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Fused roots of maxillary molars: characterization and prevalence in a Latin American sub-population: a cone beam computed tomography study

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ABSTRACT

Objectives: The upper molars generally have three roots; therefore, different combinations of fusion can occur, increasing the possibility of finding more complex root canal systems. The purpose of this study was to evaluate the prevalence and characterization of fused roots in first and second maxillary molars using cone-beam computed tomography (CBCT) in a Colombian population.

Materials and Methods: A total of 1274 teeth were evaluated, of which 534 were maxillary first molars and 740 were maxillary second molars. Axial sections were made at the cervical, middle, and apical levels to determine the prevalence of root fusion and the types of fusion.

Results: Overall, 43% of the molars (*n* = 551) presented some type of fused root. Root fusion was present in 23.4% of the maxillary first molars. The most frequent type of fused root was type 3 (distobuccal-palatal; DB-P) (58.9%). Root fusion was observed in 57.6% of the maxillary second molars, and the most prevalent type of fused root was type 6 (cone-shaped) (45.2%). Of the maxillary molars, 12.5% were classified as C-shaped.

Conclusion: Within the limitations of this study, there was a high prevalence of fused roots in maxillary molars in the Colombian population, mainly in the maxillary second molars. In first molars, the most common type of fused root was type 3 (DB-P) and in second molars, the most common type was type 6 (cone-shaped). Additionally, molars with root fusion presented variation at different levels of the radicular portion, with implications for treatment quality.

Keywords: Cone-beam CT; Fused teeth; C-shape canal; Maxillary molars; Root anatomy

INTRODUCTION

Knowledge of radicular anatomy and the root canal system is of paramount importance for endodontic therapy [1]. Molars with root fusion present considerable anatomical variations

Author Contributions

Conceptualization: Marcano-Caldera M, Mejia-Cardona JL; Data curation: Marcano-Caldera M, Mejia-Cardona JL, Blanco-Uribe MP, Chaverra-Mesa EC, Rodriguez-Lezama D; Formal analysis: Marcano-Caldera M, Mejia-Cardona JL, Parra-Sánchez JH; Investigation: Marcano-Caldera M, Mejia-Cardona JL, Blanco-Uribe MP, Chaverra-Mesa EC; Methodology: Marcano-Caldera M, Mejia-Cardona JL, Rodriguez-Lezama D, Parra-Sánchez JH; Resources: Rodriguez-Lezama D, Parra-Sánchez JH; Validation: Marcano-Caldera M, Mejia-Cardona JL, Blanco-Uribe MP, Chaverra-Mesa EC, Rodriguez-Lezama D, Parra-Sánchez JH; Writing - original draft: Marcano-Caldera M, Mejia-Cardona JL, Blanco-Uribe MP, Chaverra-Mesa EC, Rodriguez-Lezama D; Writing - review & editing: Marcano-Caldera M, Mejia-Cardona JL, Parra-Sánchez JH.

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[2,3], which can be a challenge in terms of location, cleaning, shaping, and obturation of the root canal system [4].

According to Peikoff *et al.* [5], significant variation exists in the anatomy of maxillary molars, from the number of roots to the type of root fusion. A fused root can combine variability of the root canal system with the presence of additional grooves, isthmuses, or canals that connect some or all of the roots [6,7]. Although maxillary second molars resemble maxillary first molars, a distinctive morphological feature of maxillary second molars is that their roots are occasionally grouped together or fused [8].

Fused roots are a challenge from endodontic, periodontal, prosthetic, and endodontic microsurgery points of view. A depression within the root surface refers to a groove formed from the fusion of roots, which allows bacterial migration and affects the resistance of the periodontal tissue, since the adhesion of junctional epithelium at the defect site is inadequate, thereby generating a pathway for bacterial contamination and subsequent bone destruction [9-11]. The dentinal walls of the face adjacent to the grooves are usually thinner, meaning that special care must be taken to prevent perforations, with regard to both shaping techniques and the design of intra-radicular retainers [2,4].

Studies have been done with extracted teeth using photography, sectional cuts, and micro-computed tomography (CT). Yang *et al.* [12] described 5 types of radicular fusions in the Chinese population, with a prevalence of 6.2% in maxillary first molars and 40.1% in second molars. Likewise, they reported that the prevalence of maxillary first and second molars with a C-configuration was 0.3% and 4.5%, respectively. Carlsen *et al.* [13] described six anatomical variations in maxillary second molars with three fused roots in a Danish village. Zhang *et al.* [7] reported a 42.25% prevalence of root fusion in maxillary second molars in China. Ordinola *et al.* [14], evaluated the internal and external morphology of maxillary second molars with various types of root fusion using micro-CT in Brazil.

