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Analysis of the root canal morphology of anterior teeth using Cone-Beam Computed Tomography

Análise da morfologia dos canais radiculares de dentes anteriores por meio da Tomografia Computadorizada de Feixe Cônico

Análisis de la morfología de los conductos radiculares de dientes anteriores mediante Tomografía Computarizada de Haz Cónico

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ABSTRACT

Objective: Understanding root canal anatomyis essential for successful endodontic treatment. This studyanalyzed them orphology of root canals in maxillaryand mandibular anterior teeth in a Brazilian subpopulation using cone-beamcomputed tomography (CBCT). **Methods:** A retrospective cross-sectional study was conducted with 1,975 CBCT images of anterior teeth from 268 patients. Images were analyzed using Xoran Cat software to asses the number of roots and canal configurations, classified according to Vertucci'scriteria. The chi-square test was applied ($p < 0.05$). **Results:** Most teeth (99.9%) had a single root; only 0.1% hadtwo. The most prevalentc onfiguration was Vertucci'sType I (95.8%), followed by Type III (2.8%) and Type II (1%). Types VI and VII were rare (0.3% and 0.1%). No significant association with gender was found ($p > 0.05$). **Conclusion:** Anterior teeth showed predominantly simple morphology, with single canals and roots being most common. However, anatomical variations may occur, and clinicians should be aware of them to ensure proper canal location and avoid endodontic treatment failure.

Keywords: Cross-sectional anatomy, Endodontics, Incisor, Root canal treatment, Cone beam computed tomography.

RESUMO

Objetivo: Compreender a anatomia dos canais radiculares é essencial para o sucesso endodôntico. Este estudo analisou a morfologia dos canais radiculares de dentes anteriores maxilares e mandibulares em uma subpopulação brasileira por meio de tomografia computadorizada de feixe cônico (TCFC). **Métodos:** Estudo transversal retrospectivo com 1.975 imagens de TCFC de dentes anteriores de 268 pacientes. As imagens foram avaliadas no software XoranCat quanto ao número de raízes e à configuração dos canais, segundo a classificação de Vertucci. Utilizou-se o teste do qui-quadrado ($p < 0.05$). **Resultados:** A maioria dos dentes (99,9%) apresentou uma única raiz; apenas 0,1% tinham duas. A configuração mais prevalente foi o Tipo I de Vertucci (95,8%), seguida pelo Tipo III (2,8%) e Tipo II (1%). Os Tipos VI e VII foram raros (0,3% e 0,1%). Não houve associação significativa com o gênero ($p > 0.05$). **Conclusão:** Os dentes anteriores apresentaram morfologia simples, com predominância de canais e raízes únicas. No entanto, variações anatômicas podem

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ocorrer, exigindo atenção do cirurgião-dentista para garantir a localização adequada dos canais e o sucesso do tratamento endodôntico.

Palavras-chave: Anatomia transversal, Endodontia, Incisivo, Tratamento do canal radicular, Tomografia computadorizada de feixe cônico.

RESUMEN

Objetivo: Comprender la anatomía de los conductos radiculares es esencial para el éxito de ltratamiento endodóntico. Este estudio analizó la morfología de los conductos radiculares en dientes anteriores maxilares y mandibulares en una sub población brasileña mediante tomografia computarizada de haz cónico (TCHC). **Métodos:** Se realizó un estudio transversal retrospectivo con 1.975 imágenes de TCHC de dientes anteriores de 268 pacientes. Las imágenes fueron evaluadas com el software Xoran Cat para determinar el número de raíces y la configuración de los conductos, según la clasificación de Vertucci. Se aplicó la prueba de chi-cuadrado ($p < 0.05$). **Resultados:** La mayoría de los dientes (99,9%) presentó una sola raíz; solo el 0,1% tuvo dos. La configuración más prevalente fue el Tipo I de Vertucci (95,8%), seguida del Tipo III (2,8%) y el Tipo II (1%). Los Tipos VI y VII fueron raros (0,3% y 0,1%). No se encontró asociación significativa con el género ($p > 0.05$). **Conclusión:** Los dientes anteriores presentaron morfología predominantemente simple, con raíces y conductos únicos en la mayoría de los casos. Sin embargo, pueden ocurrir variaciones anatómicas, por lo que el profesional debe estar atento para garantizar una localización adecuada de los conductos y evitar fallas en el tratamiento endodóntico.

