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Influence of anatomical features in the endodontic treatment planning of maxillary anterior teeth

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Abstract: This study evaluate the maxillary anterior teeth anatomy by micro-computed tomography (μCT), about relevant characteristic for endodontic treatment planning. Fifty maxillary central incisors (MCI), lateral incisors (MLI) and maxillary canines (MC) were scanned using a μCT device. Two and three-dimensional parameters at 1 to 5mm distance to the apical foramen, external anatomic characteristics of the teeth and qualitative analysis of the internal anatomy was performed. The roundness and form factor values revealed a circular canal in the apical third in the MCI and MC, whereas MLI showed flattening in the apical third. The linear regression test indicated a progressive increase in the major/minor diameters in the five mm assessed ($p < 0.001$). The 3D analysis revealed the greatest volume and surface area in MC. The SMI showed a cylindrical geometry of root canals. All teeth presented Vertucci's type I root canal configuration. A mild curvature was prevalent in the MCI (45%) and a moderate one in the MLI (50%) and MC (50%). Palatal shoulder volume was smaller in the MLI (11.46 ± 3.09) than in the MCI (14.15 ± 3.85) and MC (13.95 ± 2.55). The most common exit of main apical foramen was in a central (22%), distolingual (30%) and mesiobuccal position (28%) for MCI, MLI and MC, respectively. Radicular grooves were observed in 2% of MCI and 4% of MLI. Two and three-dimensional data obtained by μCT allowed to observe morphological characteristics of internal/external anatomy of the maxillary anterior teeth. These characteristics may affect the endodontic treatment planning.

Keywords: Endodontics; X-Ray Microtomography; Dental Pulp Cavity; Root Canal Therapy; Tooth.

Introduction

The success of endodontic treatment depends directly on cleaning and disinfection, modeling and three-dimensional obturation of the root canal system (RCS).[1,2,3] Knowledge of the three-dimensional morphology of the RCS is a prerequisite for successful endodontic treatment, as it helps to identify anatomical variations such as lateral canals, accessory canals and canal isthmus. This assessment contributes to the diagnosis and treatment protocol, ensuring adequate biomechanical preparation of the root canals and controlling etiological factors related to apical periodontitis.[4-7]

Micro-computed tomography (µCT) has allowed for the advancement of diagnosis and planning, as well as endodontic treatment, since it allows for three-dimensional qualitative and quantitative study of the RCS, and the *ex vivo* study of the external anatomy of different tooth groups in a non-destructive way.[2,3,8]

In recent years, anatomical studies have been carried out using µCT to study different tooth groups or specific conditions such as double-rooted mandibular canines, four-rooted maxillary second molars, single-rooted mandibular canines, enamel pearls, oval root canals, deciduous teeth, mandibular incisors, mandibular first molars with three roots, mandibular/maxillary premolars, and mandibular/maxillary molars.[2,3,8-13]

However, two- and three-dimensional quantitative morphological studies and qualitative analysis of the internal and external anatomy of maxillary anterior teeth have not yet been reported in the literature. Thus, the aim of the study was to evaluate two- and three-dimensional morphometric aspects of the internal and external anatomy of maxillary central, lateral incisors and canines using µCT.

Methodology

The sample size calculation was performed by G*Power 3.1.9.2 software (Heinrich Heine-Universität, Düsseldorf, Germany), using F and ANOVA statistical tests for fixed effects, special, main effects and interaction. The type of power analysis was a priori: Compute required sample size – given α, power, and effect size, and the imput fixed parameters were effect size f = 0.5, error type $\alpha = 0.05$, statistical power $\beta = 0.8$, numerator degrees of freedom = 3, and number of groups = 3. The output parameters showed a minimum estimated sample size of 48. So, a sample size of 50 specimens (n = 50) was chosen for each dental group.

After approval by the Research Ethics Committee (Protocol No 0072.0.138.000-09), 150 teeth (50 maxillary central incisors, 50 maxillary lateral incisors and 50 maxillary canines), with complete rhizogenesis, root structure, and tooth crowns with complete or partially intact incisal edges were obtained from a biobank and maintained in 0.1% thymol solution. The teeth were washed in running water for 24 h and their external root surface was cleaned by ultrasonic scraping (Profi II Ceramic, Dabi Atlante Ltda., Ribeirão Preto, Brazil). Next, the teeth were stored in 1% NaCl solution for 2 h to remove the remaining pulp tissue from the RCS to prevent interferences in the processing of the µCT images.

The teeth were scanned in a µCT scanner (SkyScan 1174 v.2; Bruker-microCT, Kontich, Belgium) at an isotropic resolution of 26.70 µm, 50 kV, 800 µA, rotation of 180°, step rotation of 1 and 0.5-mm aluminum filter, resulting in a total of 195 projections. The two-dimensional projections obtained from each specimen were reconstructed using NRecon v.1.6.6.0 (Bruker-microCT, Kontich, Belgium) using ring artifact reduction of 5 (0–20 scale), beam hardening correction of 40% (0 to 100%), smoothing correction of 3 (0–10 scale) and histogram ranging from 0.001 (minimum value) to 0.15 (maximum value) with 999 cross-sections images.

Internal anatomy analysis

The Individual Object Analysis (2D space) tool from CTAn v.1.13.5.1+ (Bruker microCT, Kontich, Belgium) was used for image processing and analysis. The area (mm^2), perimeter (mm), roundness, form factor (FF), major diameter (mm) and minor diameter (mm) were obtained from the root canals at 1, 2, 3, 4 and 5 mm from the apical foramen.

CTVol v.2.2.3.0 (Bruker-microCT, Kontich, Belgium) was used for visualization of three-dimensional models for the qualitative analysis of the internal and external anatomy. The analysis of the internal anatomy of different morphological types of the RCS was performed using Vertucci's[14] classification of canal morphology and the additional classifications discussed in the literature that present a total of 37 types of root canal configurations.[3,12,13,15]

Adapting the method proposed by Schneider,[16] the apical curvature of the root canal was analyzed using DataViewer v.1.5.0, which allows simultaneous visualization of three orthogonal planes to select the coronal section of the root canal with reference to the sagittal plane that passes through the center of the buccal cusp to the root apex. After the selection, the apical curvature angle formed by the intersection between the straight line along the long axis of the root canal and the straight line that passes through the exit of the apical foramen was evaluated in CTAn using the measure tool. The curvature angle was classified as slight curvature (< 10°), moderate curvature (between 10° and 25°) and severe curvature (> 25°) (Figure 1A).