In recent years, cone-beam computed tomography (CBCT) has become widely used in dentistry, especially for understanding root anatomy, as has been discussed in numerous publications. Several studies have been carried out using CBCT to determine the anatomical configuration of maxillary molars. Studies evaluating radicular fusion have shown a higher frequency in Asian populations, between 19.5% to 41.4% [15-19]. Only two studies of radicular fusion have been published in America, in United States and Brazil, with reported rates of 0.9% and 7.84% respectively [20,21].

It has been shown that dental anatomical variations are related to multiple factors, among which genetic, ethnic, and geographical factors are particularly important [1,22,23]. The objective of this study was to determine the prevalence and anatomical characteristics of maxillary first and second molars with root fusion in a Colombian population, using *in vivo* CBCT.

MATERIALS AND METHODS

This study was approved by the Bioethics Committee of the Autonomous University of Manizales, as stated in minute 62 from March 15, 2017 (No. 074-2016). It complied with the provisions of resolution 8,430 of the Ministry of Health of Colombia, which governs research in humans.

The study was a retrospective, descriptive, observational study. Access was granted to the database of a radiological center in the city of Manizales, Colombia. A total of 1,359 CBCT scans were selected from patients who required imaging for orthodontic, surgical, endodontic, or implant treatment between June 2014 and June 2016. Teeth with extensive root resorption processes, immature roots, endodontic treatment, calcifications, dental posts, and molars with roots less than or equal to 6 mm in length from the cementoenamel junction (CEJ) were excluded from the study. The tomographic images were taken with a CS 9300 PREMIUM device (Carestream Health, Rochester, NY, USA), with voxel size from 0.09 to 0.2 mm with settings of a 12-second exposure time, 15 mA, and 80 kV following the manufacturer's instructions. The images were analyzed using the CS-3D visualization software (Carestream Health).

Three transversal sections were made on the longitudinal axis of the root:
- Cervical: 3 mm apical to the CEJ.
- Middle: half the distance between the CEJ and the radiographic apex.
- Apical: 2 mm from the radiographic apex.

The frequency and type of root fusion in the first and second permanent maxillary molars were evaluated based on the axial sections of the middle and apical thirds to determine the continuity of the configuration. Root fusion was considered to be present when there was no evidence of periodontal ligament space or presence of bone between the different roots of the molars at any apical level to the bifurcation area, according to the criteria proposed by Ross and Evanchik [24]. All the images were evaluated by 4 previously calibrated observers.

To characterize the type of root fusion of the maxillary molars, the classification of Zhang *et al.* [7] was used.
- Type 1: Mesiobuccal (MB) root fused with distobuccal (DB) root.
- Type 2: MB root fused with palatal (P) root.
- Type 3: DB root fused with P root.
- Type 4: MB root fused with DB root and P root or P root with MB and DB roots (proximal groove).
- Type 5: P root fused with MB and DB roots (vestibular groove).
- Type 6: P, MB, and DB roots fused as a cone-shaped root.

Statistical analysis

The data collected were analyzed using the SPSS version 24 (IBM Corp., Armonk, NY, USA). To calculate intra- and inter-observer reliability, the kappa test was performed. The results obtained were expressed in proportions with 95% confidence intervals (CIs). The Z test was used to establish significant differences between independent variables, and the chi-square test was used to determine the significance of associations between variables. A *p*-value < 0.05 was considered to indicate statistical significance.

RESULTS

The results of the kappa test were 88% for intra-observer reliability and 83% for inter-observer reliability.

A total of 1,274 maxillary molars were analyzed in this study; 534 were first maxillary molars, and 740 were second maxillary molars. To determine the type of fusion, the transversal

sections on the middle and apical thirds of the longitudinal axis of the tooth were evaluated. The transversal coronal section of the longitudinal axis of the tooth was not considered for the classification because in many of the images of the analyzed teeth, this section ran through the pulp chamber.

Overall, 551 maxillary molars (43.2%) presented some type of radicular fusion, of which 64.1% belonged to women and 35.9% to men. There was a statistically significant difference by sex ($p < 0.05$). When applying the chi-square test, a statistically significant association was observed between female sex and the prevalence of radicular fusion ($p < 0.005$).

45.7% of the fused molars corresponded to type 1,2 and 3 (**Figure 1**). The teeth that fulfilled the characteristics of molars with a C-configuration were types 4 and 5, which presented a frequency of 12.5%. The lowest prevalence was observed for type 4 (fusion of all roots with a proximal groove, 4.3%) (**Figure 2**). The most frequently observed type of fusion was type 6 (cone-shaped, 38.7%). Only 3.8% of the fused maxillary molars did not coincide with any of the classifications established in the study (**Table 1** and **Figure 3**).

