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The anatomy of the root canal system of three-rooted maxillary premolars analysed using high-resolution computed tomography

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ABSTRACT

Aim To analyse the anatomy of the root canal system of maxillary premolars with three distinct roots using high-resolution computed tomography (µCT).

Methodology Ten three-rooted human maxillary premolars were scanned transversally from crown to apex at 42 µm intervals using a high-resolution desktop µTC system (Skyscan 1072). The images were processed and analyzed for the following features: cross-section of the roots and canals in the apical, middle and coronal thirds; location of the apical foramen; distance from the pulp chamber roof to the bi and trifurcation of the canals, and anatomic variations of the root canal system. The results were expressed descriptively.

Results The cross-sectional shape of canals was heterogeneous along the length of the roots. The location of the apical foramen varied, tending to lie palatally or distally. The buccal pulp horn was larger than the palatal. The mean distance from the most cervical region of the pulp chamber roof to the bi and trifurcation of the canals was 3.13 mm and 5.08 mm, respectively.

Conclusions Features of the internal anatomy of the pulp cavity of three-rooted maxillary premolars were identified with the use of µCT. The results revealed the heterogeneity of three-rooted maxillary premolars.

INTRODUCTION

A comprehensive understanding of the complexity of root canal systems is imperative to ensure successful root canal treatment. Post-treatment disease in maxillary premolars is often related to insufficient knowledge of their anatomic variations, particularly in relation to three-rooted maxillary premolars and those with apical bifurcation in the main root canal (Lombart & Michonneau 2005).

Although maxillary first premolars usually have two root canals, the presence of three distinct root canals, extending from the coronal region to the root apex, has been reported to occur in 1.2% (Atieh 2008) to 6% of the cases (Carns & Skidmore 1973, Vertucci & Gegauff 1979, Pécora *et al*. 1991). However, studies of these teeth are scarce and the literature is limited to the presentation of therapeutic approaches in the form of case reports (Belizzi & Hartwell 1981, Barkhordar & Sapone 1987, Sieraski *et al*. 1989, Zaatar *et al*. 1990, Ferreira *et al*. 2000, Evans 2004, Woodmansey 2006, Jafarzadeh 2007).

The introduction of µCT to dental research has facilitated the study of root canal anatomy with substantial improvements in both software and hardware decreasing voxel sizes to approximately 30-40 µm to provide considerably increased image resolution (Rhodes *et al*. 1999, Peters *et al*. 2001). However, only studies evaluating the internal anatomy of molars are available (Nance *et al*. 2000, Peters *et al*. 2000, Barton *et al*. 2003, Manocci *et al*. 2005, Eder *et al*. 2006, Matherne *et al*. 2008, Reuben *et al*. 2008, Sachdeva *et al*. 2008, Baratto Filho *et al*. 2009, Gu *et al*. 2009). There appear to be no studies evaluating the complex anatomy of the root canal system of three-rooted maxillary premolars using µCT.

This study used µCT to analyze several aspects of the anatomy of the root canal system of maxillary premolars with three distinct roots.

MATERIALS AND METHODS

This study was approved by the Research Ethics Committee of the University of Passo Fundo, Brazil.

Ten human maxillary premolars with three distinct roots and fully formed apices were selected at random from a pool of extracted teeth at the University of Passo Fundo's Human Tooth Bank. They were stored in labelled individual plastic vials containing 0.1% thymol solution until use.

For the µCT analysis, the teeth were scanned in a transversal direction using a high-resolution desk-top µTC system at 50 kV (Skyscan 1072 Kontich, Belgium). The area of interest scanned in each tooth extended from the central fissure of the occlusal surface to the apices of the roots.

