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Anatomic Comparison of Contralateral Maxillary Second Molars Using High-Resolution Micro-CT

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Abstract: The present study aimed to measure and compare anatomic parameters in contralateral maxillary second molars. A total of 18 intact maxillary second molar pairs (n = 36) extracted from 18 patients were scanned with micro-computed tomography (micro-CT) and then reconstructed. Axial, sagittal, and cross-sectional slices were used to analyze the parameters (lengths, widths, and thicknesses) and evaluate the symmetry of the right and left sides. The number of root canals and their internal patterns were classified following Vertucci's classification. The number of lateral canals and their locations were also noted. Contralateral second molar pairs demonstrated a high degree of similarity in terms of the linear measurements (lengths, widths, and thicknesses). The root canal anatomy configuration symmetry of mesiobuccal, distobuccal, and palatal roots according to Vertucci's classification were 41.1%, 88.2%, and 94.4%, respectively. In total, 41.6% of mesiobuccal roots, 2.7% of distobuccal roots, and 30.6% of palatal roots had at least one lateral canal. The apical third (38.7%) was the most frequent location of lateral canals, followed by the middle third (32.3%) of the root. This study provides insight into the anatomy of the root canals of contralateral maxillary second molars, which is valuable for both practitioners and researchers.

Keywords: micro-CT; maxillary molar; root canal configuration; bilateral symmetry

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1. Introduction

Endodontic therapy is primarily aimed at biomechanically shaping and cleaning all root canal systems thoroughly, as well as completely obturating them in three dimensions with an appropriate material. To accomplish such goals, a thorough understanding of the morphology, variety, and characteristics of the root canal system is required, which varies based on ethnicity and demographics [1]. Nevertheless, various researchers have noted that the failure rate of endodontic therapy varies between 10% and 15% [1–4]. Although there are several reasons for endodontic treatment failure, complex internal anatomy and missed canals are two of the most common [5,6].

In terms of endodontic treatment frequency, the group of teeth that are most commonly subject to treatment is the maxillary molars [7,8]. Typically, maxillary first and second molars are described as three-rooted teeth having three or four root canals; nevertheless, the internal anatomy of the respective groups of teeth can be quite different. Although the prevalence of mesiobuccal root canals was found to be increased in maxillary first molars (69.6%) compared to second molars (39.0%), the external root morphology in second molars has less predictability. The fusing or grouping together of maxillary second molars is also more common than in maxillary first molars [9–11].

Several studies have examined maxillary second molar root canal morphology with many different techniques, including diaphanization, staining, cross-sectioning, clinical operating microscope, dentin troughing under magnification, scanning electron microscope, radiographic examination, cone-beam computed tomography (CBCT), and more recently, high-resolution micro-computed tomography (micro-CT) [12,13]. However, there has been relatively little attention paid to the anatomic symmetry of teeth and root canal morphology between patients, i.e., the symmetry between the left and right sides. This has significant clinical relevance when it is necessary to deal with cases involving two opposite teeth for the same patient.

Since studies have revealed that maxillary second molars present a broad range of external and internal challenges, including C-shaped canal configuration and merged roots, the knowledge of the presence (or absence) of bilateral differences in these teeth may guide the clinical management of patients and improve the treatment outcomes. Previously published studies on the bilateral symmetry of teeth have relied heavily on CBCT imaging, where even utilizing the settings with the highest resolution may not allow the root canal morphology's anatomy to be accurately depicted [13]. Micro-CT scans provide high-quality information with high-micrometer-resolution images for extra-fine anatomic details and reliable measurements [14,15]. However, only a few existing micro-CT studies exploring bilateral symmetry have been conducted on mandibular and maxillary premolars [16,17]. As far as the authors are aware, previous researchers have not employed micro-CT for the purpose of comparing anatomic features between opposing maxillary second molars of the same patient. Therefore, the aim of the current study was to explore the morphology and root canal configurations of contralateral maxillary second molars and to determine the extent to which they were bilaterally symmetrical in a group of orthodontic patients using high-resolution micro-CT imaging. The null hypothesis was that the right and left sides of the maxillary second molar teeth displayed no differences in the number of roots, root canal configuration, or the morphological characteristics.