The qualitative analysis of the axial sections of the root canals in the cervical, middle and apical thirds was carried out in DataViewer. The location of the palatal shoulder was observed through longitudinal cuts in DataViewer. The quantitative analysis of the palatal shoulder volume was used in CTAn to determine the volume of interest in the dentin region that corresponds to 3 mm in the vertical dimension from the CEJ in the apical; the mesiodistal direction was established based on the margins of the root canal. After establishing the volume of interest of dentin that corresponds to the palatal shoulder, the

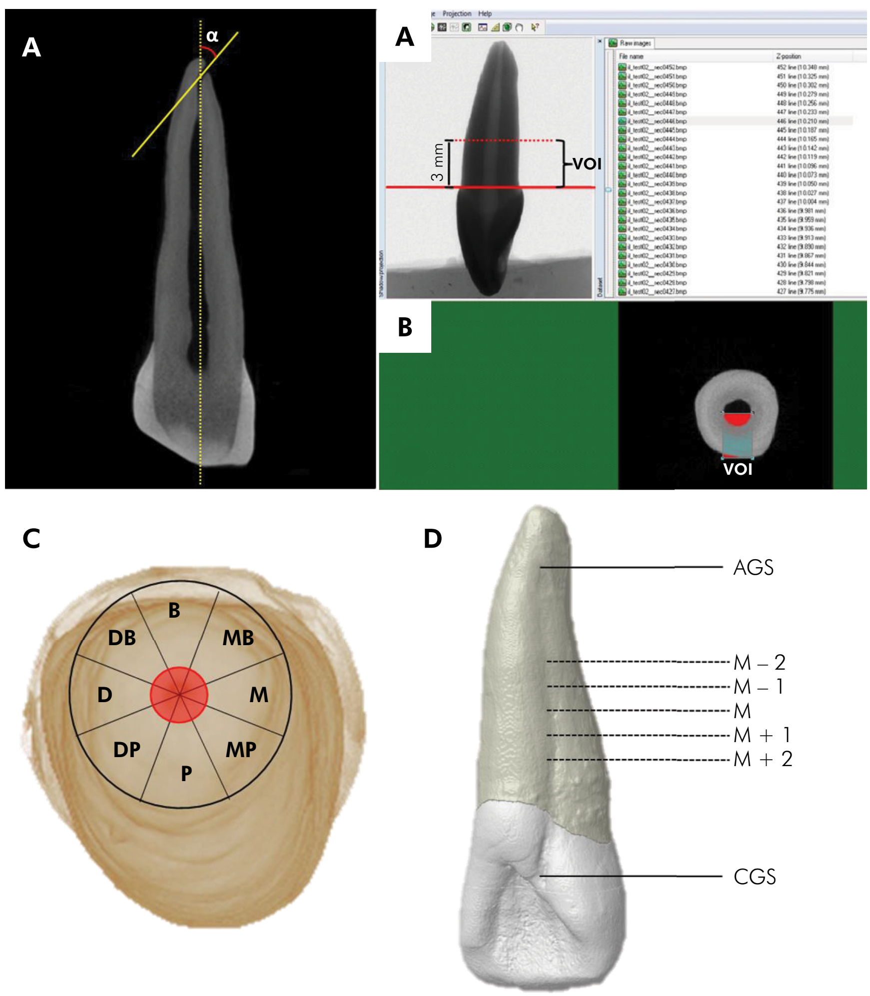

Figure 1. (A) Angle of apical curvature of the root canal (α) formed by the intersection between the dotted line that runs along the long axis of the canal and the continuous line that runs through the exit of the apical foramen, measured in the microcomputed tomography based on the method of Schneider.[15] (B) Region of interest (ROI) selection of the cervical shoulder region for volume calculation. (C) Apical foramen position classification: B - buccal; MB - mesiobuccal; M - mesial; MP - mesiolingual; P-lingual; DP - distolingual; D - distal; DB - distobuccal. Circle in red represents the center position. (D) Anatomical reference landmarks: cervical groove section (CGS), apical groove section (AGS), cross-section corresponding to half of the radicular groove extension (M), 2 mm above the central section (M + 2), 1 mm above the central section (M + 1), 2 mm below the central section (M - 2), 1 mm below the central section (M - 1).

volume, surface area and structure model index (SMI) was carried out (Figure 1B).

External anatomy analysis

CTAn was used to analyze the total tooth length (root apex to the incisal edge on the buccal surface); total crown length (CEJ to the incisal edge on the buccal surface); total root length (root apex to the limit of the CEJ on the buccal surface); crown dimensions in the mesiodistal direction, incisal edge and cingulum in the buccal-palatine direction in the anatomical region, and the distance from the apical foramen to the anatomic apex.

CTVox v.2.2.1.0 (Bruker-microCT, Kontich, Belgium) was used to carry out the qualitative analysis of the position of the foramen of the following surfaces: buccal, palatine, mesial, distal, mesio-buccal, mesiopalatal, distobuccal, distopalatal and central surfaces (Figure 1C).

The analysis of the apical foramen (structure that separates the canal termination from the external root surface) and apical constriction (apical portion of the root canal that has a minor diameter that sometimes coincides with the junction between the dentin and cementum) was carried out in CTAn to compare the two-dimensional morphometric parameters of roundness, major and minor diameter.

The presence of radicular grooves was evaluated using CTAn by measuring the cervical extension of the groove (SCS) to the apical extension of the groove (SAS) and groove depth using the Measure Tool. The depth measurements were performed on the root surface in 5 pre-established cross-sections from the cross-section corresponding to half the extent of the radicular groove (M); 2 mm above the central section (M + 2); 1 mm above the central section (M + 1); in the central section (M); 2 mm below the central section (M - 2) and 1 mm below the central section (M - 1) (Figure 1D).

Statistical analysis

Statistical analysis was performed using InStat, v.3.06 (GraphPad Software, La Jolla, USA). The data for each parameter underwent the Kolmogorov-Smirnov statistical test to verify normal distribution. The significance level was set at 0.05. Due to normal distribution of the data, one-way ANOVA and Tukey post-hoc test were used to compare the three groups of teeth for each parameter. Simple linear regression was used to determine the influence of apical foramen distance on the parameters that were assessed.

