Microcomputed tomographic analysis of the furcation grooves of maxillary first premolars

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Summary
***Objectives*. The aims of this study were to conduct a morphometric analysis on the buccal furcation grooves in freshly extracted bifurcated maxillary first premolars (MFPs) and to correlate all anatomical measurements using microcomputed tomography.**
***Materials and Methods*. Twenty-three human MFPs with bifurcated canals were selected for this study. The specimens were analyzed with microcomputed tomography. The length, the beginning, and the ending of the grooves were measured. The minimum cross-sectional canal wall thickness in the grooves was located, and the width of the dentin thickness was calculated. All measurements were recorded and statistically analyzed.**
***Results*. The concavity of the grooves begins before the bifurcation site in 9/23 samples and after the bifurcation in 56.5% of samples. The groove length varied between 1.1-9 mm; the cross-sectional area with minimum palatal dentin thickness was 0.78±0.14 mm, which was located at a mean distance of 7.1 mm from the cementoenamel junction (CEJ) and 1.38 mm from the furcation.**
***Conclusions*. The presence of the furcation grooves in the palatal aspects of the buccal roots of the MFPs was 100%. The length, depth, location, and width of the dentin thickness of the grooves varied in relation to tooth length, bifurcation, and CEJ. These parameters should be taken into consideration before any endodontic or restorative procedures are performed. Reducing dentin width too vigorously by intracanal instrumentation can predispose to vertical root fractures or perforations; if a post cannot be avoided, it should not extend 6.5 mm from the CEJ.**

Key words: Buccal furcation groove, maxillary premolar, microcomputed tomography, morphometric analysis.

Introduction

Maxillary first premolars (MFPs) have a unique anatomical features includes bifurcated roots, a narrow furcation entrance, deep mesial concavities, and multiple canals (1). Few studies have mentioned the presence of the furcation grooves in the palatal aspects of the buccal roots of the MFPs (2-5). The prevalence of this phenomenon was reported to be very high, ranging from 62% to 100% (6-8). A lack of knowledge about the extent and thickness of the dentin in this area might lead to excessive thinning or perforation of the dentinal wall during either endodontic or restorative procedures, increasing the possibility of vertical root fractures (9-11).
Furthermore, morphometric studies on the palatal groove of the buccal root and its relationship to the dentin width found that the palatal wall in unprepared roots was, on average, less than 1 mm (4, 5, 9-12). Nevertheless, several studies have shown that posts must be surrounded by 1 mm of sound dentin (13-15).
Several methods have been used to assess tooth morphology, including the use of simple visual inspection of sectioned or cleared teeth (16, 17) and radiographic examination (18-21). The furcation grooves in MFPs were investigated initially by Tames et al. (4). They used the Tool Makers Microscope after embedding the teeth in acrylic and sectioning them into 1-mm-thick slices from the apex to the furcation. Lammertyn et al. (22) used a sectioning method and profile projector to assess the furcation grooves in the buccal roots of MFPs. This approach is complicated, time consuming, and can introduce artifacts and distortion of internal tooth anatomy (23). Although the authors produced three horizontal slices (2 mm from the furcation, 2 mm from the anatomic apex, and the third slice equidistant between the first and second slices), they still could not provide a complete picture of the furcation grooves.
Recently, a more advanced and non-destructive method to evaluate furcation grooves has been made available. Microcomputed tomography (MCT) scanning is a non-destructive method and, allowing the view of three-dimensional structures, has promising applications in endodontics (24, 25). MCT has been used to investigate the presence of anatomical structures (13, 26) and evaluate the centering ability and efficiency of rotary systems and hand files when used for root canal preparations (27-29).

However, to date, there are no reports on the use of MCT scanning to assess the furcation grooves in the buccal roots of MFPs.
This *in vitro* study aimed to conduct a morphometric analysis on the palatal grooves of the buccal roots in a sample of freshly extracted bifurcated MFPs using MCT.