2. Materials and Methods

2.1. Patient Enrolment

The Research Ethics Committee of the University provided the necessary ethical approval (Protocol No: 2021-90-1339). There have been no studies that compare the right and left sides of the same teeth using micro-CT. A limited number of studies have used CBCT for comparison. As a result, we did not conduct a power analysis. Instead, as many patients as possible were included who met the selection criteria within the study duration, following the principle of the "Law of Large Numbers". Based on the orthodontic indications, the Department of Orthodontics referred the patients for extraction of maxillary second molar teeth, and informed consent was given. Inclusion criteria of the patients were the absence of conditions predisposing patients to dental developmental/congenital disorders and having contralateral maxillary second molar teeth that had no grave caries or coronal restorations, no root canal fillings, and periapical lesions. These criteria were evaluated by both clinical and radiological examinations of the teeth. Patients for whom the inclusion criteria were not satisfied were not included.

2.2. Micro-CT Analysis

A high-resolution micro-CT system was used for the purpose of scanning the maxillary second molar tooth pairs (Bruker Skyscan 1275, Belgium). The device settings were fixed at 210 mA, 32 kVp, with no filter, and 0.2 rotation steps with a pixel size of 10.1 lm. Calibration of the detector was performed prior to every imaging process for the purpose of reducing artifacts. Rotation of samples was performed for an entire circle during 5 min of integration time. On average, it took approximately 1 h to process the scans. Inputting of the optimal contrast limit and the settings for beam hardening correct were based on the user guidelines according to prior scans and reconstructing images of the respective samples.

CTAn was used for visualizing and quantitatively analyzing the obtained samples (version 1.19.11.1; SkyScan) and NRecon (version 1.6.10.5; SkyScan) software in addition to the aforementioned modified algorithm [18]. Two-dimensional (2D) axial images (1000 · 1000 pixels) were obtained. In terms of the parameters for reconstruction, ring artifact and smoothing were set at zero, while beam artifact correction was set at 40%. After being acquired with the scanner, images were reconstructed using NRecon software to allow 2D slices of the samples to be displayed. Skyscan CTVox (version 3.3.1; Skyscan) was used for further processing of the images after they were reconstructed for visualization purposes. All regions of interest were drawn such that the whole sample was included using CTAn software, and the sample was then analyzed after the image had been reconstructed. Serial sagittal, coronal, and axial sections were obtained to enable the teeth's external and internal morphology to be evaluated. Two observers (observer 1 had 15 years of experience in three-dimensional imaging and software; observer 2 had 5 years of experience in three-dimensional imaging and software) evaluated 36 teeth twice over a period of four weeks to ensure reliability. One consultant radiologist attended the calibration session, where 50 micro-CT images were examined separately and analyzed before the actual examination.

The following parameters were evaluated:

1. Morphology of external root and root canal morphology based on Vertucci's classification with modification [19].

2. Linear measurement of distances between each cusp (mesiobuccal, distobuccal, and mesiopalatal) to the cementoenamel junction (CEJ), corresponding root apex, and corresponding pulp horn.

3. Linear measurement of dentinal thicknesses in mesiodistal (M-D) and buccopalatal (B-P) directions in three different root levels of each root: 1.5 mm before apex (apical), halfway between the apex and cementoenamel junction (middle), and at the level of furcation (coronal).

4. Lateral canal presence, number, and location (any additional canals branching off from the main root canal to the root surface and located coronal to the apical 0.5 mm) [20].

5. The number of apical foramina in the root canal's apical third the sum of main (the main apical opening of the root canal) and accessory (an orifice on the surface of a root communicating with a lateral or accessory canal) foramina) [21].

6. Volumetric measurements of tooth and pulp space.

2.3. Statistical Analysis

All statistical analyses were conducted using GraphPad Prism 5.0 (GraphPad Software, Inc., San Diego, CA, USA). The Kolmogorov–Smirnov test was employed to verify whether the data were normally distributed. Analysis of the normally distributed data was performed using one-way analysis of variance, while paired comparisons were assessed with Tukey's test. Data that were not normally distributed were assessed with the Kruskal–Wallis test and then Dunn's test. In all statistical analyses, the significance level was accepted as $p < 0.05$.