Results

Anatomy assessment of the root canals

Table I shows the mean and standard deviation values of the two-dimensional parameters (area, roundness, form factor, major and minor diameter) in central, lateral incisors and maxillary canines. No statistical difference was observed between the central, lateral incisors and maxillary canines ($p > 0.05$) in terms of area (Table 1). The simple linear regression test revealed that the area presented similar gradual increases of 0.08 mm^2 for central incisors and canines and 0.10 mm^2 for lateral incisors for each mm increment distance from the apical foramen ($p < 0.001$) (Figure 2I). As for the perimeter, the values of lateral incisors were higher at 3 and 4 mm from the apical foramen compared with central incisors and canines ($p < 0.05$) (Table 1). Linear regression revealed that the perimeter showed gradual increases of 0.27 mm for central incisors, 0.35 mm for lateral incisors and 0.29 mm for canines for each mm increment distance from the apical foramen ($p < 0.001$) (Figure 2II).

The mean values of roundness and form factor showed a circular tendency of the roots in central incisors and canines with a slight tendency to flattening in the maxillary lateral incisors (Table 1). This tooth group presented the lowest values of roundness and form factor in the 5 apical millimeters evaluated ($p < 0.05$) (Table 1). Linear regression showed that both roundness and form factor remained constant for central, lateral incisors and maxillary canines in the 5 apical millimeters evaluated ($p > 0.05$) (Figures 2III and 2IV).

Regarding the diameters, the mean value of the major diameter at 1 mm from the apical foramen was close to the mean value of the minor diameter in both central incisors and canines, unlike the lateral incisors in which the major diameter was approx. 1.5 times the minor diameter, confirming the flattening of

Table 1. Mean ± standard deviation values of two and three-dimensional morphometric analysis of: area, perimeter, roundness, form factor, major and minor diameters, volume, surface area and SMI in maxillary central and lateral incisors and canines.

Tooth	Distance from apical foramen	Area (mm^2)	Perimeter (mm)	Roundness	Form factor	Major diameter (mm)	Minor diameter (mm)	Volume (mm^3)	Surface area (mm^2)	SMI
	1 mm	0.16 ± 0.07^{a}	1.49 ± 0.38^{a}	0.77 ± 0.06^{a}	0.87 ± 0.05^{a}	0.50 ± 0.13^{ab}	0.41 ± 0.10^{a}			
	2 mm	0.20 ± 0.11^{a}	1.68 ± 0.46^{a}	0.75 ± 0.10^{a}	0.86 ± 0.06^{a}	0.57 ± 0.17^{b}	0.46 ± 0.11^{a}			
MCI	3 mm	0.31 ± 0.20^{a}	2.00 ± 0.57^{ab}	0.76 ± 0.12^{a}	0.85 ± 0.07^{a}	0.68 ± 0.21^{ab}	0.52 ± 0.13^{a}	8.40 ± 4.62^{a}	42.29 ± 13.28^{a}	2.51 ± 0.91^{a}
	4 mm	0.37 ± 0.19^{a}	2.27 ± 0.61^{ab}	0.76 ± 0.11^{a}	0.84 ± 0.07^{a}	0.77 ± 0.21^{b}	0.60 ± 0.17^{a}			
	5 mm	0.47 ± 0.25^{a}	2.55 ± 0.69^{ab}	0.75 ± 0.10^{a}	0.85 ± 0.07^{a}	0.87 ± 0.24^{b}	0.67 ± 0.17^{a}			
	1 mm	0.16 ± 0.11a	1.53 ± 0.57^{a}	0.64 ± 0.15^{b}	0.81 ± 0.10^{b}	0.56 ± 0.24^{a}	0.36 ± 0.11^{b}			
	2 mm	0.22 ± 0.16^{a}	1.76 ± 0.65^{a}	0.61 ± 0.13^{b}	0.79 ± 0.08^{b}	0.65 ± 0.25^{a}	0.40 ± 0.14^{a}			
MLI	3 mm	0.31 ± 0.21^{a}	2.11 ± 0.70^{b}	0.63 ± 0.13^{b}	0.80 ± 0.08^{b}	0.77 ± 0.27^{a}	0.48 ± 0.15^{a}	7.93 ± 3.57^{a}	39.95 ± 8.50^{a}	2.60 ± 0.41^{a}
	4 mm	0.43 ± 0.27^{a}	2.53 ± 0.81^{b}	0.62 ± 0.14^{c}	0.78 ± 0.09^{b}	0.91 ± 0.30^{a}	0.56 ± 0.17^{a}			
	5 mm	0.54 ± 0.31^{a}	2.90 ± 0.79^{a}	0.63 ± 0.16^{b}	0.76 ± 0.12^{c}	1.04 ± 0.30^{a}	0.65 ± 0.20^{a}			
	1 mm	0.14 ± 0.08^{a}	1.35 ± 0.39^{a}	0.73 ± 0.10^{a}	0.87 ± 0.05^{a}	0.47 ± 0.13^{b}	0.37 ± 0.10^{b}			
	2 mm	0.18 ± 0.11^{a}	1.60 ± 0.49^{a}	0.74 ± 0.11^{a}	0.86 ± 0.06^{a}	0.55 ± 0.18^{b}	0.43 ± 0.13^{a}			
MC	3 mm	0.24 ± 0.15^{a}	1.81 ± 0.63^{a}	0.74 ± 0.12^{a}	0.86 ± 0.07^{a}	0.63 ± 0.24^{b}	0.49 ± 0.15^{a}	14.46 ± 5.27^{b}	66.20 ± 18.82^{b}	2.28 ± 0.81^{a}
	4 mm	0.33 ± 0.22^{a}	2.15 ± 0.77^{a}	0.70 ± 0.11^{b}	0.84 ± 0.07^{a}	0.75 ± 0.29^{b}	0.55 ± 0.18^{a}			
	5 mm	0.44 ± 0.27^{a}	2.52 ± 0.83^{b}	0.67 ± 0.13^{b}	0.81 ± 0.08^{b}	0.89 ± 0.32^{b}	0.60 ± 0.19^{a}			

Different letters indicate statistical difference between rows (Tukey Test, $p < 0.05$).

these root canals (Table 1). Linear regression showed a progressive increase in major and minor diameters at the five evaluated levels ($p < 0.001$), with increases of 0.09 mm and 0.07 mm for central incisors; 0.12 mm and 0.07 mm for lateral incisors and 0.11 mm and 0.06 mm for canines (Figures 2V and 2VI).