From 405 to 500 slices with voxel sizes of 34 x 34 x 42 µm were scanned of each tooth. Each image had a Z value (in mm) on its left upper corner, indicating the distance from one slice to the previous one, which facilitated measurements. The images generated by the µCT system were processed and analyzed by an experienced endodontist for the following:

1. Cross-sections of the roots and canals at the three root thirds: cervical (approximately 2 mm from canal trifurcation), middle (equidistant from the cervical and apical thirds) and apical (the most apical slice that contained the section of the three roots). Variations of the cross-section of the canals along their length were recorded;

2. Location of the apical foramen;

3. Position of the pulp horns in relation to the oclusal surface of the teeth. When the buccal and palatal pulp horns were localized, their position in a crown-apex direction was recorded for further measurement of the distance between them.

4. Distance from the buccal and palatal pulp horns and the most cervical portion of the pulp chamber roof to the bi and trifurcation of the canals. In the μCT scans corresponding to these anatomic aspects, the Z value was recorded so that the referred distances could be further measured;

5. Anatomic variations of the root canal system regarding the presence of lateral canals, apical delta (localized in the apical 2 mm), furcation canals, etc, in the different root thirds.

The results were expressed descriptively.

RESULTS

Cross-section of the roots and canals

Overall, the mesiobuccal root was larger than the distobuccal root, mainly in the bucco-palatal direction. The cross-section of the buccal roots was ovoid, while the palatal root had a more circular cross-section (Figure 1).

The large number of μTC images obtained from each tooth revealed variability in the cross-sectional shape of the canals in the cervical, middle and apical thirds (Table 1) (Figure 2a-i). Even in the same third there was substantial heterogeneity in cross-sectional shape. In 4 specimens, the mesiobuccal canals were “comma-like” in cross-section at the cervical third (Figure 2a,b), and the isthmus zone of the section was always directed to the palatal surface. This shape was also identified in the canal of the DB root of 1 specimen in the middle (Figure 2d) and apical thirds. A circular cross-section was the most frequent finding in the apical third of all canals (Figure 2h). In 3 specimens, the root canal of the P root had a dumbbell-shaped apical cross-section (Figure 2 g,i), and one of them bifurcated more apically (Figure 2g).

Location of the apical foramen

Table 2 reveals that the location of the apical foramen varied considerably, tending to lie on the palatal and distal aspects of the roots. In a few specimens, the apical foramen coincided with the radiographic apex (RA). In the palatal roots of four specimens an apical delta was found, ending in two foramina that opened in different directions. In one of the specimens, one of the foramina opened more cervically to the distal, where the diameter of the cemental canal increased towards the apex, and another foramen with smaller diameter opened more apically, in a distobuccal location. In the distobuccal root, an apical delta was found in the final 2 mm of the root, ending in three apical foramina (Figure 3).

Position of the pulp horn in relation to the occlusal surface

In 8 out of 10 specimens, the buccal pulp horn was located more occlusally than the palatal one. The difference in height between the pulp horns ranged from 0.69 to 2.57 mm, with a mean of 1.55 mm. In only one specimen was the palatal pulp horn located more occlusally than the buccal pulp horn, at a distance of 1.07 mm. In 1 specimen the pulp chamber roof was not present and so it was not possible to evaluate this factor.

Distance from the pulp chamber roof to the bi and trifurcation of the canals

Table 3 reveals the mean, maximum and minimum distances from the buccal (Figure 4a) and palatal (Figure 4b) pulp horns, and from the most cervical region of the pulp chamber roof (Figure 4c) to the bi (Figure 4d,e) and trifurcation (Figure 4f) of the canals. Canal bifurcation, resulting in a buccal and a palatal canal, occurred at a mean distance of 3.13 mm from the most cervical region of the pulp chamber roof. Distances of up to 7.88 and 0.77 mm were measured from the bifurcation to the buccal pulp horn and to the most cervical region of the pulp chamber roof, respectively. Trifurcation of canals, resulting in a mesiobuccal, distobuccal and palatal canal, occurred at a mean distance of 5.08 mm from the most cervical region of the pulp chamber roof. Distances of up to 10.84 mm and 2.57 mm were measured from trifurcation to the buccal pulp horn and to the most cervical region of the pulp chamber roof, respectively.