3. Results

A total of 36 contralateral maxillary second molars were collected from 18 volunteer patients (14 females, 4 males; mean age, 14.25 years (standard deviation $\pm$ 1.71 years) at the Dental Hospital of the Faculty of Dentistry in Near East University.)

3.1. External Root and Root Canal Morphology

Figure 1 shows exemplary 3D models of contralateral pairs maxillary second molar teeth and the external morphology of roots. Figure 2 shows the axial sections of eighteen maxillary second molar teeth pairs. Table 1 shows the number of roots and configurations of the root canals in contralateral maxillary second molars. Of the thirty-six teeth, three had two roots, and the other thirty-three had three roots. Regarding the number of roots, symmetry of the maxillary second molars was detected in 94.4% of the 18 pairs. In the maxillary second molars, the configuration of the root canal of the mesiobuccal (MB) root was 57.1% type I, 18.2% type V, 12.1% type II, 6.1% type III, and 6.1% type IV. The configuration of the root canal of the distobuccal (DB) root was 97% type I and 3% type III, while the canal configuration of the palatal (P) root was 97.2% type I and 2.8% type III. Of the three buccal (B) roots in teeth with two roots, two had type V, and the configuration of the root canal in one was type I. Regarding the root canal configurations, MB, DB, and P root pairs were found to be symmetrical in 41.1%, 88.2%, and 94.4% of cases, respectively.

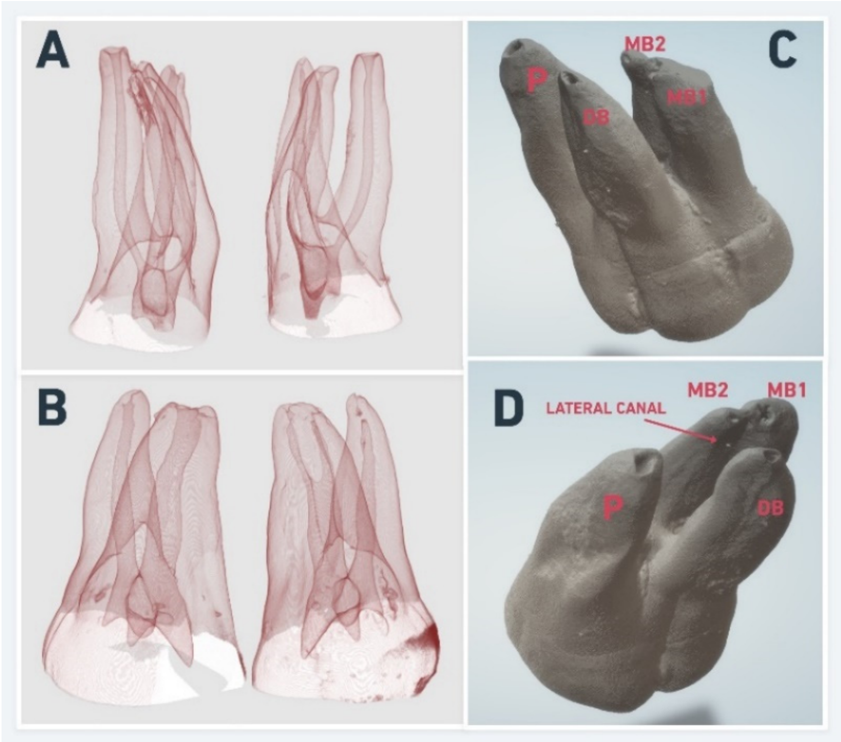

Figure 1. Three-dimensional models of contralateral pairs of three-rooted (**A**) and two-rooted (**B**) maxillary second molar teeth. (**C**,**D**) show the root canal foramina of mesiobuccal (MB), distobuccal (DB), and palatal (P) roots. Red arrow indicates apically located lateral canal opening in the distal side of the mesiobuccal root.

Table 1. Number of roots and root canal configurations in contralateral maxillary second molars.