Maxillary root fusion analysis showed that root fusion was present in 124 (23.3%) of the maxillary first molars and in 427 (57.7%) of the maxillary second molars. The Z test showed a statistically significant difference ($p < 0.05$). The type of root fusion with the highest prevalence in the first maxillary molars was type 3 (DB-P), whereas type 6 (cone-shaped) was most common in the second maxillary molars. A statistically significant difference was observed between the first and secondary maxillary molars for 5 of the 6 types of fusion (**Table 2**).

In the apical third of the fused roots, the most common configuration was type 6 (cone-shaped, 27.2%), followed by type 1 (16.3%). Furthermore, 14.2% of the teeth had separate roots in the apical third, and the lowest prevalence was observed for type 5 (P with MB and DB roots, with a buccal groove), in 2.5% of the teeth.

The apical section was compared with the middle section of each tooth to determine the level of variability in the radicular configuration and to analyze coincidences or discrepancies within the configuration. The type of radicular fusion that presented the most variability in its configuration was type 5 (82.2%), followed by type 6 (42.3%). Teeth with type 1 fusion demonstrated the highest percentage of continuity between the middle third and the apical third (77.6%). Roughly 20% of teeth with configuration type 1, 2, or 3 in the middle third had an apical termination in separate apices (**Table 3**).

To establish the symmetry of radicular fusion between the first maxillary molars, 56 patients were evaluated, of whom 46.4% presented fusion in both the right and left maxillary first molars. For the second maxillary molars, the percentage of symmetry was 63.2% (**Figure 4A**).

Of the 334 patients who presented fusion of the second maxillary molars, 19.8% also showed fusion of the first maxillary molars (**Figure 4B**).