Materials and methods

Twenty-three untreated human bifurcated permanent MFPs were selected from a pool of teeth that were freshly extracted from an adult Saudi population for orthodontic reasons and stored in 10% neutral buffered formalin. Teeth were scanned using a MCT scanner (1172 scanner; SKYSCAN, Kontich, Belgium) at 100 kV and 100 A with a resolution of 18.6 m and a 0.5-mm-thick aluminum filter and 54% beam-hardening reduction. Using NRecon software (SKYSCAN), these images were reconstructed, producing two-dimensional, cross-sectional slices of the tooth structure. Subsequently, CT Analyzer software (SKYSCAN) was used for the linear measurements of all variables, including canal length (measured coronally from the first slice where enamel appear to the last slice of the root dentin disappear apically) (Fig. 1), the points where the grooves begin and end (starting from the first slice where grove depression appear to the last slice where the depression of the groove disappear) (Fig. 2) in relation to the cementoenamel juction CEJ (measured from the last slice show enamel on the buccal canal)

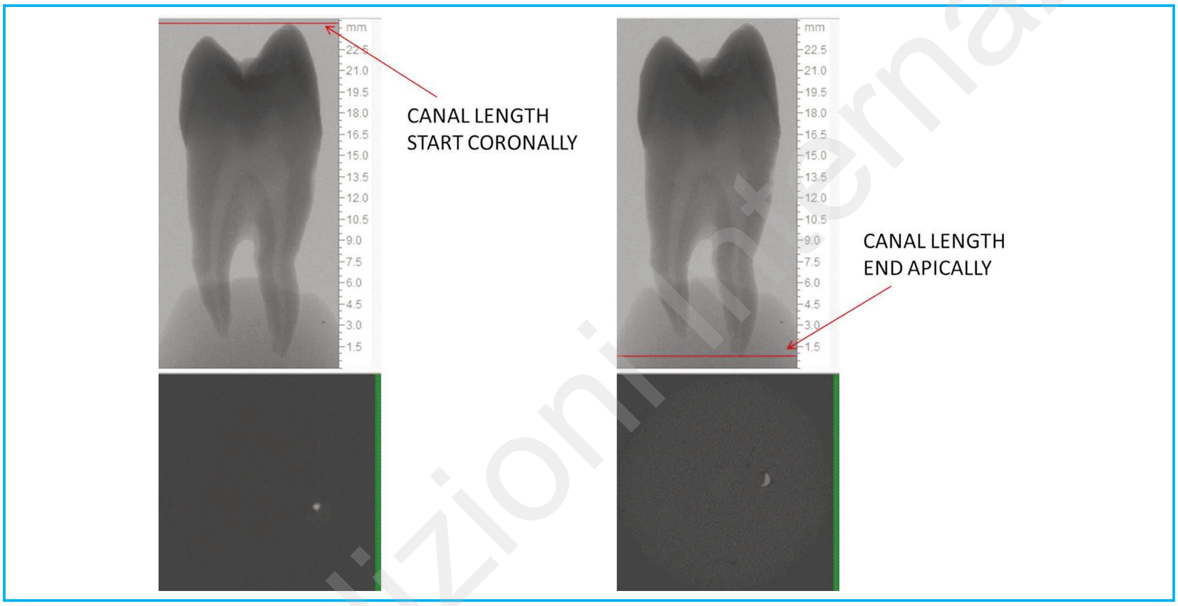

Figure 1. Canal length.