Patient No.	Right			Left			Symmetry in No. of Roots	Symmetry in Root Canal Configurations
	No. of Roots	Root	Vertucci's Classification	No. of Roots	Root	Vertucci's Classification		
1	3	MB DB P	Type V Type I Type I	3	MB DB P	Type I Type I Type I	Yes	No Yes Yes
2	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
3	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
4	3	MB DB P	Type I Type I Type I	3	MB DB P	Type II Type I Type I	Yes	No Yes Yes
5	3	MB DB P	Type V Type I Type I	3	MB DB P	Type III Type I Type V	Yes	No Yes No

Table 1. *Cont.*

Patient No.	Right			Left			Symmetry in No. of Roots	Symmetry in Root Canal Configurations
	No. of Roots	Root	Vertucci's Classification	No. of Roots	Root	Vertucci's Classification		
6	2	B P	Type I Type I	2	B P	Type V Type I	Yes	No Yes
7	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
8	3	MB DB P	Type II Type I Type I	3	MB DB P	Type II Type I Type I	Yes	Yes Yes Yes
9	3	MB DB P	Type I Type I Type I	3	MB DB P	Type II Type I Type I	Yes	No Yes Yes
10	2	B P	Type V Type I	3	MB DB P	Type I Type I Type I	No	No No Yes
11	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
12	3	MB DB P	Type III Type I Type I	3	MB DB P	Type V Type I Type I	Yes	No Yes Yes
13	3	MB DB P	Type I Type I Type I	3	MB DB P	Type V Type I Type I	Yes	No Yes Yes
14	3	MB DB P	Type V Type I Type I	3	MB DB P	Type IV Type I Type I	Yes	No Yes Yes
15	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
16	3	MB DB P	Type I Type I Type I	3	MB DB P	Type V Type I Type I	Yes	No Yes Yes
17	3	MB DB P	Type I Type I Type I	3	MB DB P	Type I Type I Type I	Yes	Yes Yes Yes
18	3	MB DB P	Type IV Type III Type I	3	MB DB P	Type I Type I Type I	Yes	No No Yes

MB: mesiobuccal root; DB: distobuccal root; B: buccal root; P: palatal root.

3.2. Cusp-to-Pulp Horn, Cusp-to-Apex, and Cusp-to-CEJ Distances

The mean distances from the MB, DB, and P cusps to the corresponding pulp horn, root apex, and CEJ are presented in Figure 3. The mean distance between the MB cusp and the pulp horn was significantly less than the DB cusp-to-pulp horn ($p < 0.01$) and P cusp-to-pulp horn distances ($p < 0.01$). Regarding the cusp-to-apex measurements, the P cusp-to-apex distance was considerably greater than the others ($p < 0.05$). With regard to the cusp-to-CEJ distances, significant differences were not detected ($p > 0.05$). The contralateral measurements of the same parameters for the right and left sides were not significantly different ($p > 0.05$).

Figure 2. The axial sections of eighteen maxillary second molar teeth pairs.

3.3. Smallest Dentinal Thickness in Apical, Middle, and Coronal Thirds

Figure 4 shows the smallest dentinal thickness values of MB, DB, and P roots in two different directions (M-D and B-P) and three root levels (apical, middle, and coronal) of each root. Concerning the contralateral measurements of all evaluated parameters for the smallest dentinal thickness, no significant differences between the right and left sides were found ($p > 0.05$). The B-P dimensions of the DB and MB roots were significantly higher compared to the M-D dimensions in all root levels ($p < 0.01$). For the P root, the smallest dentinal thickness values were similar between M-B and B-P measurements in the apical and coronal levels ($p > 0.05$). However, in the P root's middle third, the M-D dimension was significantly higher than the B-P dimension for the smallest dentinal thickness ($p < 0.05$; $p < 0.01$). Figure 5 represents the differences between the MB, DB, and P roots for the smallest dentinal thickness values in the M-B and D-B directions. The P root showed the thickest dentinal tissue in the M-D direction for all root levels ($p < 0.01$), whereas in the B-P direction, the MB root showed the thickest dentinal tissue for all root levels ($p < 0.01$).