Anatomic variations of the root canal system

Apical deltas were found in 6 specimens, 3 in the distobuccal root (Figure 3) and 4 in the palatal root. Lateral canals were found in 6 specimens, 2 in the distobuccal root and 4 in the palatal root. Two lateral canals were found in one of the palatal roots (Figure 5). Furcation canals were found in two specimens (Figure 6). Calcification or accentuated narrowing of the canals was observed in 3 specimens, 2 in the mesiobuccal root (Figure 2i), 2 in the distobuccal root and 1 in the palatal root.

DISCUSSION

Lack of knowledge of the internal anatomy of maxillary premolars with three root canals may lead to failure of root canal treatment. The endodontic treatment of three-rooted maxillary premolars is complex (Lombart & Michonneau 2005) and, in many cases, conventional periapical radiography is of limited value in identifying the cross-sectional shape of root anatomy, especially in multi-rooted teeth, due to superpositioning of adjacent structures (Robinson *et al*. 2002). µCT analysis determines precisely the number of roots and, in case of separate roots, the level and extension of the bi or trifurcation. The pathway of the canals in the roots, the relationship between the canals, and whether or not they join at some point can also be seen.

The present study investigated several anatomic aspects of the root canal system of three-rooted maxillary premolars, using a recent technological resource that provides three-dimensional and detailed views of the internal anatomy of teeth without the need of sectioning, preparation or destruction of the specimens (Bjorndal *et al*. 1999, Rhodes *et al*. 1999). Nevertheless, despite the countless anatomic details that can be visualized with this technology, its application in clinical endodontics is not viable due to the high radiation dose, the long exposure time, the limited availability and the high costs (Velvart *et al*. 2001).

In this study, the mesiobuccal root had a greater volume than the distobuccal root in the bucco-palatal direction. These teeth were similar to the maxillary first molar regarding the disposition of the roots in the dental arch, number of roots and cross-section. However, it is important to emphasie that the mesiobuccal root did not have two canals in any of the specimens, which is a common finding in maxillary first molars (Barton *et al*. 2003). An interesting finding of the present study was that, especially in the cervical third, the mesiobuccal canal had a “comma-like” cross-section, with the isthmus directed to the palatal.

In the sample examined, three distinct root canals - a mesiobuccal, a distobuccal and a palatal canal- were found in all maxillary premolars. According to Kerekes & Tronstad (1977), root canal instrumentation techniques should be adapted to the morphological characteristics of each tooth. So, an adequate access to the pulp chamber, which creates a triangular-shaped cavity with the base facing the buccal surface, may facilitate the localization of canals in these teeth (Sieraski *et al*. 1989). The fragility of the buccal roots of these teeth must also be considered during instrumentation, with apical preparation being limited in diameter and taper in order not to compromise the integrity of the roots.

The study revealed a substantial variation in the anatomic configuration in each third of the canals (Table 1) and even within the same canal third. The location of the apical foramen varied considerably, tending to the palatal or distal aspect of the roots. The fact that the innervation of these teeth comes from a distal direction might have contributed to this occurrence. In a few cases, the foramen was coincident with the root apex,.

The buccal pulp horns were located more occlusally than the palatal pulp horns in 8 of the 9 specimens analysed (Table 3). The clinical implications of this finding are important in deep carious lesions where exposure of the buccal pulp horn is more likely compared to the palatal.

During access cavity preparation in teeth with more than one canal, care should be taken not to damage the pulp chamber floor. The present investigation revealed that, although the mean distance between the most cervical region of the pulp chamber roof and the canal bifurcation was 3.13 mm, in some cases, distances less than 1 mm were found. Therefore, access to the pulp chamber of maxillary premolars with three canals should be prepared with care to avoid inadvertent perforation of the pulp chamber floor, directing the bur to the palatal side where the canal is larger. The convexity of the intact pulp chamber floor aids in the localization of the canal entrances during canal negotiation, instrumentation and filling. On the other hand, distances up to 7.88 mm were measured between the bifurcation and the buccal pulp horn, which means that the volume of the pulp chamber in these teeth varied considerably. Therefore, the presence of large pulp chambers in three-rooted maxillary premolars would minimize the risk of accidental perforation of the pulp chamber floor during access cavity preparation but, on the other hand, it would be more difficult to find the canal entrances because the canals in this case would invariably be located more apically.