DISCUSSION

This is the first study conducted in South America to characterize patterns of root fusion in maxillary molars analyzed with CBCT *in vivo*.
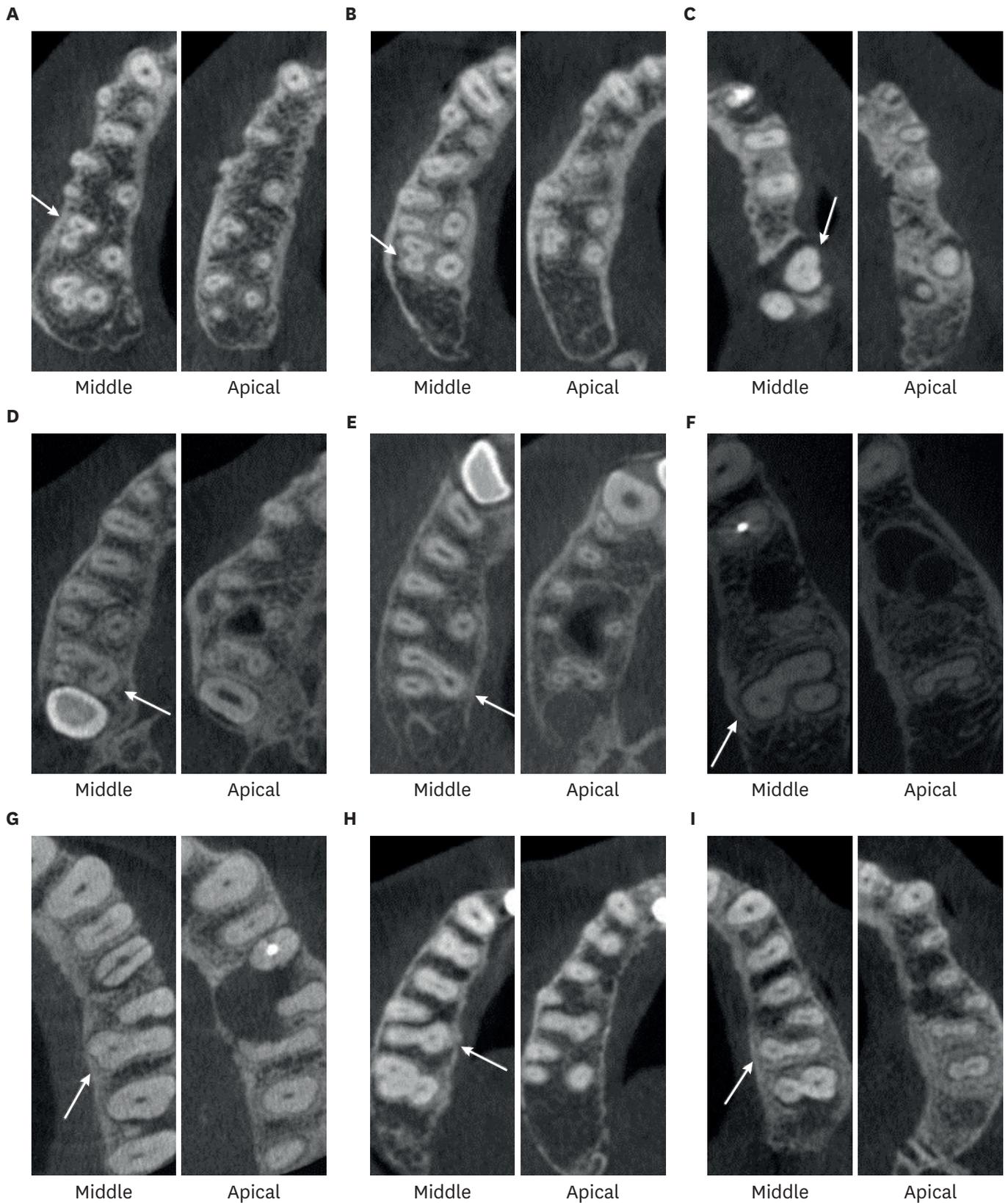
Figure 1. Maxillary first and second molars, fused root type 1, 2 and 3. (A-C) Variations of type 1 root fusion (MB-DB roots) (arrows); (D-F) Variations of type 2 root fusion (MB-P roots) (arrows); (G-I) Variations of type 3 root fusion (DB-P roots) (arrows).
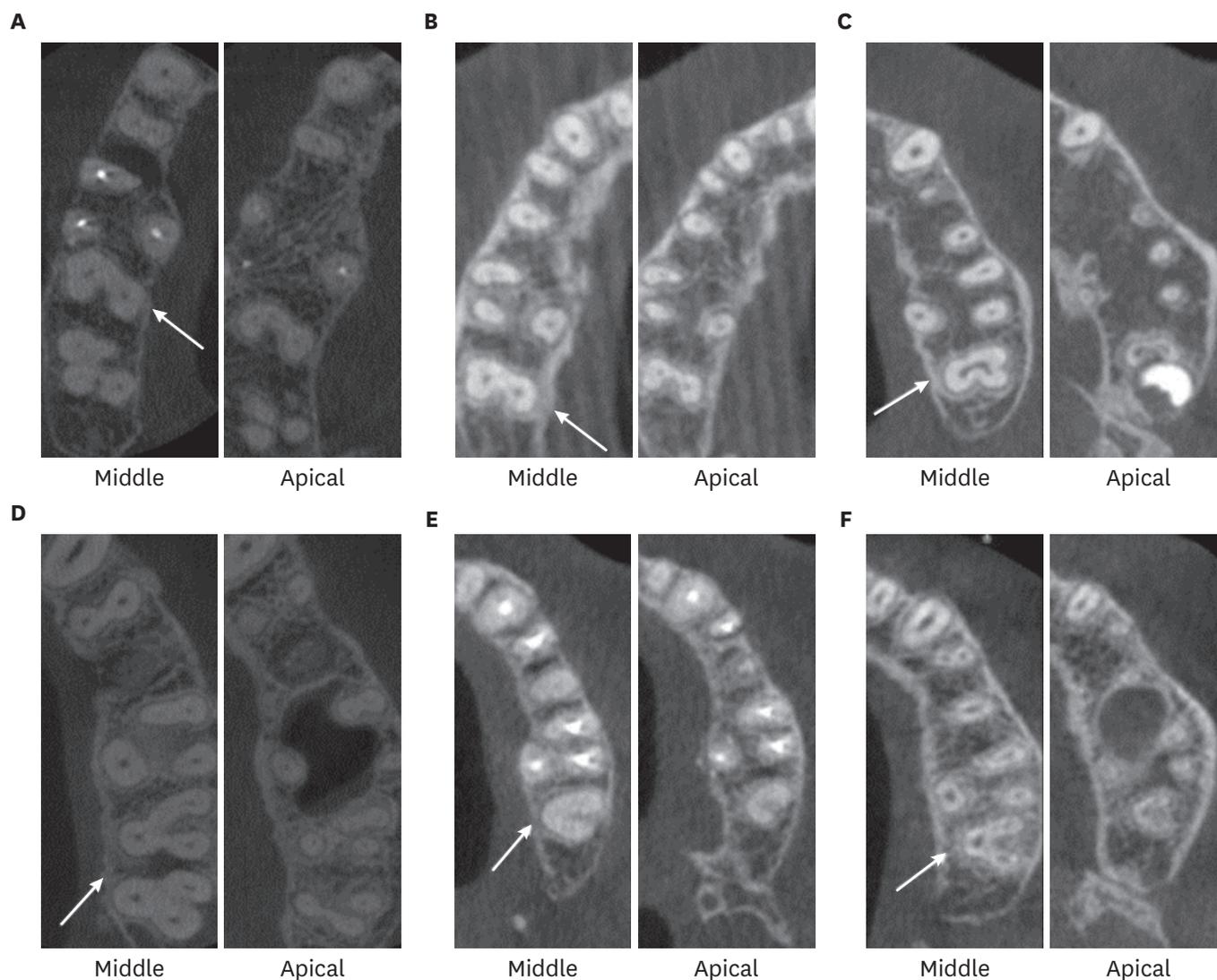MB, mesiobuccal; DB, distobuccal; P, palatal.