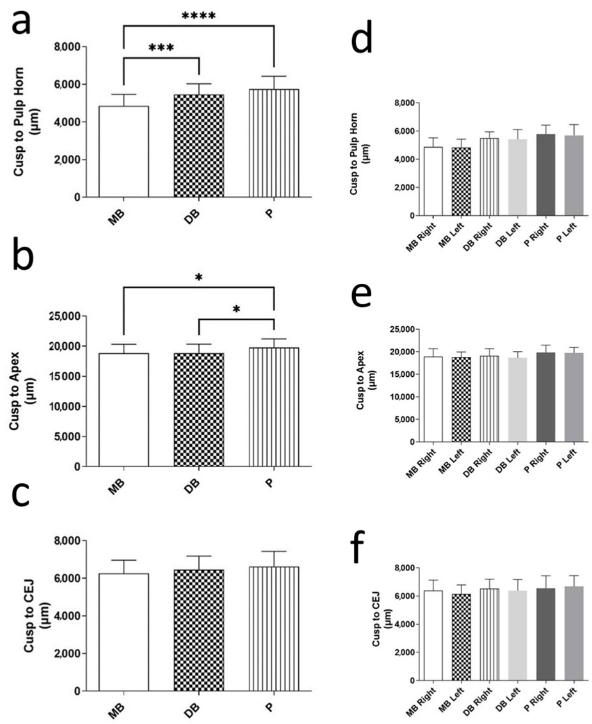

Figure 3. The mean distances from the mesiobuccal (MB), distobuccal (DB), and palatal (P) cusps to the corresponding pulp horn (**a**), root apex (**b**), and cementoenamel junction (CEJ) (**c**). The contralateral measurements of the same parameters for the right and left sides are presented in (**d**–**f**). * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, **** = $p < 0.0001$.

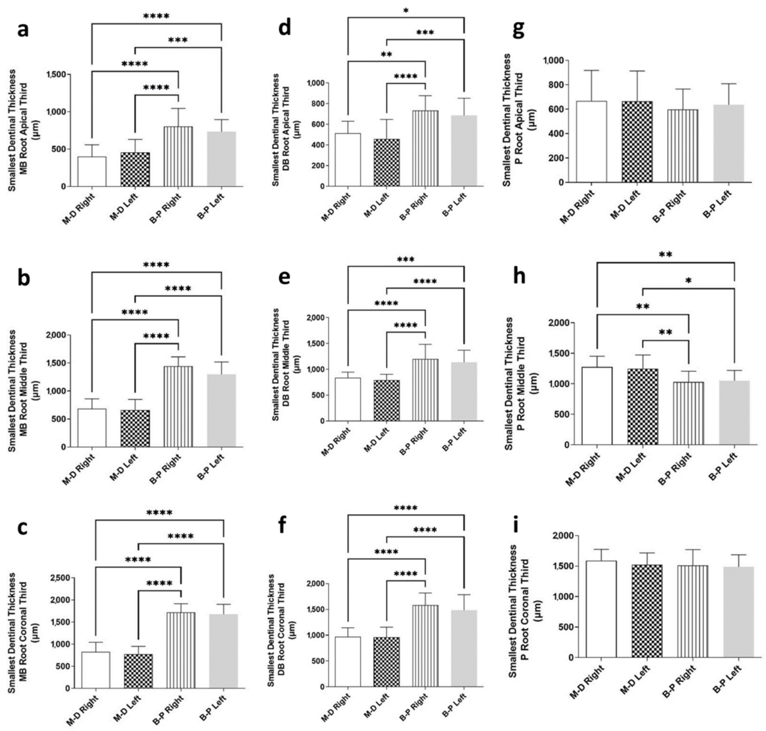

Figure 4. The smallest dentinal thickness values of mesiobuccal (**a**–**c**), distobuccal (**d**–**f**), and palatal roots (**g**–**i**) in two different directions (mesiodistal (M-D) and buccopalatal (B-P)) and three root levels (apical, middle, and coronal) of each root. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, **** = $p < 0.0001$.