Another finding of clinical applicability of the present study was that in three-rooted maxillary premolars, starting from the pulp chamber towards the root apex, the canal system divides initially into a buccal and a palatal canal. Then, more apically, the buccal canal bifurcates again, giving the three root canals (mesiobuccal, distobuccal and palatal), characterizing the three rooted maxillary premolar.

The data in Table 4 show that, in general, the formation of thee canals or the bifurcation of the buccal canal occurs at a distance of approximately 2 mm from the pulp chamber floor, since the mean distance between the most cervical region of the pulp chamber roof up to the canal bi and trifurcation was 3.13 and 5.08 mm, respectively. The distances between the most cervical point of the pulp chamber roof to the canal trifurcation ranged from 2.57 to 8.01 mm. Thus, bifurcation of the buccal root may occur at any position along the root length.

The use of µTC revealed the rich internal anatomy of the root canal system of three-rooted maxillary premolars, with the presence of lateral canals, apical delta, furcation canals, as well as the gradual changes of the canal anatomy along the root.

CONCLUSIONS

1. The cross-section of canals in three-rooted maxillary premolars was heterogeneous along the root length;

2. The position of the apical foramen was variable, tending to lie on the palatal and distal aspects of the roots;

3. The buccal pulp horn was larger than the palatal pulp horn;

4. The mean distance between the most cervical region of the pulp chamber roof and the canal bi and trifurcation was 3.13 and 5.08 mm, respectively;

5. µCT can contribute to a better understanding of root canal system anatomy.

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Table 1. Cross-sections of the canals of three-rooted maxillary premolars at the different root thirds.

Cross-section	**Mesiobuccal canal**			**Distobuccal canal**			**Palatal canal**		
	Cervical	**Middle**	**Apical**	**Cervical**	**Middle**	**Apical**	**Cervical**	**Middle**	**Apical**
Comma-like	4	-	-	-	1	1	-	-	-
Circular	5	8	6	5	4	7	8	10	7
Ovoid	1	1	2	4	5	2	-	-	-
Elliptical	-	1	1	1	-	-	2	-	-
Dumbbell	-	-	-	-	-	-	-	-	3
Total	10	10	9*	10	10	10	10	10	10

*In one of the specimens, the apical cross-section of the mesiobuccal canal was totally calcified.

Table 2. Direction of the apical foramen opening in the mesiobuccal, distobuccal and palatal roots of three-rooted maxillary premolars.

Specimen	Apical foramen opening		
	Mesiobuccal canal	**Distobuccal canal**	**Palatal canal**
1	Distal	Radiographic apex	Distal
2	Distopalatal	Palatal and Mesial*	Distal and Distopalatal*
3	Radiographic apex	Distal	Buccal and Distal *
4	Radiographic apex	Palatal	Buccal
5	Distal	Palatal and Palatal*	Palatal
6	Palatal	Palatal, Mesiopalatal and ?*	Palatal
7	Palatal	Radiographic apex	Distal and Buccal*
8	Palatal	Distopalatal	Distal and Distobuccal*
9	Palatal	Distal	Mesial
10	Distobuccal	Distopalatal	Mesial

RA = radiographic apex.

*Roots with apical delta ending in two or three apical foramina. The location of the apical foramen opening of one of the canals could not be established.

Table 3. Distance* (mm) form the pulp chamber roof to the bi and trifurcation of the canals.

	Bifurcation			Trifurcation		
	Mean	**Max**	**Min**	**Mean**	**Max**	**Min**
Buccal pulp horn	5.95	7.88	3.47	7.90	10.84	5.27
Palatal pulp horn	4.69	6.34	2.79	6.64	9.30	4.54
Most cervical region of the pulp chamber roof	3.13	5.06	0.77	5.08	8.01	2.57

* Distance measured in 9 specimens due to the absence of crown in one specimen.