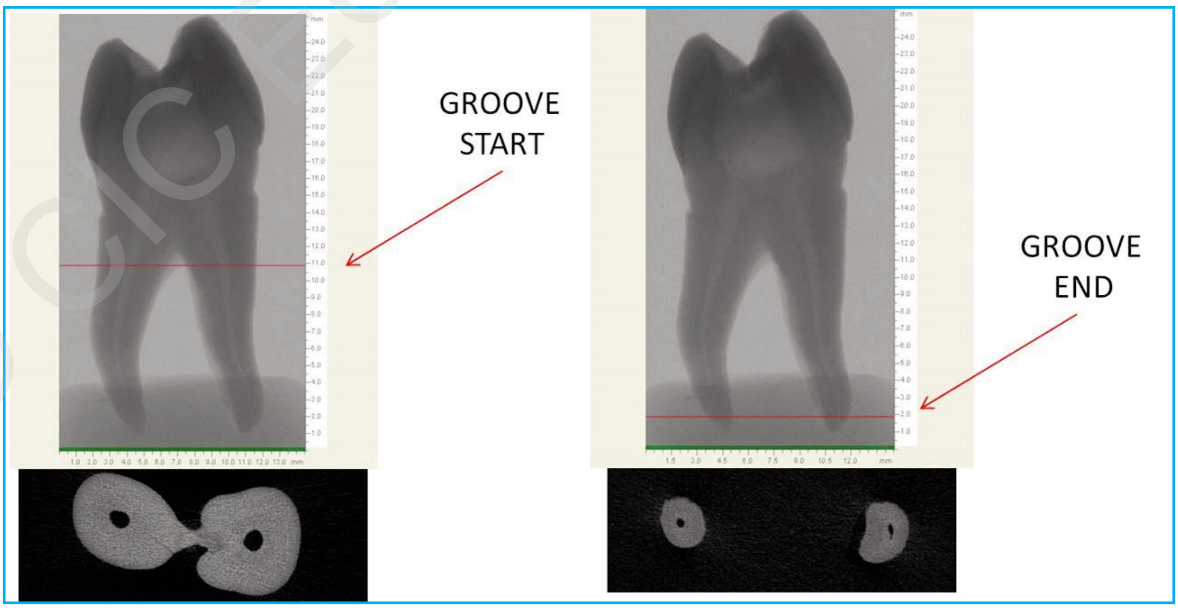

Figure 2. Groove start and end points.

(Fig. 3) and furcation, groove length, and the location of the minimum cross-sectional canal wall thickness in the grooves (all slices in the groove length measured and the one with minimum cross section thickness selected and average reading were recorded) (Fig. 4).

Statistical analysis

Collected data were statistically analyzed using SPSS 15 for Windows software (SPSS Inc, Chicago, IL); Pearson correlation coefficients *r* with two-tailed significance were