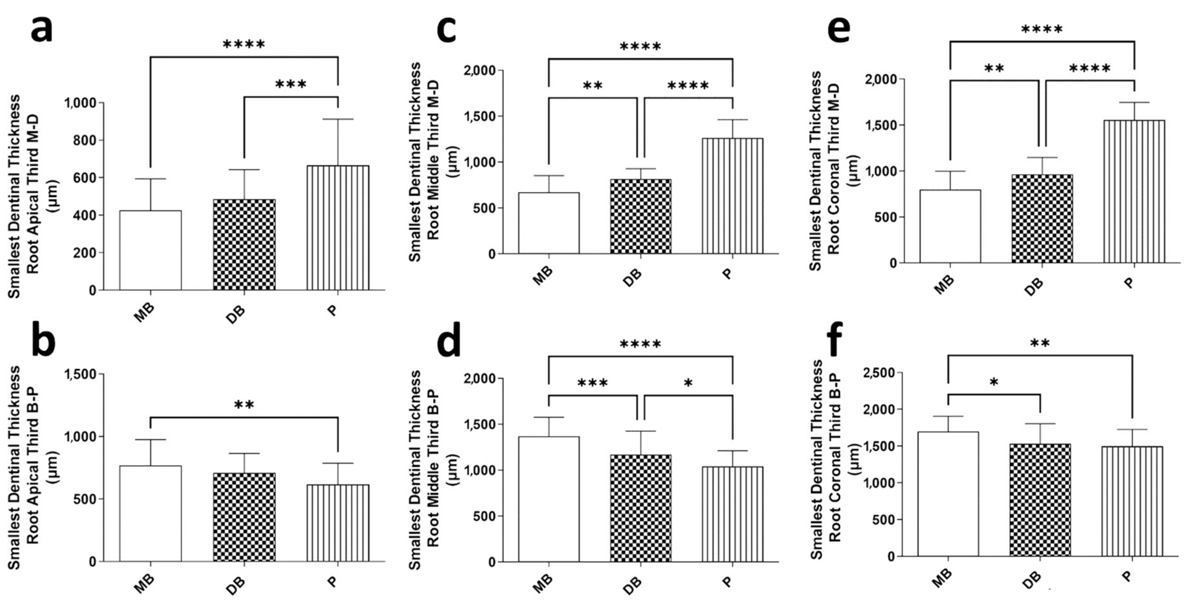

Figure 5. The differences between mesiobuccal (MB), distobuccal (DB), and palatal (P) roots for the smallest dentinal thickness values in mesiobuccal (M-B) and distobuccal (D-B) directions at the apical (**a**,**b**), middle (**c**,**d**), and coronal (**e**,**f**) root levels. * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$, **** = $p < 0.0001$.

3.4. Number of Foramina and Lateral Canals and Locations of Lateral Canals

Tables 2 and 3 demonstrate how the foramina and number of lateral canals were distributed for MB, DB, and P roots. Concerning the contralateral measurements for the number of foramina and lateral canals, the right and left sides of the same root did not exhibit any significant differences ($p > 0.05$). However, the number of lateral canals in the MB and P roots was significantly higher compared to that in the DB root ($p < 0.01$). In addition, the mean number of foramina in the MB root was significantly higher than in the DB and P roots ($p > 0.01$). Table 4 demonstrates how the lateral canals were distributed. With respect to the MB root, the highest number of lateral canals was in the middle third, whereas for the P root, the apical third had the highest number of lateral canals.

Table 2. Number of foramina.

Patient No.	MB		DB		B		P	
	Right	Left	Right	Left	Right	Left	Right	Left
1	2	3	2	1			1	1
2	1	1	1	2			1	1
3	1	1	1	1			1	1
4	3	2	1	1			1	1
5	2	2	1	1			2	2
6					2	4	1	1
7	2	1	2	1			2	1
8	6	4	1	1			1	1
9	1	1	1	1			1	1
10	2		1			3	1	1
11	1	1	1	1			1	1
12	3	2	1	1			1	1
13	2	1	1	1			1	1
14	2	1	1	1			1	1
15	1	1	1	1			1	1

Table 2. *Cont.*

Patient No.	MB		DB		B		P	
	Right	Left	Right	Left	Right	Left	Right	Left
16	2	2	1	1			1	1
17	1	4	1	1			1	1
18	4	3	1	1			1	1

MB: mesiobuccal root; DB: distobuccal root; B: buccal root; P: palatal root.