Palabras clave: Anatomía transversal, Endodoncia, Incisivo, Tratamiento del canal radicular, Tomografía computarizada de haz cónico.

INTRODUCTION

Understanding the anatomy of root canals and their variations is a prerequisite for successful endodontic treatment (VERTUCCI FJ, 2005). Early studies in dental anatomy assumed that maxillary and mandibular anterior teeth had a single root with a single canal (SOMMER RF, et al., 1961). However, multiple studies have revealed significant variability in the morphology of anterior tooth root canals across different populations (LIU J, et al., 2014; MAUGER MJ, et al., 1998; RAHIMI S, et al., 2013; SERT S, et al., 2004; VERTUCCI FJ, 1974; VERTUCCI FJ, 2005).

The morphology of the root canal system (RCS) can be studied using cross-sections, diaphanization, scanning electron microscopy, and micro-computed tomography (BUHRLEY LJ, et al., 2002; GULABIVALA K, et al., 2002; VERTUCCI FJ, 1984; ZHENGYAN Y, et al., 2016). However, these techniques can only be applied to extracted teeth (HAN T, et al., 2014).

Among the techniques available for in situ evaluation of dental anatomy, imaging exams such as radiographs (BARATTO FILHO F, et al., 2009; VERSIANI MA, et al., 2012) and cone-beam computed tomography (CBCT) (ZHANG R, et al., 2011) stand out.

Conventional periapical radiographs are commonly used in various stages of root canal treatment. However, they provide a two-dimensional image, which may limit the assessment of complex structures like root canals (BARATTO FILHO F, et al., 2009; VERSIANI MA, et al., 2012). Anatomical variations in the number of root canals can only be inferred from periapical radiographs when there is a visible change in the shape or direction of the canal, or when the canal is not fully visualized, suggesting the possible presence of two canals (BARATTO FILHO F, et al., 2009).

CBCT has been increasingly used for diagnosis, treatment planning, or during endodontic procedures when periapical radiographs fail to resolve clinical doubts (ZHANG R, et al., 2011). CBCT images allow for three-dimensional visualization without the superimposition of anatomical structures, enabling a more accurate evaluation of tooth and root canal anatomy (KIM S, 2012).

METHODS

This study was approved by the Research Ethics Committee (approval no. 1.840.898, CAAE no. 61340816.0.0000.5147). It is a retrospective cross-sectional study evaluating CBCT scans collected from the database of the Department of Radiology at the Federal University of Juiz de Fora (UFJF, Minas Gerais, Brazil).

A total of 1,975 CBCT images of maxillary and mandibular anterior teeth, including central incisors, lateral incisors, and canines from 268 patients (153 females and 102 males), were selected based on the following criteria: availability of scans of maxillary or mandibular anterior teeth, complete root formation, and absence of root resorption, calcifications, root canal fillings, or posts.

The images were obtained using the same CBCT device (I-Cat®, Imaging Sciences International, Hatfield, Pennsylvania, USA) with the following acquisition protocol: 120 kV, 8 mA, 26.9 sec, 0.25 mm slice thickness, and a minimum FOV of 7 cm. All CBCT images were analyzed using XoranCat software, version 3.1.62 (Xoran Technologies, Ann Arbor, Michigan, USA).

Brightness and contrast adjustments were applied to enhance visualization, and the scanner screen was set to multiplanar reconstruction (MPR) mode with 0.2 mm slice intervals and no filters. The images were evaluated by a trained and experienced examiner in CBCT imaging.