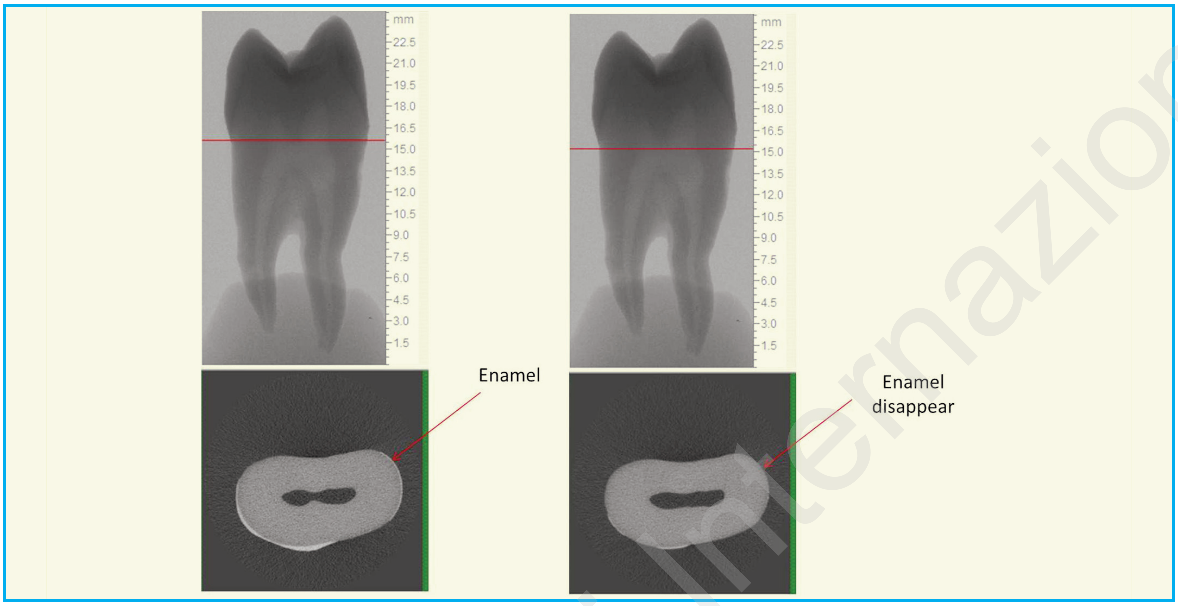

Figure 3. CEJ measures.

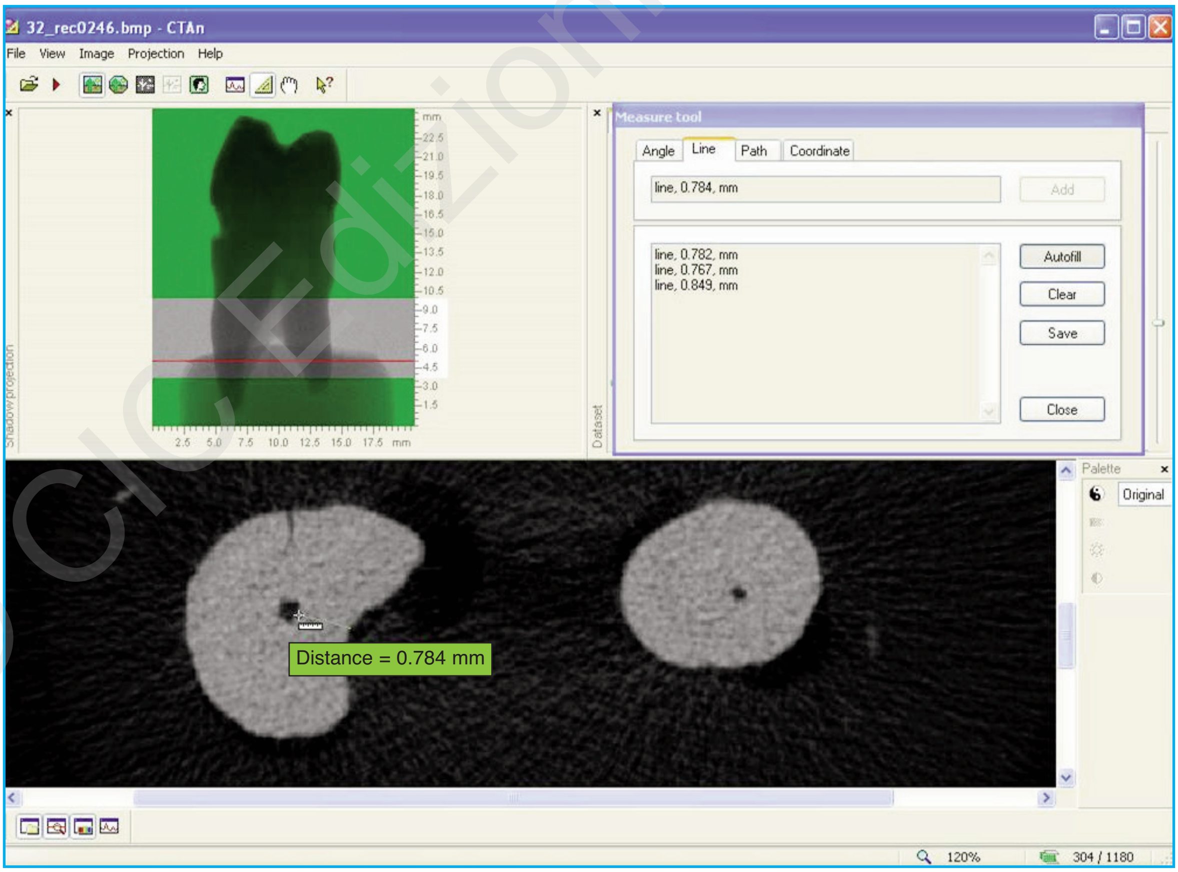

Figure 4. Dentin thickness measurements.

calculated for all pairs of measurements. The test was considered statistically significant when $p < 0.05$.