Table 3. Number of lateral canals.

Patient No.	MB		DB		B		P	
	Right	Left	Right	Left	Right	Left	Right	Left
1	1	1	0	0			1	0
2	0	0	0	0			0	0
3	0	0	0	0			0	0
4	1	0	0	0			0	0
5	0	1	0	0			1	2
6					1	0	0	1
7	1	2	1	0			1	2
8	0	0	0	0			0	0
9	0	1	0	0			1	1
10	0		0			2	0	0
11	1	2	0	0			0	0
12	1	2	0	0			0	1
13	1	0	0	0			0	0
14	0	3	0	0			0	0
15	0	0	0	0			0	0
16	2	1	0	0			1	0
17	0	0	0	0			0	1
18	0	0	0	0			0	0

MB: mesiobuccal root; DB: distobuccal root; B: buccal root; P: palatal root.

Table 4. Locations of lateral canals.

Lateral Canal Locations	MB	DB	B	P
Coronal_Buccal	1	0	0	3
Coronal_Palatal	2	0	0	0
Coronal_Mesial	1	0	0	0
Coronal_Distal	2	0	0	0
Middle_Buccal	2	0	0	0
Middle_Palatal	3	0	1	0
Middle_Mesial	3	0	0	0
Middle_Distal	3	0	0	1
Apical_Buccal	1	0	0	6
Apical_Palatal	2	0	2	1
Apical_Mesial	0	1	0	0
Apical_Distal	1	0	0	2

MB: mesiobuccal root; DB: distobuccal root; B: buccal root; P: palatal root.

3.5. Tooth and Pulp Space Volume

Figure 6 shows the mean volumes of teeth and pulp spaces. In terms of volumetric measurements, the left and right sides of the same tooth did not exhibit any significant differences ($p > 0.05$).

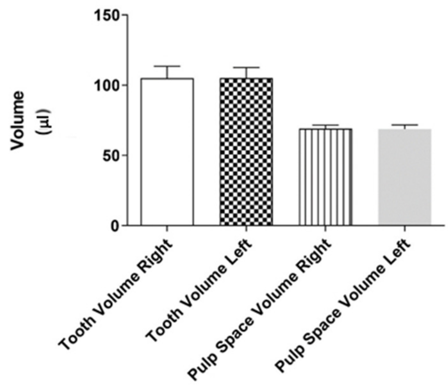

Figure 6. The mean volumes of teeth and pulp spaces.

4. Discussion

The use of advanced imaging technologies allows root canal systems to be examined more precisely as well as the teeth's external and internal morphology to be analyzed in greater detail. For studying root canal systems and understanding their complex morphology, micro-CT technology is currently regarded as a research tool that offers optimal accuracy and reliability [12]. The present research utilized the nondestructive micro-CT imaging technique to precisely measure linear and volumetric parameters. Thus, it was possible to evaluate tooth morphology quantitatively and classify it at the same time without causing damage to the tooth structures [22].

The current study's findings reveal that 94.4% of the patients had symmetrical second molars (17/18) concerning the number of roots. However, the root canal configuration was found to be symmetrical in only 38.8% of the patients (7/18). This outcome is quite contrary to that of Plotino et al. [13], who found that only 79.6% of patients studied had symmetrical maxillary second molars. In their study, the results also only showed the presence of the second mesiobuccal canal in 13.4% of the maxillary second molars, whereas many other researchers have reported an increased prevalence of second mesiobuccal canals, varying between 21% and 83% of teeth [23–25]. The latest meta-analysis on the second mesiobuccal root canal in maxillary molars reported that multiple root canals were present in the mesiobuccal root in 37.0% of the maxillary second molars [26]. This also accords with the present results, which show that 41.1% of the evaluated teeth had a second mesiobuccal canal. Demographics such as the age, sex, and location of the individual could be factors that influence the internal anatomy of teeth. It was hypothesized that Asians and Europeans have smaller teeth compared to Africans, which may explain the lower incidence of second mesiobuccal canals [27].

