in mandibular incisors (27), whereas a second study from the Black Sea area reported higher values, 65.4% (28). Of two Iranian studies from different provinces, one reported that most central (84.6%) and lateral incisors (78.2%) had a single root canal (29), whereas a second study reported that 70.3% of incisors having a single canal (30). Another study from Israel found a prevalence of one canal in 59.5% of central incisors and 62.1% of laterals (7). Regarding the South Asia region, two studies from the same state in India report one canal in 66.5% and 65%, which are comparable (31, 32).

One study from the Americas originated from Chile, with a prevalence of one canal in 78.3% of central incisors and 79.1% for laterals (21). Supplementary configurations were also reported in other studies assessing mandibular incisors (7, 21, 22, 23, 27). It is obvious that countries have regions and cities with different and/or various ethnic groups that usually reflect on the tooth morphology types (2), including mandibular incisors (33).

There is currently a paucity of evidence regarding the other outcomes assessed in the present study. A limited number of two rooted mandibular incisors have been reported in previous studies (6, 21, 23), although their absence has been recorded in the present study and previous ones (29, 30). Differences in the number of canals in mandibular incisors associated with sex, not evident in the present study and another investigation (27), have been previously reported (6, 7, 23). Bilateral symmetry regarding root canal numbers has been calculated in a Saudi population as 91.2% for central incisors whereas for lateral was 85.8% (6), whereas values from a Chinese study were higher, at 95.2% and 93.8%, respectively (26). Another study from China reported symmetry for Vertucci III of 44.4% for central and 63.4% for lateral incisors, whilst for type V bilateral symmetry was 7.9% for central and 6.3% for lateral incisors (17). In addition, an Iranian study found no significant differences when comparing the presence/absence of a second canal in the left and right sides (29). Distinctly lower symmetry values (18–17.2%) were reported in a study from Germany.

Previous CBCT-based clinical studies compared the use of Vertucci and/or Ahmed et al. classifications in mandibular incisor teeth in Saudi (34, 35), South African (36), and Malaysian sub-populations (37). Thus, the present study is the first based in Europe. The study from Malaysia reported several non-classifiable root canal variations (37), as in the present study. Conversely, studies from Saudi Arabia (34) and South Africa were able to allocate all morphologies to Vertucci types (36).

The position of canal splitting has attracted particular attention recently with the findings of the current study being in agreement with a study from Beijing (China) (17). In the present study, the CEJ was used as the reference as this is a visible anatomic landmark (17). Therefore, the CEJ can be used as a reference for clinicians whilst aiming to locate further canals, which has a significant clinical translation, as missed canals are associated with treatment complications and the need of further treatment (8, 9). Only the most coronal splitting was considered in the present study, as a limited number of teeth having more than two canals was found. Overall, root canal split more commonly in the coronal and middle root thirds (17).

Differences in the findings can be attributed to methodological issues, including the CBCT machine used, imaging setting and the visualization process, apart from differences in the datasets of subjects included (22). The clinical translation of the above results is that the high *similarity* and *symmetry* of the configuration of the canals can guide the clinician, though, in the absence of perfect agreement, it should not be an anatomical diagnostic tool, and individual assessment for each tooth is crucial.

The present study fulfils the recently published guidelines listed in the "Preferred Reported items for Cross-Sectional Studies on Root and Canal anatomy using CBCT technology" and PROUD 2020 (1, 2). CBCT imaging has several advantages for this purpose, as previously reviewed, including its non-destructive nature, and relatively low cost (1, 2). In addition, when compared with micro-computed tomography, an *ex-vivo* contemporary alternative for the assessment of root canal morphology, it has been concluded that CBCT has high accuracy in the assessment of root canal configuration (38). One limitation of the present study is that a database from a single centre may have limited external validity even within the same city. A second limitation is that only subjects of age above 18 years were included and that the findings were not analyzed according to the age group of the subjects also considering that physiological dentine deposition related to ageing can alter internal root canal morphology, including the location of canal splitting (17). The inability to evaluate the effect of age was because of the anonymization of the datasets, which included the age of the participants, and the availability of CBCT datasets for younger subjects, which is relatively limited in the primary setting.

The findings of the present study support the recommendation from the American Association of Endodontists to consider CBCT imaging for the initial assessment of mandibular incisors scheduled for root canal treatment (39), as these have the potential for extra canals and a complex morphology should be suspected. An *a priori* understanding of root canal morphology and the likely position of canal splitting is crucial in decision-making and treatment planning. For example, access cavity design may be modified in the presence of a lingual canal (40), and non-surgical retreatment instead of surgical may be chosen if a missed canal is identified. These CBCT applications are aligned with those reported in recent surveys (41, 42). Further multi-centre studies to assess the variability in morphology of mandibular incisors using the Ahmed et al. classification are recommended globally to better understand the root and canal morphology of root types not classifiable based on the Vertucci classification.

## CONCLUSION

One canal was present in two-thirds of mandibular incisor teeth in a Spanish subpopulation. In the presence of two canals, various configurations were found, and the position of the most coronal canal splitting was associated with the canal morphology. *Symmetry* and *similarity* were also prevalent in the database assessed.

## Disclosures

**Ethics Committee Approval:** The study was approved by the University of Salamanca Ethics Committee (no: 508, date: 20/10/2020).

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