To assess method reproducibility, 10% of the scans were re-evaluated one week after the initial assessment. Teeth were analyzed in axial, coronal, and sagittal CBCT views to determine the number of roots and root canal configurations, classified according to Vertucci FJ (2005) and symmetry between sides:

- **Type I:** A single canal extends from the pulp chamber to the apex.
- **Type II:** Two separate canals leave the pulp chamber and merge before the apex to form a single canal.
- **Type III:** A single canal leaves the pulp chamber, divides into two within the root, and then merges again to exit as a single canal.
- **Type IV:** Two separate and distinct canals extend from the pulp chamber to the apex.
- **Type V:** A single canal leaves the pulp chamber and splits before the apex into two separate and distinct canals with separate apical foramina.
- **Type VI:** Two separate canals leave the pulp chamber, merge within the root, and then divide again before the apex to exit as two distinct canals.
- **Type VII:** A single canal leaves the pulp chamber, divides, rejoins within the root, and finally splits again into two distinct canals before the apex.
- **Type VIII:** Three separate and distinct canals extend from the pulp chamber to the apex.

The number of roots identified in the axial CBCT images was classified according to Pecora et al. (1992) (PECORA; SAQUY; SOUSA NETO; WOELFEL, 1992):

- **Single-rooted teeth:** Teeth with a clear single root or two independent canals appearing as two roots but actually fused.
- **Multi-rooted teeth:** Teeth with two roots, either partially or completely bifurcated, or three roots, with three completely independent roots or bifurcations along the buccal or palatal roots.

Descriptive statistical analyses were performed using IBM SPSS Statistics software (version 15.0; IBM Corp., Armonk, New York, USA).

Associations between gender, number of roots and canals, and the Vertucci's classification (VERTUCCI FJ, 2005) were analyzed using the chi-square test. A 95% confidence interval was used ($p < 0.05$).

RESULTS

A total of 1,975 CBCT images of maxillary and mandibular anterior teeth, including central incisors (CI), lateral incisors (LI), and canines (C), were evaluated. **Table 1** presents the frequency of the evaluated teeth.

The vast majority of anterior teeth (99.9%) had a single root, while 0.1% had two roots (lower central and lateral incisors). All two-rooted teeth (n=2) were classified as Type III according to Vertucci (2005). No significant differences were observed between the number of roots and gender (p = 0.182).

Tabela 1 - Frequency of Teeth in the Sample.

Variable	Tooth (FDI notation)	N (%)
Upper right side	Central incisor (11)	188 (9.5)
	Lateral incisor (12)	189 (9.6)
	Canine (13)	186 (9.4)
Upper Left side	Central Incisor (21)	182 (9.2)
	Lateral Incisor (22)	177 (9.0)
	Canine (23)	185 (9.4)
Lower left side	Central incisor (31)	146 (7.4)
	Lateral incisor (32)	147 (7.4)
	Canine (33)	142 (7.2)
Lower right side	Central incisor (41)	146 (7.4)
	Lateral incisor (42)	143 (7.2)
	Canine (43)	144 (7.3)
	Total	1975

Source: Teixeira BP, et al., 2025.

Table 2 shows the prevalence of different root canal types. Type I (95.8%) was the most prevalent, followed by Type III (2.8%). Type II was found in 1% of the sample, while Types VI and VII were observed only in lower central and lateral incisors (0.3% and 0.1%, respectively).

Types IV, V, and VIII were not observed. No statistically significant differences were found among the six age groups ($p > 0.05$). Additionally, no association was found between root canal configurations and gender ($p > 0.05$).