Figure 2. Maxillary C-shaped second molars, fused root type 4 and 5. (A-C) Variations of type 4 root fusion (MB-DB-P roots, proximal groove) (arrows); (D-F) Variations of type 5 root fusion (P-MB-DB roots, buccal groove) (arrows).
MB, mesiobuccal; DB, distobuccal; P, palatal.

Table 1. Prevalence and distribution of the different types of fusion in upper molars

Type of fusion	No. (%)
1	49 (8.9)
2	104 (18.8)
3	99 (18.0)
4	24 (4.3)
5	45 (8.2)
6	213 (38.7)
Not catalogued	17 (3.1)
Total	551 (100.0)

The presence of root fusion and root grooves has been associated with highly complex root canal systems [14], and prior knowledge of possible anatomical variations is essential for the success of conventional or surgical endodontic treatment [4]. Although the advantages
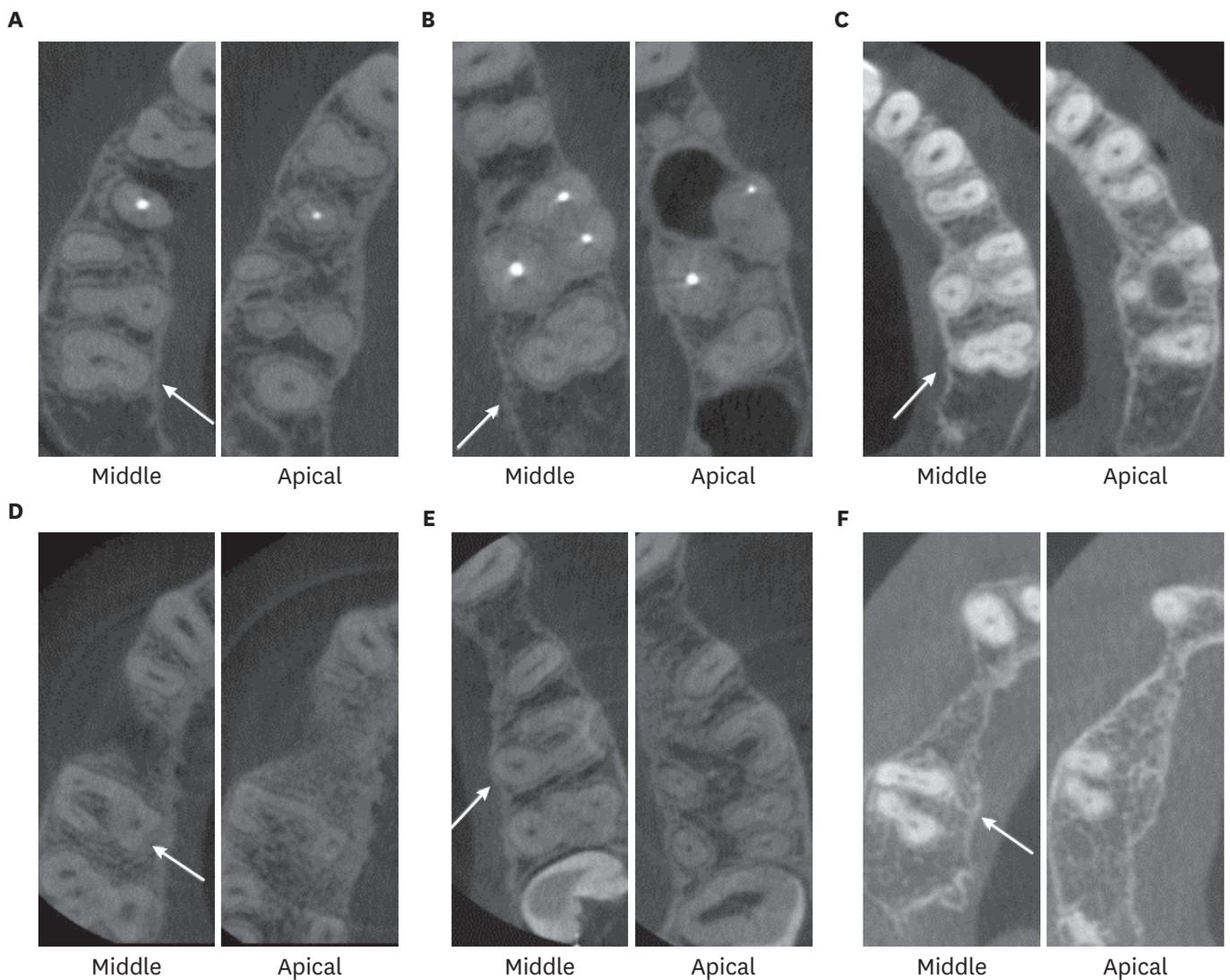
Figure 3. Maxillary first and second molars, fused root type 6 and not catalogued. (A-C) Variations of type 6 root fusion (single root, cone-shape root) (arrows); (D-F) Variations of not catalogued root fusion (arrows).