The present study's results reveal a high incidence of asymmetry in the root canal configuration of maxillary second molars, which could have some implications for endodontic treatment planning and execution. It is important to keep in mind that there can be differences in the root canal anatomy of opposite molars in the same patient, with variations of up to 60%. This should be considered when treating both molars. This information is crucial from a clinical standpoint as failure to identify, clean, and fill an additional canal in molar teeth can result in poor long-term outcomes due to lingering infection [5]. Studies have shown that root canal treatment for maxillary molars has high failure rates, possibly because of their complex root and canal structure, and variations in additional root canals [28,29]. Thus, specialized instruments or techniques, such as an operating microscope or laser-assisted irrigation, may need to be used during treatment in order to navigate and clean the root canals more effectively.

According to the limited findings of this study, MB pulp horns are more prominent in maxillary second molars than in other pulp horns. Analogous findings were also recorded by Baltacioglu et al. [27] for MB pulp horns of maxillary first molars. Thus, caution is advised when providing restorative treatment to prevent accidental pulp exposure. The results of the current research also show that the distances on the left and right sides, from different pulp horns to cusps, were quite similar to each other. The same observation was made for the cusp-to-apex and cusp-to-CEJ distances. These results suggest that the right and left teeth are highly symmetrical in terms of these specific parameters. Similar morphometric measurements such as thickness, width, and length were also studied by Johnsen et al. [16] in maxillary premolars, and they reported that contralateral premolar teeth were highly bilaterally symmetrical.

Significant differences were shown for the smallest dentinal thickness values when comparing differences between palatal, distobuccal, and mesiobuccal roots. The dentine thickness of the MB canal in the mesiodistal dimension was significantly thinner than the others in all root levels. Several reports in the literature have investigated the thickness of dentine at the furcation level of maxillary molars, commonly known as the "danger zone" [30]. It is important to reduce the volume of dentin that is removed through mechanical means when endodontic treatment is applied, especially for mesiobuccal canals that are placed close to furcal concavities, in order to avoid the development of perforations [30]. This study confirms that the mesiobuccal root is particularly at risk for root perforations, which are challenging to treat, and so care should be taken to prevent them.

In the present study, mesiobuccal roots were found to have the highest number of lateral canals. Similar observations have been reported by others [29,30]. Vertucci [31] reported the rates of mesiobuccal, distobuccal, and palatal roots that have a lateral canal were 50%, 29%, and 42%, respectively. Wolf et al. [32] also reported that mesiobuccal roots had the highest rate of lateral canals at 27%, while distobuccal roots had a rate of 11.3% and palatal roots had a rate of 14.6%, respectively. In the present report, mesiobuccal (%44.1), distobuccal (2.9%), and palatal (%30.5) roots had at least one lateral canal. The distinct difference regarding findings on the distobuccal root between this study and others can be attributed to factors such as the size of the sample, the methods and design of the study, the ethnicity of the participants, and distinctions in the age and gender of the subjects. The complicated anatomy of the canal, which includes lateral canals and other potentially inaccessible areas, particularly on maxillary molars' mesiobuccal roots, poses a threat to chemomechanical preparation. Therefore, the use of advanced disinfection techniques in the endodontic treatment of these teeth will increase the success rate.

The present research had several limitations, the most significant being the small sample size. Another limitation is that the impact of sexual dimorphism was not considered due to the small sample size. As a result, the findings may not be applicable to other demographics, such as age, sex, and location. In order to address these limitations, future studies should include larger samples and investigate possible differences related to age, gender, and population.

5. Conclusions

To date, no micro-CT studies have been conducted to examine the extent to which right and left maxillary second molars are anatomically symmetrical due to the difficulty of finding a patient with both types of teeth. The present data indicate that the contralateral maxillary second molars were highly bilaterally symmetrical according to the morphometric measurements. Root canal configuration varied between contralateral pairs, most notably in mesiobuccal roots. Therefore, the null hypothesis was partially accepted. Micro-CT can be effectively used to study and compare contralateral teeth morphology.

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