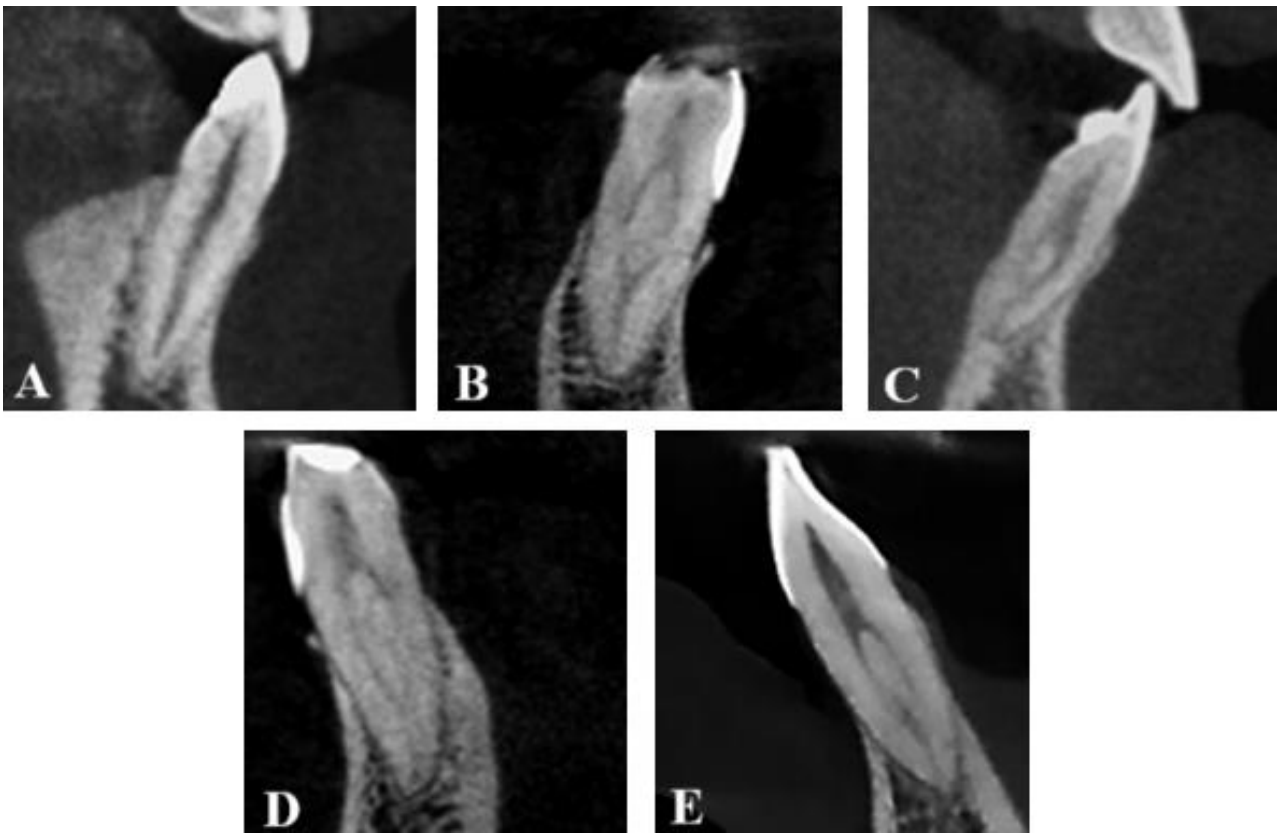
Tabela 2 - Prevalence of root canal types.