Table 2. Comparison of the types of fusion between first and second upper molars

Type of fusion	First molars	Second molars	Z test
1	7 (5.7)	42 (9.8)	1.66
2	12 (9.7)	92 (21.5)	3.57*
3	73 (58.9)	26 (6.1)	−11.55*
4	2 (1.6)	22 (5.2)	2.27*
5	4 (3.2)	41 (9.6)	2.98*
6	20 (16.1)	193 (45.2)	7.11*
Not catalogued	6 (4.8)	11 (2.6)	−1.09
Total	124 (100.0)	427 (100.0)	13.38*

Data shown are number (%).
*Statistical difference ($p < 0.05$).

of CBCT have been widely described [15,16], the American Society of Endodontists and the American Academy of Oral and Maxillofacial Radiology have published a guide to rationalize their use in endodontics [25].

Table 3. Variation of the continuity of the configuration from the middle third to the apical third

Middle third	Apical third							
	T 1	T 2	T 3	T 4	T 5	T 6	NC	Separate
T 1 (n = 49)	38 (77.6)	0 (0.0)	0 (0.0)	1 (2.0)	0 (0.0)	0 (0.0)	0 (0.0)	10 (20.4)
T 2 (n = 104)	11 (10.6)	67 (64.4)	0 (0.0)	4 (3.8)	0 (0.0)	3 (2.9)	0 (0.0)	19 (18.3)
T 3 (n = 99)	4 (4.0)	0 (0.0)	65 (65.7)	2 (2.0)	0 (0.0)	4 (4.0)	3 (3.0)	21 (21.2)
T 4 (n = 24)	5 (20.8)	0 (0.0)	0 (0.0)	15 (62.5)	0 (0.0)	3 (12.5)	0 (0.0)	1 (4.2)
T 5* (n = 45)	2 (4.4)	7 (15.6)	4 (8.9)	0 (0.0)	8 (17.8)	17 (37.8)	1 (2.2)	6 (13.3)
T 6 (n = 213)	27 (12.7)	7 (3.3)	6 (2.8)	15 (7.0)	6 (2.8)	123 (57.7)	10 (4.7)	19 (8.9)
NC (n = 17)	3 (17.6)	1 (5.9)	1 (5.9)	0 (0.0)	0 (0.0)	0 (0.0)	10 (58.8)	2 (11.8)