FIGURE LEGENDS

Figure 1. Cross-sections of the MB, DB and P roots from the cervical (a), middle (b) and apical (c) thirds of three-rooted maxillary premolars

Figure 2. Cross-sectional µCT scans of three-rooted maxillary premolars from the cervical (a,b,c), middle (d,e,f) and apical (g,h,i) thirds. Note: MB (a,b) and DB (d) canals with a comma-like shape; fusion of the DB and P roots after separation of the MB root (c); circular cross-section of the canals, in the cervical (c), middle (e) and apical (h) thirds; accentuated narrowing of the MB (f,i) and DB (f) canals; P canal with a dumbbell shape (g,i), ending in a bifurcation (g).

Figure 3. Presence of an apical delta in the DB root, ending in 3 foraminal openings in the apical 2 mm of the root. The sections are arranged sequentially from cervical to apical. Note: apical foramen opening to the palatal side of the more

cervical canal of the delta (a, b); cross-section showing only one canal (c); presence of two canals again (d), one of which opens to the MP (e) side. The opening of the third foramen could not be determined (f)

Figure 4. Cross-sectional μCT scans of three-rooted maxillary premolars, from cervical to apical, showing B (a) and P (b) pulp horn areas, the more cervical region of the roof of the pulp chamber (c), bifurcation of the B and P canals (d), cross-section of the B canal before its bifurcation in MB and DB (e) canals and trifurcation of the canals (f)

Figure 5. Cross-sectional μCT scans of three-rooted maxillary premolars, from cervical to apical, showing the presence of 2 lateral canals in the P root, one directing to D (a,b,c – white arrows) and one directing to B (c, d, e, f – black arrows)

Figure 6. Cross-sectional μCT scans of three-rooted maxillary premolars, from cervical to apical, showing the presence of a furcation canal (white arrow), exiting from the B canal before its bifurcation and taking a palatal direction in the furcal region.