Teeth		Vertucci's Classification n (%)					Total
		Type I	Type II	Type III	Type VI	Type VII	
Upper right side	Central incisor (11)	188 (100)	0 (0)	0 (0)	0 (0)	0 (0)	188 (100)
	Lateral incisor (12)	189 (100)	0 (0)	0 (0)	0 (0)	0 (0)	189 (100)
	Canine (13)	185 (99.5)	1 (0.5)	0 (0)	0 (0)	0 (0)	186 (100)
Upper left side	Central incisor (21)	180 (98.9)	2 (1.1)	0 (0)	0(0)	0 (0)	182 (100)
	Lateral incisor (22)	177 (100)	0 (0)	0 (0)	0 (0)	0 (0)	177 (100)
	Canine (23)	184 (99.5)	1 (0.5)	0 (0)	0 (0)	0 (0)	185 (100)
Lower left side	Central incisor (31)	126 (86.3)	5 (3.4)	12 (8.2)	2 (1.4)	1 (0.7)	146 (100)
	Lateral incisor (32)	130 (88.4)	3 (2.0)	13 (8.8)	1 (0.7)	0 (0)	147 (100)
	Canine (33)	140 (98.6)	0 (0)	2 (1.4)	0 (0)	0 (0)	142 (100)
Lower right side	Central incisor (41)	125 (85.6)	5 (3.4)	14(9.6)	2 (1.4)	0 (0)	146 (100)
	Lateral incisor (42)	125 (87.4)	3 (2.1)	13 (9.1)	1 (0.7)	1 (0,7)	143(100)
	Canine (43)	142 (98.6)	0 (0)	2 (1.4)	0 (0)	0 (0)	144(100)
Total		1891 (95.8)	20 (1)	56 (2.8)	6 (0.3)	2 (0.1)	1975 (100)

Source: Teixeira BP, et al., 2025.

Figure 1 - Types of anatomy found according to Vertucci's (VERTUCCI, 2005) classification.

A) Vertucci's Type I. **B)** Vertucci's Type II. **C)** Vertucci's Type III. **D)** Vertucci's Type VI. **E)** Vertucci's Type VII.



Source: Teixeira BP, et al., 2025.

DISCUSSION

Knowledge of root canal anatomy and morphological variations is essential for the success of endodontic treatment and can be critical for other dental procedures, such as periodontal treatment, periapical surgery, and tooth extraction. Beyond its medical relevance, anatomical variations are also important for anthropological science and forensic investigations (KAYAOGLU G, et al., 2015). From a genetic and ethnic perspective, the Brazilian population is highly diverse and considered one of the most heterogeneous in the world (SILVA EJ, et al., 2014).

The morphological investigation of the root canal system (RCS) using periapical radiography is the most commonly employed method for diagnosis and endodontic treatment planning, as it is a low-cost and easily performed examination (HAN T, et al., 2014).

However, the information obtained from periapical radiographs is limited due to the three-dimensional (3D) anatomy of the region being imaged, which is compressed into a two-dimensional (2D) image, leading to superimposition in the buccolingual plane (BARATTO FILHO F, et al., 2009; BULUT DG, et al., 2015; VERSIANI MA, et al., 2012).

Several methods are used to study the morphological characteristics of the RCS, such as diaphanization, in vitro macroscopic examination, scanning electron microscopy, contrast-enhanced radiography, and micro-computed tomography (BUHRLEY LJ, et al., 2002; GULABIVALA K, et al., 2002; VERTUCCI FJ, 1984; ZHENGYAN Y, et al., 2016).

However, these methods can only be applied to extracted teeth (HAN T, et al., 2014) and require a significant amount of time and often rely on relatively small sample sizes (RAJAKEERTHI R e NIVEDHITHA

MS, 2019). Consequently, cone-beam computed tomography (CBCT) has become the primary technique for studying the root canal system of human teeth in vivo (LIAO Q, et al., 2011; YANG H, et al., 2013).

CBCT is widely recommended for complex clinical situations that require a detailed view of both the internal and external anatomy of teeth due to its ability to provide highly accurate three-dimensional images (NEELAKANTAN P, et al., 2010; ZHENGYAN Y, et al., 2016).

Thus, CBCT is particularly useful for visualizing root canal morphology, which may not be clearly visible in periapical radiographs (KIM S, 2012). Furthermore, CBCT makes it possible to analyze the dental anatomy of large groups, with information on gender, race, and age, which better reflects the reality of a population compared to analyses based on small samples (RAJAKEERTHI R e NIVEDHITHA MS, 2019). Considering the advantages of CBCT, the present study utilized this imaging technique to evaluate the root canal morphology of anterior teeth in a Brazilian subpopulation.