Data shown are number (%).
T, type; NC, not catalogued.
*Most variability in its configuration from the middle third to the apical third.
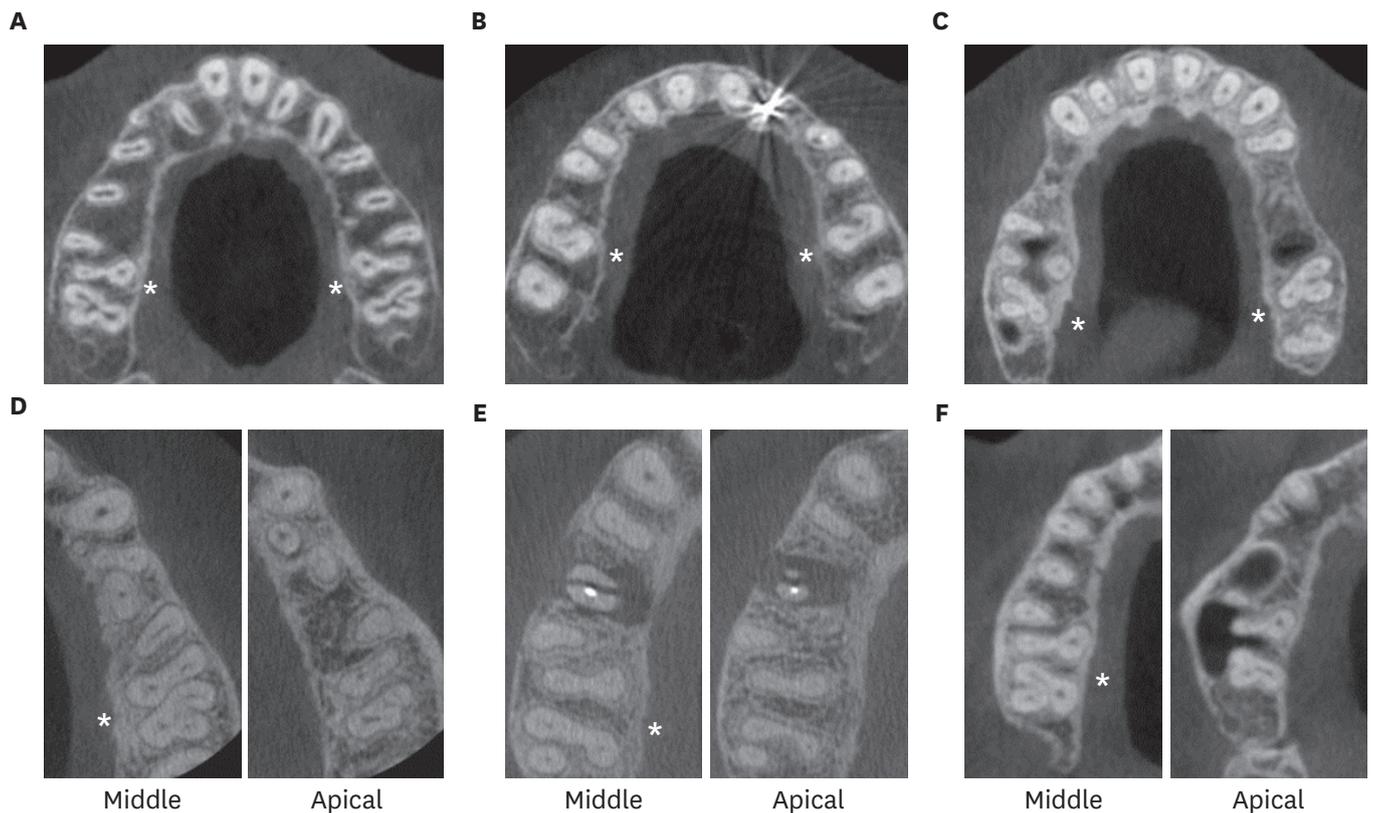
Figure 4. Maxillary first and second molars, symmetry and fusion in adjacent molars. (A-C) Examples of symmetry (*) between right and left maxillary molars. (D-F) Examples of root fusion in the adjacent (*) first and second maxillary molars.

Fusion has been defined as the deposition of cementum on the radicular surface from the CEJ to the apex [18]. The term "fused root" is also defined as two or more roots that are united through deposits formed in the course of an individual's life or as the result of an alteration in the development of the Hertwig epithelial root sheath in the furcation area [7,14,26,27]. It is considered that fusion of the teeth can occur anywhere and that the location of fusion can be in any of the cervical, middle, or apical thirds or in some combination thereof [12]. The major difference in the prevalence of molars with fused roots between upper and lower teeth is due to the fact that upper teeth have more roots, yielding a greater possibility of different combinations compared to the lower molars [26,28].

Some publications have investigated the anatomical characteristics of the maxillary first and second molars, both in terms of root anatomy and the root canal system, but did not mention the prevalence or specify the type of fusion, due to the complexity of these structures [18,20,21].

Of the molars that presented some type of fusion, 64.4% belonged to women and 35.6% to men. This result agrees with the results obtained in a Chinese population, where a higher prevalence of fused teeth was observed in women (67%), while the prevalence in men was 33% [19]. Similar results, but with lower percentages, were observed in the Portuguese population, with a prevalence of 20.5% in women and 12.3% in men [26].