The morphometric analysis of the three-dimensional models of root canals showed that the mean volume and surface area in canines (14.46 ± 5.27 mm^3 and 66.20 ± 14.82 mm^2) was significantly higher ($p < 0.05$) than that of central incisors (8.40 ± 4.62 mm^3 and 42.29 ± 13.28 mm^2) and lateral incisors (7.93 ± 3.57 mm^3 and 39.95 ± 8.50 mm^2), which were statistically similar to each other. Mean SMI values of 2.51 ± 0.91, 2.60 ± 0.41 and 2.28 ± 0.81 were found for central, lateral incisors and canines, respectively, suggesting a three-dimensional geometric shape with a slightly higher cylindrical trend for the former two groups (Table 1), but differences were not significant.

The three-dimensional models showed that 100% of the central, lateral incisors and maxillary canines could be classified according to Vertucci's[14] classification of canal morphology. Type I was the only classification found in all the tooth groups evaluated (Figure 3A-B). Analysis of the axial sections of the root canal revealed that central incisors and maxillary lateral incisors were predominantly circular with tendency for flattening in the apical third (Figures 3A-I and 3B-II). On the other hand, the axial section of maxillary canines showed the presence of oval-shaped canals in the cervical and middle thirds, with a longer diameter in the buccal-palatine direction in the middle third of the root, and a decreased flattening in the apical third. In addition, decentralized root canals and decreased dentin thickness in the apical region of teeth presenting an accentuated curvature were observed (Figure 3C-III).

The apical curvature angle of the root canal in central incisors showed a higher incidence of slight curvature (45%) compared with lateral incisors and canines, which showed a higher incidence of moderate curvature (50%) (Figure 4). The longitudinal sections showed that the location of the palatine shoulder in the three tooth groups evaluated was more prominent in the canine group (Figure 5). Quantitative analysis showed that a lower mean

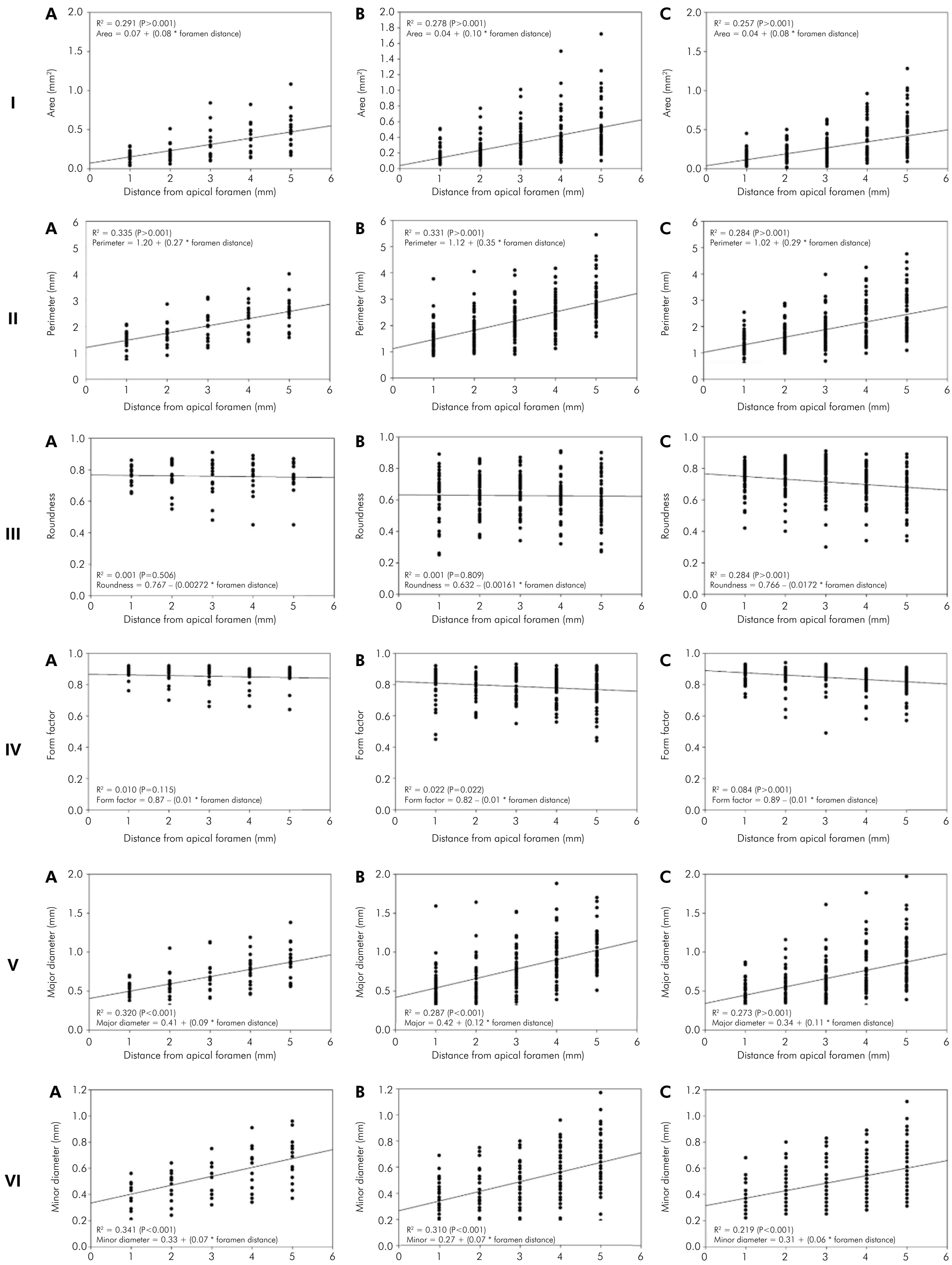

Figure 2. Analysis of correlation between two-dimensional parameters and the distance from the apical foramen (mm) for maxillary central (A) and lateral (B) incisors and canines (C). (I) Area; (II) Perimeter; (III) Roundness; (IV) Form factor; (V) Major diameter; (VI) Minor diameter.