Figure 1

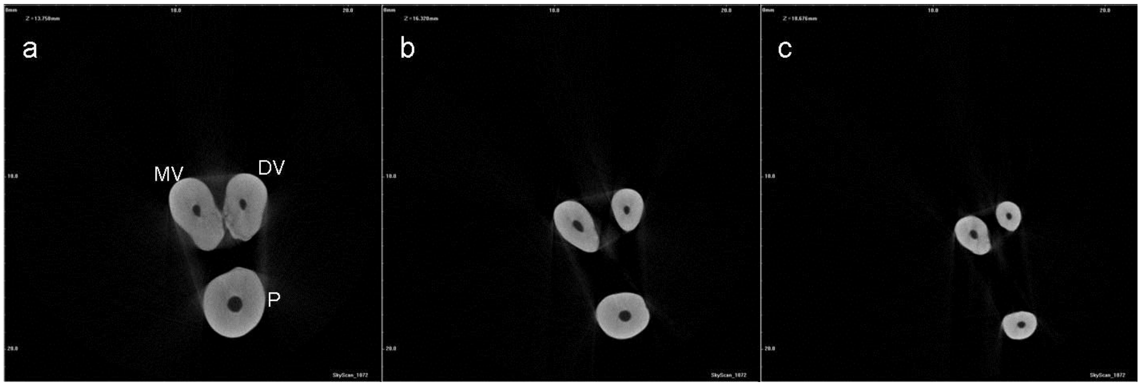

Figure 2

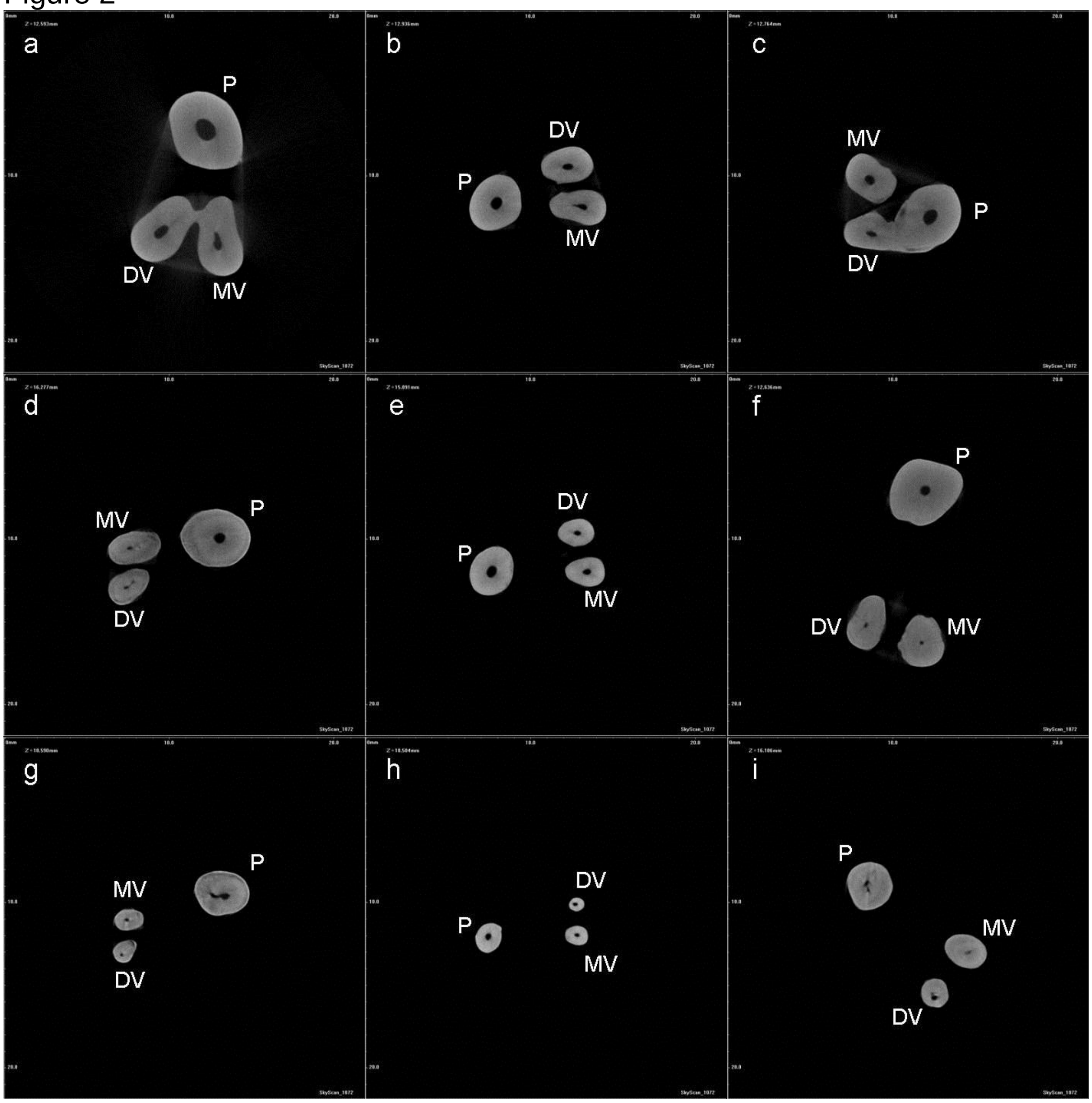