Results

Palatal invagination on the bifurcation aspect of the buccal roots was present in all samples selected for this study. Measurements were taken at the vertical and horizontal planes (Fig. 5).

The concavity of the grooves began before the bifurcation site in 9/23 samples (39.1%) with a mean value of 0.47±0.43 mm and exactly where the furcation began in one sample (4.4%) (Fig. 6). In the rest of the samples (13/23 [56.5%]), the grooves began after the furcation with a mean value 0.77±0.98 mm (Tab. 1).

The groove lengths varied between 1.1-9 mm with a mean ±SD value of 4.7±2.08 mm; the mean ±SD cross-sectional area with minimum palatal dentin thickness was 0.78±0.14 mm, located at a mean distance of 7.1 mm

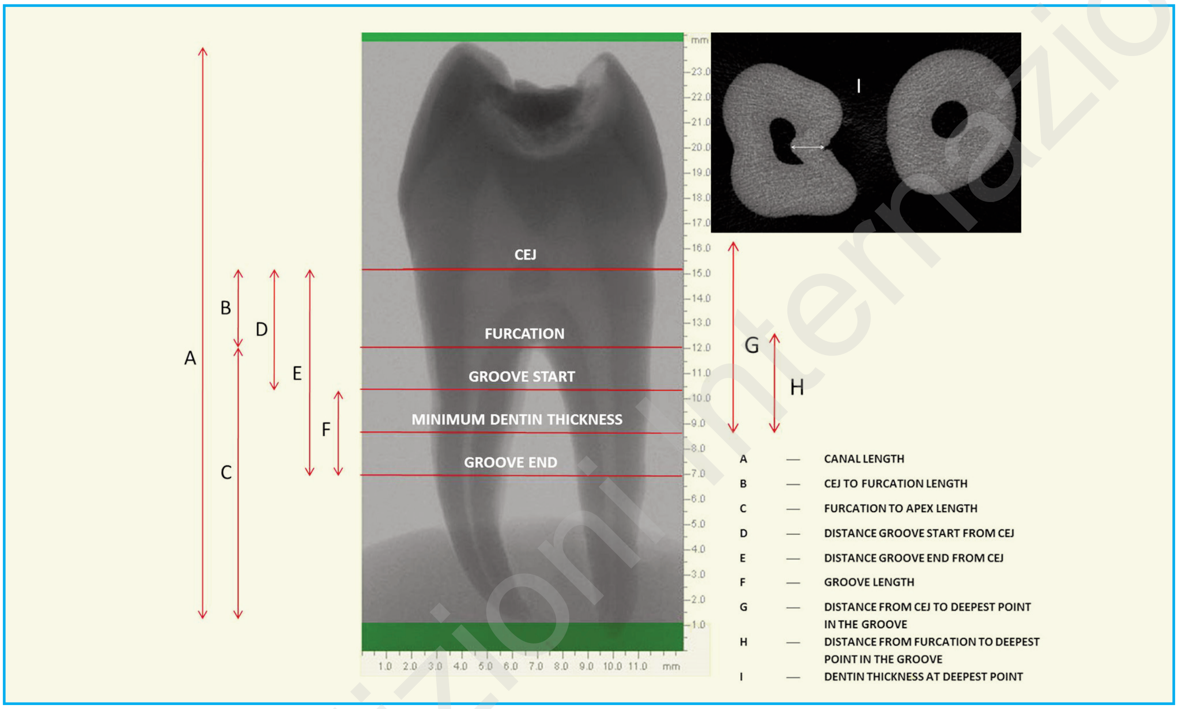

Figure 5. Measurements at vertical and horizontal planes.