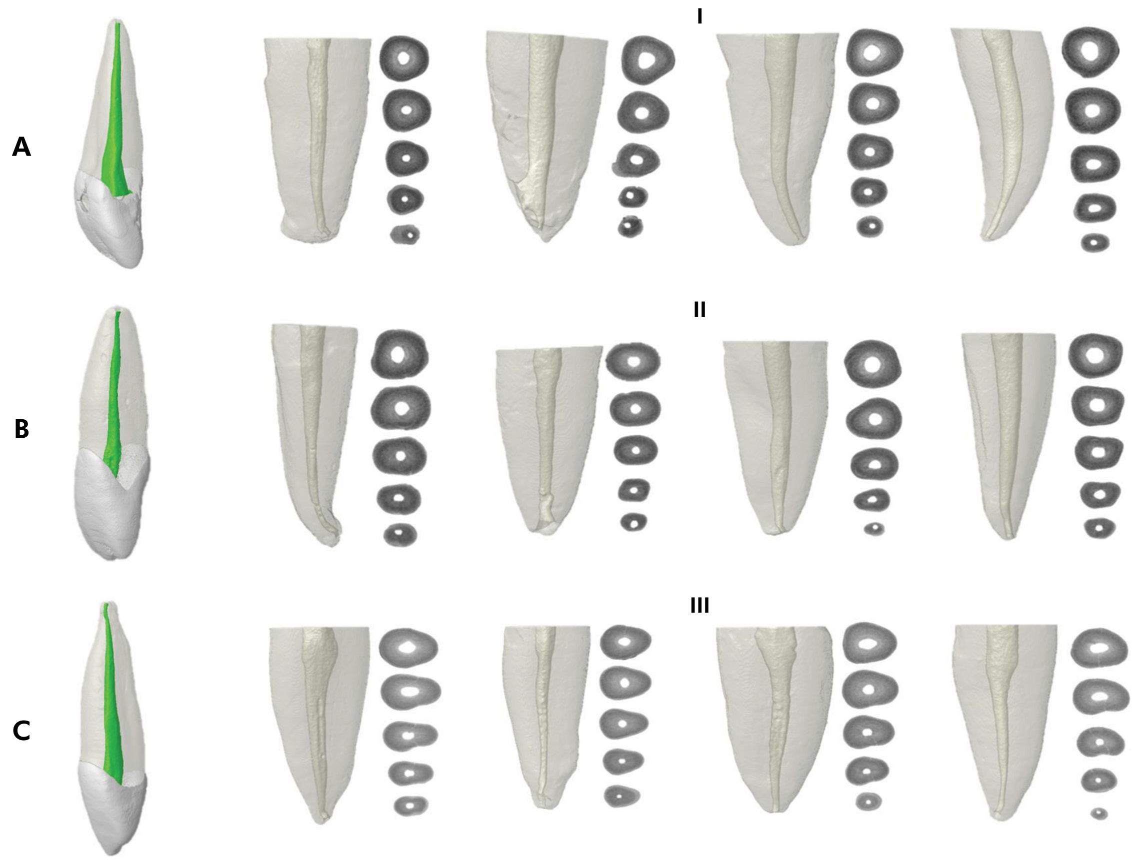

Figure 3. Root canal system internal anatomy according to Vertucci's classification.[14]

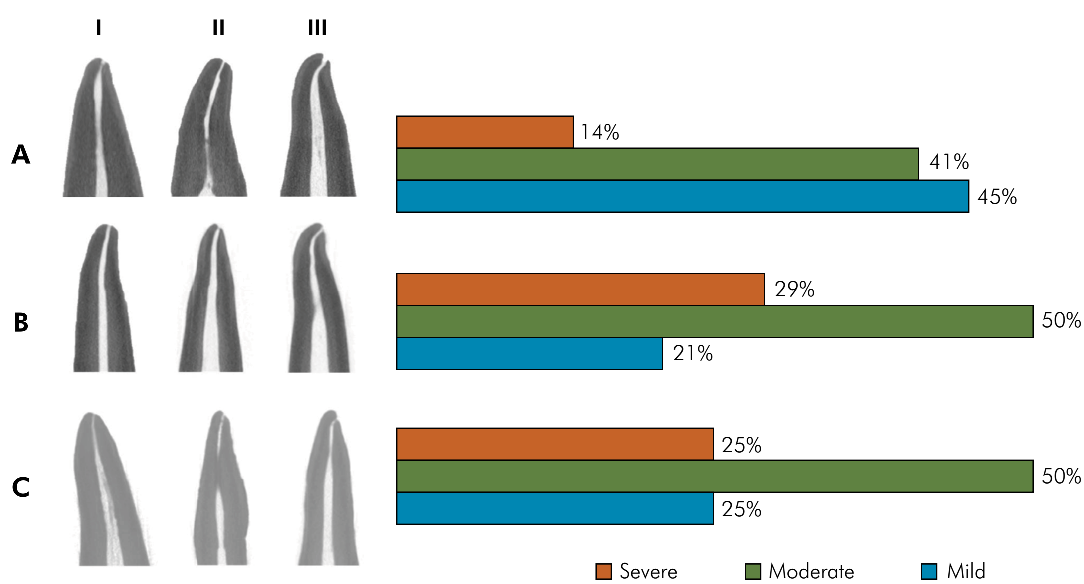

Figure 4. Percentage of each type of curvature observed in maxillary anterior teeth: (A) central incisors, (B) lateral incisors and (C) canines. (I) mild curvature; (II) moderate curvature and (III) severe curvature.

Figure 5. Longitudinal sections showing the location of the cervical shoulder (yellow arrows) in maxillary anterior teeth: (A) central incisors; (B) lateral incisors and (C) canines.

Table 2. Volume (mm^3) of dentin (Mean ± SD) in the region of cervical shoulder.

Variable	MCI (mm^3)	MLI (mm^3)	MC (mm^3)
Cervical shoulder	14.15 ± 3.85[a]	11.46 ± 3.09[b]	13.95 ± 2.55[a]

Different letters indicate statistical difference between columns (Tukey Test, $p<0.05$)

volume of the palatal shoulder was found in maxillary lateral incisors ($p < 0.05$) in relation to the central incisors and canines, which presented similar values ($p > 0.05$) (Table 2).

External anatomy analysis

The mean values and standard deviations of total tooth length, root length, crown height, and distance from the apical foramen to the anatomic apex are shown in Figure 6 (A- Central incisors; B- Lateral incisors; C- Canines).

The presence of central incisors with shovel-shaped crowns was observed in 88.5% of the sample, distributed as follows: 65.4% were shovel-shaped crowns, 17.3% were double shovel-shaped crowns, and 38.5% were shovel-like crowns. The presence of finger-like crowns was observed in 1.9% of the teeth evaluated. For the lateral incisors, the presence of shovel-shaped crowns was observed in 100% of the sample, distributed as follows: 63.0% were shovel-shaped, 22.2% were double shovel-shaped, and 3.7% were shovel-like. The presence of finger-like was also observed in 11.1% of the teeth evaluated.