Figure 3

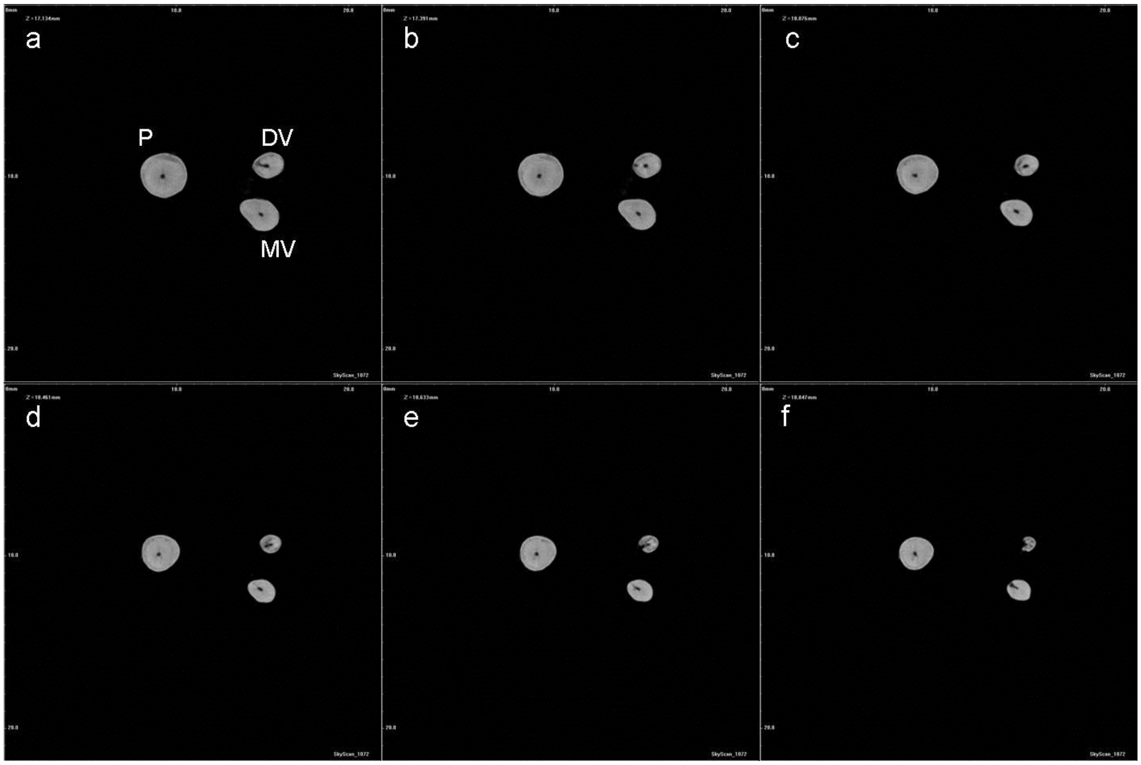

Figure 4