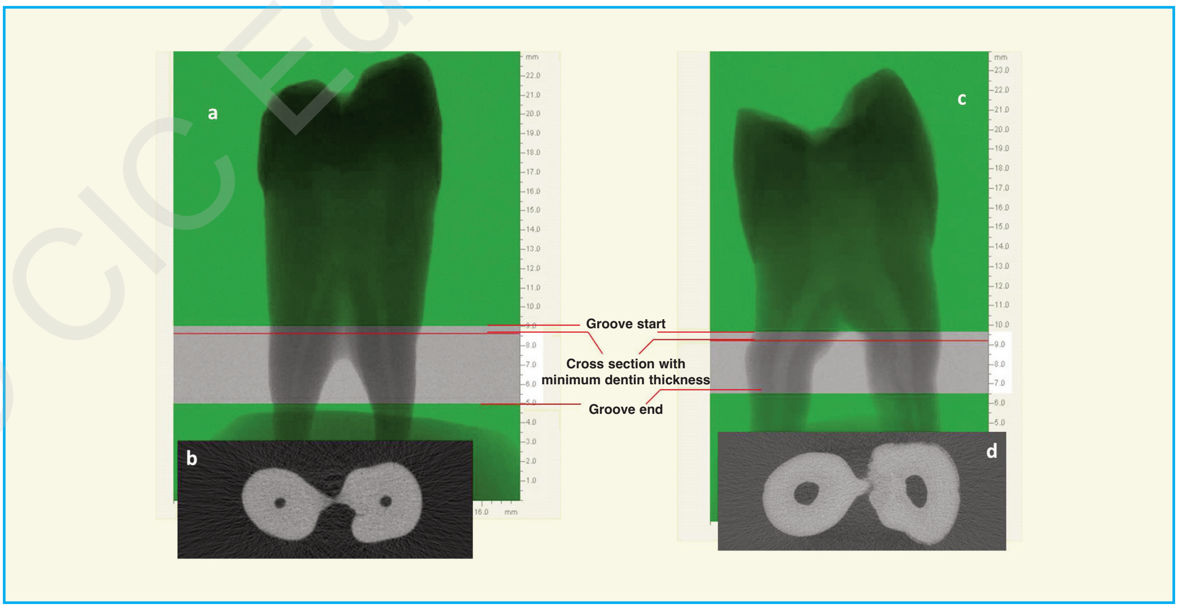

Figure 6. Sample with groove starts before furcation (a). Cross section at furcation area (b). Sample with groove starts after furcation (c). Cross section at furcation area (d).

Table 1. Mean±SD, and groove length in relation to furcation.

	N	%	Range (Min/Max)	Mean±SD
Groove begins before furcation	13	39.10	0.10–1.60	0.48±0.43
Groove begins at furcation	1	4.40	-	-
Groove begins after furcation	9	56.50	0.10–3.20	0.78±0.99

from the CEJ and 1.38 mm from the furcation (Tab. 2). Correlation coefficients and significance between all pairs of measurements in the vertical and horizontal planes are presented in Table 2. Significant positive correlations exist between A and C (r = 0.62, p = 0.00), A and E (r = 0.59, p = 0.00), A and F (r = 0.44, p = 0.04), E and F (r = 0.86, p = 0.00), and E and G (r = 0.59, p = 0.00). The length of groove F was negatively correlated with dentin thickness of palate wall I, that is, as the length increased, the palatal dentin thickness decreased, and vice versa (r = - 0.42, p = 0.02); a similar relationship was present between G and I (r = - 0.41, p = 0.05) (Tab. 2).

and periradicular bone destruction (32, 33). Moreover, our current technique overcomes the shortcomings of previously reported techniques (16, 22). In addition, with the use of MCT, cross-sections can be made at a precise distance from the apex, furcation, or CEJ.
It was possible to trace the grooves from their start points (where the concavity appears coronally) to their ends (where the concavity disappears). The groove lengths varied between 1.1-9 mm with a mean ±SD value of 4.7±2.08 mm in 39.1% of the samples, and the grooves began before the furcation with a mean ±SD value of 0.47±0.43 mm and a mean ±SD distance of 5.5±1.05 mm from the CEJ.