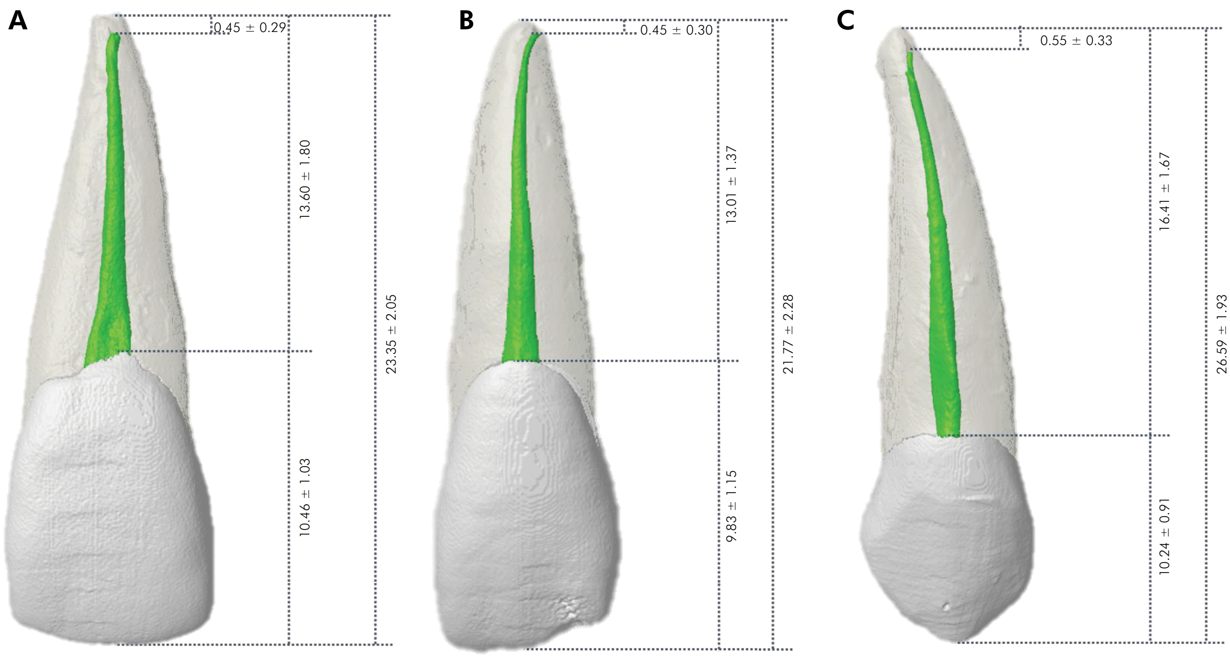

Figure 6. Volume rendering showing the mean values of distances (mean ± SD) of total tooth length, root length, crown height, and perpendicular distance from the apical foramen to the anatomic apex in maxillary anterior teeth (mm): (A) central incisors; (B) lateral incisors and (C) canines.

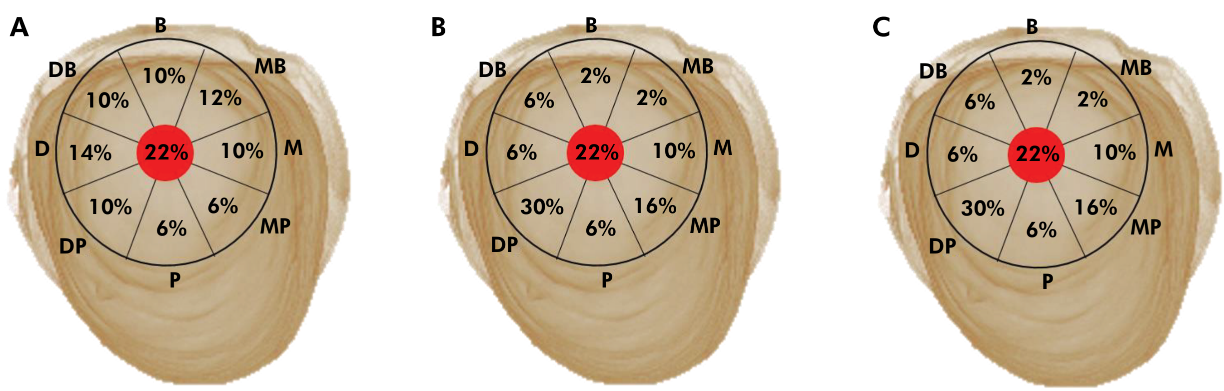

Figure 7. Percentage of the position of the apical foramen in maxillary anterior teeth: (A) central incisors; (B) lateral incisors and (C) canines. The circle in red represents the central region of the root apex. B: buccal position; DB: distobuccal position; D: distal position; DP: distolingual position; P: lingual position; MP: mesiolingual position; M: mesial position; MB: mesiobuccal position.

Analysis of apical foramen

In maxillary central incisors, the apical foramen was located in the central region of the root apex in only 22% of the teeth (Figure 7A). In maxillary lateral incisors, the apical foramen was located in the distopalatal region of the root apex in most cases (30%), with a lower incidence (2%) in the buccal and mesio-buccal regions (Figure 7B). In the maxillary canines, the highest (28%) and lowest (2%) incidence were found in the mesio-buccal and distopalatal regions, respectively (Figure 7C). In the central incisors and canines, the canal in the region of apical constriction (minor foramen) presented a more circular shape compared with the canal form in the apical foramen (major foramen) ($p < 0.005$) (Table 3). In addition, the major diameter in canines increased as it was more distant from the apical constriction towards the apical foramen ($p<0.005$) (Table 3). In the maxillary lateral incisors, no statistical difference was found among the parameters evaluated ($p> 0.05$) (Table 3).

Table 3. Two-dimensional morphometric analysis of roundness, major and minor diameter (mean ± standard deviation) of the root canal in the apical constriction and in the apical foramen of maxillary central and lateral incisors and canines.