Previous studies (CALISKAN MK, et al., 1995; KAMTANE S e GHODKE M, 2016; KARTAL N e YANIKOGLU FC, 1992; RAHIMI S, et al., 2013; SIKRI V e SIKRI KP, 1994) investigating root morphology and canal configuration have reported variations in findings due to differences in methodology, study populations, and sample sizes. In this study, a total of 1,975 teeth were analyzed, and only 0.1% of the evaluated teeth presented more than one root, a finding consistent with other studies (AMINSOBHANI M, et al., 2013; ARSLAN H, et al., 2015; ESTRELA C, et al., 2015; HAN T, et al., 2014; KAYAOGLU G, et al., 2015; LIN Z, et al., 2014).

The present study employed Vertucci's. (2005) classification, which divides the anatomy of the RCS into eight types. Type I was observed in 1,891 teeth (95.7%), aligning with previous studies (ALTUNSOY M, et al., 2014; HAN T, et al., 2014; LIN Z, et al., 2014; LIU J, et al., 2014; ZHAO Y, et al., 2014; ZHENGYAN Y, et al., 2016) that also used CBCT.

However, some studies (KAMTANE S e GHODKE M, 2016; LEONI GB, et al., 2014; RAHIMI S, et al., 2013) reported Type I in approximately 62-65%. These discrepancies may be attributed to differences in study populations and sample sizes, as seen in the works of Kamtane S and Ghodke M. (2016) and Leoni GB, et al. (2014) as well as the diaphanization method used in Rahimi S, et al. (2013).

Type III was the second most common configuration found in this study, accounting for 2.8% of the sample. This type was also the second most frequently observed in other studies (HAN T, et al., 2014; KARTAL N e YANIKOGLU FC, 1992; LEONI GB, et al., 2014; VERSIANI MA, et al., 2014; LIN Z, et al., 2014; VERTUCCI FJ, 2005; ZHAO Y, et al., 2014). Caliskan MK, et al. (1995) and Sert S, et al. (2004) reported that in a Turkish population, 27.18% of anterior teeth were classified as Type II according to Vertucci's classification (VERTUCCI FJ, 2005).

This finding does not align with the present study, where only 1% of the sample was classified as Type II. This discrepancy may be explained by differences in studied populations and methodologies, as the Turkish population was assessed using the diaphanization method, whereas the present study analyzed a Brazilian population using CBCT imaging. In this study, Types IV, V, and VIII were not observed.

Types VI and VII were identified in only a few previous studies (HAN T, et al., 2014; LEONI GB, et al., 2014; ZHAO Y, et al., 2014), with results comparable to those found in this study: 0.6% (Type VI) and 0.1% (Type VII). Some authors (ARSLAN H, et al., 2015; CALISKAN MK, et al., 1995; KARTAL N and YANIKOGLU FC, 1992; LEONI GB, et al., 2014; PECORA JD, et al., 1993; SERT S, et al., 2004; ZHAO Y et al., 2014) have reported additional canal configurations.

No significant association was found between sex and either the number of roots or the Vertucci. (2005) classification ($p > 0.05$), which contrasts with other studies (BUHRLEY LJ, et al., 2002; GULABIVALA K, et al., 2014; SERT S, et al., 2004; ZHENGYAN Y, et al., 2016). This difference may be attributed to variations in populations analyzed across studies. Based on the parameters assessed, it was observed that the morphology of the root canals in anterior teeth is variable, with the possibility of additional canals and a wide range of canal configurations. Dentists should be aware of these potential variations, as they may lead to difficulties in locating root canals and, consequently, unsuccessful endodontic treatment.

CONCLUSION

The vast majority of the studied teeth had a single root canal. However, a small minority showed a single canal emerging from the pulp chamber, dividing into two, and then merging again in the apical region. Cone-beam computed tomography (CBCT) proved to be an excellent tool for detecting morphological variations and root canal configurations. Therefore, greater attention to potential anatomical variations in the root canal system (RCS) is essential to ensure the success of endodontic treatment.

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