The prevalence of fused maxillary molars in the Colombian population studied was 43%, similar to the results obtained in China (41.37%) [19] and higher than the results obtained in Portugal (17.6%) [26], Korea (11.3%) [29], Brazil (7.84%) [21], Thailand (6.43%) [30], and the United States (0.9%) [20]. A possible contributor to the high prevalence reported herein may be the fact that teeth with fusion, at least in the middle third of the roots, were classified as fused roots, unlike other studies that reported lower percentages because only teeth that presented complete radicular fusion were considered to be fused [7,15].

Root fusion was observed in 23.2% of first maxillary molars. This percentage is higher than has been reported in China (1.38% - 2.71%) [17,18], Korea (3.2%) [29], India (1%) [15], Portugal (7.1%) [26], and Thailand (0.2%) [30]. In Egypt, absence of fused roots [31] was reported. The most commonly observed type of fusion was type 3 (DB-P), which was found in 58.9% of fused first maxillary molars, coinciding with the type of fusion with the highest prevalence in a Portuguese population [26]. Our results differ from those obtained in Korea, where the type of fusion with the highest prevalence was type 1 (MB-DB) [29].

In second maxillary molars, the frequency of root fusion was observed to be 57.7%. This result is much higher than those reported by other studies conducted in Korea (19.5%) [16], China (23.9%) [18]), India (6.7%) [15], Portugal (25.2%) [26], Egypt (8.3%) [31], and Thailand (12.9%) [30]. The most frequent configuration was type 6 (cone-shape) in 45.3% of fused molars, followed by type 2 fusion (MB-P) in 21.5%. These results are very different from a previous study in Portugal that reported a higher prevalence of type 2 (MB-P) fusion (27%) [26] and a study in Korea that reported a 35.6% prevalence of type 2 fusion [29]. However, our findings are similar to those of an anatomical study carried out in 1992 by Carlsen *et al.* [13] in sections of extracted single root teeth, a classification that was proposed as a new variant by Martins *et al.* [26]. The most similar results to those of this study have been reported in studies on extracted teeth, where the presence of radicular fusion has been demonstrated to be between 31% and 49% [12,13,32].

The high frequency of root fusion in both maxillary first and second molars could be related, as mentioned above, with the criteria used to classify molars as having fused roots and with ethnic and racial factors specific to this Latin American region [1,16,22-24,29].

According to Fan *et al.* [6], in mandibular molars, for a tooth to be cataloged as C-shaped, it must meet three requirements: fused roots, a longitudinal groove in the lingual or buccal face of the root, and at least one C-configuration (C1, C2, or C3) in some third of the root length. According to these criteria, only type 4 and 5 (fusion of all roots with a proximal or buccal groove) molars (12.4%; *n* = 69), were classified as C-shaped molars.

Martins *et al.* [28], Ordinola-Zapata *et al.* [14], and Jo *et al.* [29] cataloged C-shaped molars, according to two criteria: having fusion of some roots and an anatomy of an elongated canal or two canals joined by an isthmus. The prevalence in Portugal of C-shaped molars was 1.1% in first molars and 3.8% in second molars [28], and in Korea it was 0.8% in first molars and 2.7% in second molars [29]. The results regarding the C-shape configuration in this study differ from the aforementioned findings, because the criteria for cataloging this anatomical variation were different.

In relation to the continuity of the root configuration, this is the first study in maxillary molars to perform this type of analysis with the goal of determining the variability and complexity of molars with fused roots. The molars with type 5 fusion presented the greatest amount of variation in their apical third, where only 17.8% of the teeth maintained the same configuration as the middle third. In contrast, the molars with type 1 and 3 fusion maintained continuity of their configuration in 77.6% and 65.7% of cases, respectively. It was observed that the other types of fusions maintained the same type of root configuration in the middle and apical thirds in over 58% of cases.

Bilateral root fusion in maxillary first molars was observed in almost half of the teeth examined, and maxillary second molars showed bilateral root fusion in more than 60% of cases.

Furthermore, approximately 20% of patients with radicular fusion in the maxillary second molars had root fusion in the adjacent first maxillary molars.

CONCLUSION

Within the limitations of this study, there was a high prevalence of root fusion in maxillary molars in Latinamerican sub population (Colombia), especially in the second molars. The type of root fusion most frequently observed in the first maxillary molars was the union of DB and P roots, and in the second maxillary molars, the most common type was type 6, (cone-shape). A high prevalence of C-shape molars was observed. The high prevalence of root fusion in maxillary molars and the variability of their configuration generate additional considerations during conventional endodontic therapy, apical microsurgery, and alternative surgical techniques such as intentional reimplantation and dental auto-transplantation. Knowledge of anatomic root configuration is important, as it can affect the diagnosis, therapeutic modality, and long-term success of root canal therapy.

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