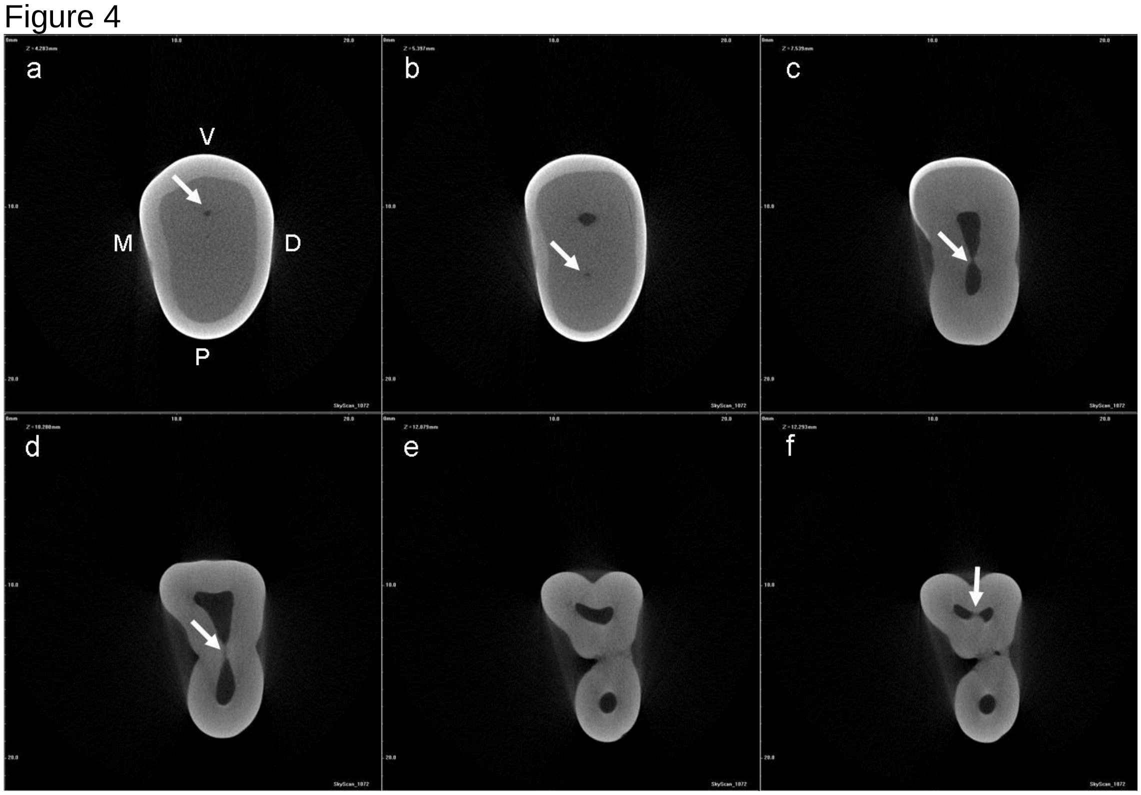

Figure 5

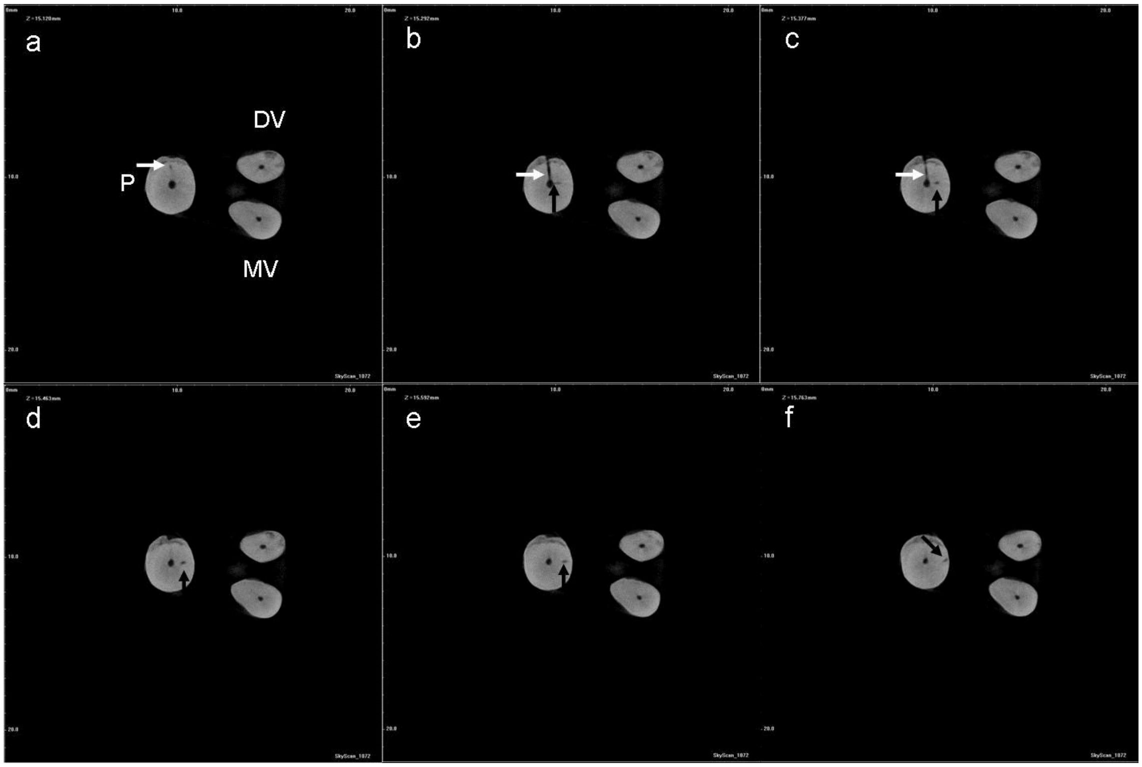

Figure 6