Variable	Apical constriction	Apical foramen
MCI		
Roundness	0.77 ± 0.06[a]	0.67 ± 0.12[b]
Major diameter (mm)	0.50 ± 0.13[a]	0.51 ± 0.15[a]
Minor diameter (mm)	0.41 ± 0.10[a]	0.37 ± 0.11[a]
MLI		
Roundness	0.64 ± 0.15[a]	0.65 ± 0.13[a]
Major diameter (mm)	0.56 ± 0.24[a]	0.54 ± 0.23[a]
Minor diameter (mm)	0.36 ± 0.11[a]	0.36 ± 0.12[a]
MC		
Roundness	0.73 ± 0.10[a]	0.65 ± 0.14[b]
Major diameter (mm)	0.47 ± 0.13[a]	0.54 ± 0.19[b]
Minor diameter (mm)	0.37 ± 0.10[a]	0.36 ± 0.09[a]

Different letters indicate statistical difference between columns (Tukey Test, $p < 0.05$).

Assessment of radicular grooves

Radicular grooves were observed in 4% of the maxillary central incisors, of which 50% were located on the buccal surface and 50% on the distal surface (Figure 8). In the maxillary lateral incisors, the incidence was 8%, of which half were located on the mesial surface and half on the distal surface (Figure 8). In both central and lateral incisors, the origin of 100% of grooves began in the enamel (Figure 8). The grooves were deeper in the cross-section that corresponded to half the total extent of the groove (M) for maxillary central incisors (0.28 ± 0.04 mm). In the maxillary lateral incisors, the deepest grooves were 2 mm above (M + 2) the central section of the groove (M). In addition, radicular grooves in maxillary lateral incisors presented a higher total mean length compared with the maxillary central incisors (Table 4).

Discussion

The quantitative analyses of the two-dimensional parameters evaluated in this study showed that, regarding roundness and form factor, the root canals of the central incisors and maxillary canines were more circular compared with the maxillary lateral incisors, which present a slight tendency to flatness. This might be attributed to the higher incidence of root curvature in the apical third of this dental group.

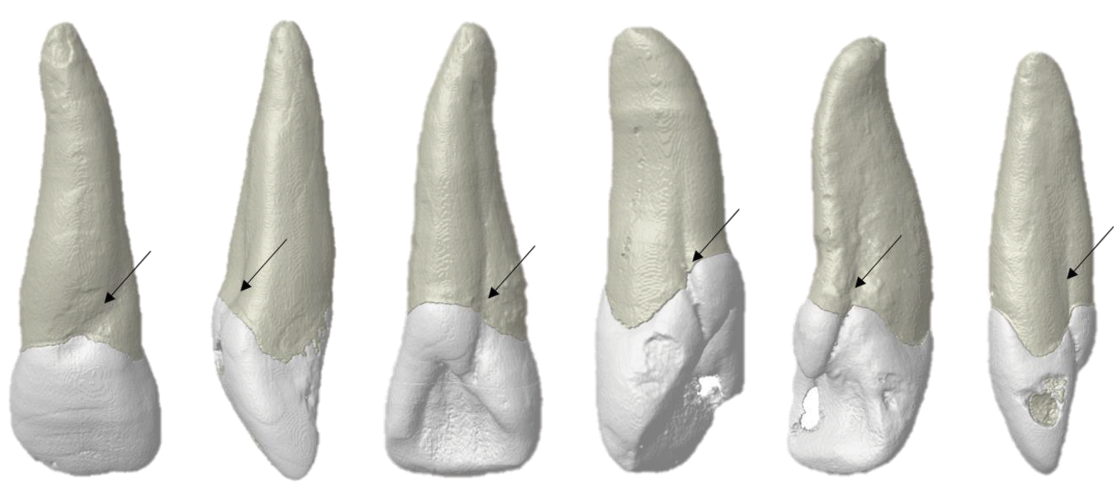

Figure 8. Qualitative distribution and location of radicular grooves in maxillary central and lateral incisors. The arrows indicate the presence of radicular grooves in the mesial and distal faces.

Table 4. Descriptive analysis of radicular grooves in maxillary central and lateral incisors and canines.

Teeth	Radicular grooves		
	Landmarks	Depth (mm)	Length (mm)
MCI	M-2	0.13 ± 0.01	4.38 ± 0.53
	M-1	0.21 ± 0.00	
	M	0.28 ± 0.04	
	M+1	0.26 ± 0.10	
	M+2	0.26 ± 0.08	
MLI	M-2	0.22 ± 0.07	4.80 ± 0.12
	M-1	0.22 ± 0.07	
	M	0.22 ± 0.09	
	M+1	0.24 ± 0.11	
	M+2	0.27 ± 0.08	
MC	No grooves		

Thus, the tendency to flattening in the root canals may hinder biomechanical preparation, effective cleaning and, consequently, root canal filling.[7]

The tendency for canal flattening in the apical third of the lateral incisors was reflected in the difference between the major and minor diameter, which was higher than that of the central incisors and maxillary canines. Although canals presented a greater tendency for roundness, the difference between the major and minor diameters must be considered during biomechanical preparation, since instrumentation in the major diameter canals can lead to the occurrence of lateral perforations before completing necessary instrumentation.[3] In the minor diameter direction of the root canals, instrumentation may be insufficient, making cleaning impossible. In this context, it is important to determine the clinical anatomical diameter prior to the biomechanical preparation, since it indicates the amount of instrumentation that should be performed in the apical region.

Another point that must be highlighted is the increase in the difference between the major and minor diameters along the levels that were evaluated, which could be observed mainly in lateral incisors and canines, presenting a significant increase in taper. However, despite a more accentuated taper, the difference between the taper of the major and minor diameters in central incisors was more discreet. This data is important when planning biomechanical preparation as instruments with different tapers and/or kinematics must be used to allow greater surface contact of the instrument.[17,18] According to Buchanan,[19] one must be aware of the anatomical differences of each third of the root canal to optimize the function of each instrument.

The analysis of the three-dimensional parameters showed that the highest volume and surface area were found in the root canals of maxillary canines, while the lower mean values were observed in lateral incisors. The SMI values were similar in central, lateral and canine incisors, evidencing the three-dimensional cylindrical shape of the RCS in maxillary anterior teeth.

As for the qualitative analysis of the three-dimensional models, 100% of the central, lateral incisors and maxillary canines evaluated in the present study showed a type I morphological pattern according to Vertucci's[14] classification. These data corroborate the studies by Vertucci[4], Vertucci[14] and Çalişkan et al.[20] who found type I root canal configuration in 100% of the central, lateral incisors and maxillary canines. However, the literature shows the presence of two or more canals in 0.6 to 4.2% of central incisors, 2.9% to 6% of lateral incisors and 1.2% to 11.6% of maxillary canines.