Table 2. Mean, SD, correlation coefficient, and significance of measurement sites in the vertical and horizontal planes.

	Mean	SD	Correlation Coefficient and (Significance)								
			A	B	C	D	E	F	G	H	I
A	23.92	1.73		.25	.62**	.26	.59**	.44*	.41	.23	-.41
				.26	.00	.23	.00	.04	.06	.27	.05
B	5.74	1.34			-.42*	.74**	.27	-.14	.50*	-.23	-.19
					.05	.00	.24	.54	.01	.28	.37
C	9.10	1.56				-.17	.41	.48*	.11	.48*	-.31
						.43	.05	.02	.61	.02	.15
D	5.56	1.05					.19	-.33	.46*	-.10	-.01
							.40	.13	.03	.65	.96
E	10.31	2.03						.86**	.59**	.43*	-.52*
								.00	.00	.04	.01
F	4.71	2.08							.36	.50*	-.42*
									.09	.01	.02
G	7.16	1.86								.70**	-.41*
										.00	.05
H	1.38	1.64									-.28
											.11
I	0.78	0.14									

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

Discussion

Several studies found the presence of grooves on the furcation aspects of the buccal roots of MFPs varied between 62% and 100% of cases using different evaluation methods (2-8), supporting the results of the current investigation.
Our study appears to be the first study to investigate furcation grooves using MCT, which made it possible to obtain a two-dimensional analysis of the external and internal macromorphologies of the root complex. MCT is non-destructive and a very accurate and useful tool with which to study external and internal tooth anatomy. Parallel findings have been previously reported using MCT to study external and internal tooth morphologies (30, 31)

These results disagree with those of Tamse et al. (4) who described the grooves as concavities that begin at the bifurcation. These findings make the CEJ a more reliable and clinically relevant reference point than the furcation.
Another interesting finding is the highly significant correlation between the length of canal A and the end of groove E (r = 0.59, p = 0.00); as canal length increased, the groove was longer and ended further from the CEJ, resulting in a natural thinning of the palatal dentin thickness of the buccal root. Therefore, discretion should be taken to avoid over-instrumentation, especially with long roots.
Several studies have shown that posts must be surrounded by 1 mm of sound dentin (14, 34). Other studies

measured the average groove depths and dentin thicknesses at different levels (4, 8, 22). Tamse et al. (4) found that the concavities reach a maximum value of 0.40 mm at a mean distance of 1.18 mm from the furcation, 5.3 mm from the apex, and a mean distance of 0.81 ± 0.24 mm from the invagination to the canal wall. In the present study, the cross-sectional area with minimum palatal dentin thickness within the groove for each sample was located and measured. The mean ± SD thickness was 0.78 ± 0.14 mm, and the mean ± SD distance was 7.1 ± 1.8 mm from the CEJ and 1.3 ± 1.6 mm from the furcation. Therefore, before any endodontic or restorative procedures are performed, it should be noted that reducing the dentin width too vigorously by instrumentation with either hand files or rotary instruments could predispose to vertical root fractures or perforations.
Based on previous discussions about the extent of post preparation in the buccal canal of an MFP if the buccal root cannot be avoided as an anchor for the post, at least 7 mm of gutta-percha must remain (4, 9). This recommendation is in agreement with the findings of the present study: the post must not extend more than 6.5 mm from the CEJ, as the groove begins with a mean of 5.5 ± 1.05 mm from the CEJ. Even if the root is long enough (as indicated above), there is a highly significant correlation between the length of the tooth and the end of the groove: as tooth length increases, the groove lengthens and ends further from the CEJ.
In conclusion, the length, depth, location, and width of the lingual dentin thickness of the groove vary in relation to tooth length, bifurcation, and CEJ. These parameters require the clinician close attention and assessment of the quantity of dentin removed during endodontic preparation or post application on the buccal root of the MFPs.

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