We found that all evaluated root canals presented curvature in the apical third, indicating lateral exit of the apical foramen. The data on apical curvature of the root canal showed moderate to severe curvature in more than 50% of central, lateral incisors and canines. The data obtained in the present study are in accordance with the study by Willershausen et al.[21] who, using radiographic analysis, found mild and moderate curvature in 100% of the maxillary anterior teeth studied.

As for root curvature, despite the frequency of straight roots (61%) in central incisors, morphological variations are present, and they are a challenge to the dentist. Lateral incisors and canines showed a prevalence of accentuated curvature to the distal portion (58% and 55% respectively), which is in agreement with the literature that maxillary central incisors usually have straight roots with little or no inclination, while lateral incisors and canines present a more accentuated curvature to the distal portion following the curvature of the dental arch.[20, 22] It should be noted that most of the root canals are curved in their apical portion and this anatomical finding may not be identified in conventional radiography due to anatomical overlap; thus, only the anatomical features in the mesiodistal direction can be observed, compromising visualization of the characteristics in the buccolingual direction.[23] Thus, the results presented in this study enable the dental surgeon to understand instrumentation access to the critical apical region which, due to curvatures, can be challenging. Most of the time, a lack of experience, professional negligence and iatrogenesis results in surgical accidents such as excessive wear, perforations, steps, apical deviations, and possible instrument fracture due to the stress caused by the curvature.[4, 24- 27]

A common anatomical feature in maxillary anterior teeth observed in this study is the presence of the palatal shoulder, which was more prominent in canines compared with central and lateral incisors in the qualitative analysis, corroborating the higher values of dentin volume in this region of the shoulder, along with central incisors. The projection of dentin into the cervical palatine region makes the correct localization and biomechanical preparation of the root canals difficult, since it prevents the instruments from reaching the palatine wall,[28-30] favoring the accumulation of dentinal scrapings and necrotic material that can lead to the failure of the endodontic treatment in anterior teeth.[1,28,31,32] Thus, in these cases, cervical preparation to remove the palatal shoulder is of fundamental importance.

The results of the external analysis revealed that the highest mean of total tooth length was for canines, followed by central incisors and lateral incisors. Regarding crown height, central incisors and canines presented the highest mean values compared with lateral incisors, as reported by other authors.[1,3,4,12,14]

Although the distribution of the position of the apical foramen observed in this study was heterogeneous between the central, lateral incisors and canines, most were lateral to the root surface (mesial, distal, mesio-buccal, mesiopalatal, distobuccal, distopalatal, buccal and palatine roots). This observation is in agreement with the literature that shows that, in most cases, the apical foramen is in a lateral position to the anatomic apex.[8,14,33,34] However, other authors reported that the apical foramen may coincide with the anatomic apex in 6.7% to 46% of the cases.[4,14,22,34] The classic concept of the apical root anatomy is based on three anatomical and histological points: apical constriction, dentin-cementum junction and apical foramen.[35] Apical constriction is the anatomical point where, theoretically, it is the desirable limit for biomechanical preparation,[36] but it presents morphological variations that make its identification unpredictable.[37] The dentin-cementum junction is located approximately 1 mm from the apical foramen and it may not coincide with apical constriction.

In this study, the values found for the major and minor diameter of the canal approximately correspond to instruments #50 - #55 for major diameter and #35 - #40 for minor diameter and they have implications on the cleaning and shaping procedures. However, these diameter values, except for the major diameter in canines, did not present statistical differences compared with the diameters evaluated in the apical foramen, which may interfere with the reliability of the apical locators when determining the working length, since the diameter of the apical foramen has been reported as an important factor for equipment performance.[38]

Another important characteristic observed in the external anatomy analysis was the presence of radicular grooves at different lengths and locations. Radicular grooves or depressions are reported as developmental morphological defects on the surface of the dental root that act as a predisposing factor for periodontal disease.[39] In the present study, the presence of radicular grooves was observed in 4% of the central incisors and 8% of the lateral incisors. These grooves began in the cervical region of the crown and were located on the buccal, mesial and distal surfaces. The literature reveals that the presence of radicular grooves in central and lateral incisors ranges from 0.6 to 11.1% of cases. In addition, in most cases, these grooves are located on the buccal, mesial and distal surfaces, starting at the coronal region, in enamel, extending throughout the root surface,[39] supporting the results found in this study.

It should be taken into account that the presence of radicular grooves can favor retention and accumulation of bacteria, which can lead to the periodontal and endodontic diseases.[39] Simon et al.[39] reported that in case of pulp necrosis of the RCS, bacteria can reach the radicular grooves due to the reduced thickness of dentin in the deepest groove region, which can lead to the development of periodontal lesions of endodontic origin. Thus, because the radicular grooves in anterior teeth start in the coronal portion, they contribute to the clinical diagnosis and are paramount for successful treatment.

The data presented on the internal anatomy and external dental anatomy of the RCS in this study do not differ from the studies conducted with other traditional methods for this type of study. However, µCT provides two- and three-dimensional geometric parameters of area, roundness, form factor, diameters, volume, surface area, SMI, among others, which cannot be obtained with other evaluation techniques.[2, 40, 41] It provides information that can help predictability and treatment planning, and aid in the selection of anterior teeth for ex-vivo studies, since the two- and three-dimensional data using stratified proportional sampling technique ensure the standardization of the sample in each group.[38-41]

According to De-Deus,[40] who states that high-resolution microtomography can provide homogeneous distribution of the sample and consequently improve the validity of the experiment, the morphometric data obtained by µCT analysis in this study may contribute to the knowledge of anatomy and variations, since these teeth are commonly used as samples in studies in the field of Endodontics, particularly in mechanical tests.[40,41]

Therefore, the data obtained in laboratory scientific research, together with the information obtained by the clinical radiographic examinations, allow the dental surgeon to recognize the type of root and root canal anatomy and variations and choose the best clinical protocol for biomechanical preparation and obturation of the RCS, thus contributing to successful endodontic treatment.

Conclusions

Overall, based on the results obtained in this study, it may be concluded that quantitative and qualitative two- and three dimensional morphometric analysis of the internal and external anatomy of maxillary anterior teeth, allow the clinician to recognize the anatomical variations present and decide on the most appropriate endodontic protocol, in search of successful treatment.

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