Classification and morphology of middle mesial canals of mandibular first molars in a Southern Chinese subpopulation: a cone-beam computed tomographic study

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Abstract

Background：Cone-beam computed tomography (CBCT) was used to study the morphology and curvature of the middle mesial canals (MMCs) of the mandibular first molars (MFMs).

Methods：CBCT scanning was performed on the MFMs of 1100 patients. The pa tients' images which met the inclusion criteria were divided into group A (<40 years old) and group B (≥40 years old) for further study. To study the incidence of the MMCs at different ages, to measure the curvature of MMCs of mesiodistal and buccolingual direction by Schneider method, and to observe the anatomical morphology of the mesial root canal system.

Results：In 875 patients, 1750 MFM images met the inclusion criteria, among which 158 MFMs contained a MMC, with an incidence rate of 9.03%. The incidence rate of MMCs was 11.22% in group A and 6.61% in group B, with statistically significant differences ($P<0.05$). The curvature in group A was 29.39±8.53° in mesiodistal direction while group B was 26.06±8.50 °, with statistical differences ($P<0.05$). It has been shown that curved regions in group A and B were often found out in the middle 1/3. There is no significant difference in the distance between MMC orifices and mesiobuccal canal orifices or mesiolingual canal orifices ($P>0.05$). The most common mesial root canal morphology type was type II (3-2) (53.80%).

Conclusion：The incidence of MMCs in MFMs was showed to decline along with the increase of age. The canal system of MMCs was varied and complex, mostly with mesiodistal curve obviously. CBCT is an outstanding assistant examination to the root canal therapy.

Background

The MFMs are the first permanent molars to grow into the mouth, which are often needed root canal treatment due to pulpitis and periapical periodontitis [1]. Because of the complexity of the root canal system, it is easy to lead to the failure of treatment. The success of root canal treatment depends on many factors, such as insufficient understanding the internal anatomy of the root canal, failure to thoroughly clean, shape, and properly seal the root canal [2–4]. The root canal system of the MFM is one of the most complicated in human teeth. For example, c-shaped root canal [5], distolingual roots (DLRs) [6], the middle mesial canals and the occurrence of fusion root [7]. In 1974, De Pablo OV discovered the existence of a third canal between the mesiobuccal canal and mesiolingual canal in the mesial root of MFM [8]. Pomeranz et al. then divided the canal into three types: independent, confluent, and fin [9]. Later, this kind of root canal was also called “middle mesial canal”[9], “accessory mesial canal” [10]. Scholars at home and abroad have conducted a large number of studies on MMCs with different methods, but most of them are mainly case reports, and the incidence rate of MMCs ranges from 0.26–46.15% [11–16]. The traditional methods of root canal research are mostly carried out on in vitro teeth, but the sample size is small and inconvenient. And the application of microCT is the most sophisticated method for root canal research, but it is not suitable for clinical detection.

CBCT is a clinical auxiliary imaging equipment developed rapidly in recent years. Compared with the commonly used apical film and panoramic radiograph, it has the advantages of small radiation dose, high image resolution, three-dimensional reconstruction and simple operation. It can be analyzed by computer and displayed on sagittal plane, coronal plane and axial plane at the same time, which is more suitable for oral clinical needs [17, 18]. According to the imaging studies on the morphology of the MMC, CBCT can clearly, stereoscopically and intuitively display the morphology of MMC in the coronal, sagittal, axial and 3D images, providing the first-hand and reliable imaging data for the clinic [19–21].

At present, CBCT has been gradually applied to the field of dental pulp diseases, as a clearer and more intuitive auxiliary examination method based on X-ray imaging examination. Although many scholars have applied CBCT to study MMC, there are few studies on the morphological classification and curvature of MMC in a Southern Chinese subpopulation. The purpose of this experiment is to study the curvature and curved regions of MMC in a Southern Chinese subpopulation,and to explore the correlation with age. Based on previous research the root canal types of mesial root canal of MFM for reference, we try to classify the type of mesial root of MFM in our sample in order to provide a reference for clinical root canal therapy.

Methods

Patients

CBCT scans were performed on the mandibular first molars of 1,100 patients in southern China who required CBCT imaging in the database of the department of oral radiology, Nanfang hospital, Guangzhou. With the informed consent of the patients, this study was approved by the ethics committee of Nanfang hospital. All images were collected with the CBCT imaging system between January 2018 and January 2019. All images were included in the study and further analyzed according to the following inclusion criteria:

1. MFMs without periapical disease;
2. MFMs had not been endodontically treated;
3. MFMs have no root canals with open apices or absorption;
4. MFMs absence of coronal or post and core restorations which may obscure image study;
5. CBCT images of good quality, clear and without artifacts.

CBCT scanning condition

The CBCT images were taken using a Planmeca Romexis 3D CBCT scanner (Planmeca, Finland). The board-certified radiologists operated the x-ray tube at an accelerated potential of a peak voltage of 84 kv with a beam current of 14 mA and the exposure time was 12 seconds for a full arch. The voxel size was

200μm×200μm and the minimum thick-layer was 0.15mm. The detector resolution was 1024×1024 pixels and the pixel size was 127 μm×127 μm. Image data were exported in DICOM format.

Analytical method and content

All CBCT images are reconstructed and measured by the image reconstruction software of Planmeca Romexis CBCT. The running system of the software is a 32-bit windows7 system, and the display screen is a display screen of Lenovo Company. The screen resolution is 1280 × 1024. The whole CT image is observed and analyzed in the dark room.Serial axial, coronal, and sagittal CBCT images were thoroughly examined from the pulp orifice to the apex. All of the images were assessed separately by 2 endodontists. To confirm the reliability of the data, intraexaminer calibration was performed before the experiment. In cases of disagreement, these 2 endodontists were discussed until a consensus was reached.

MMCs classification standard

In CBCT images, the mesial root canal system of MFMs was classified based on classic Vertucci classification and its additional root canal classification [22–25].

Type□(3-3): Pulp chamber bottom have three root canal orifices, and always has three independent root canals, and finally there are three different apical foramens.

Type□(3-2): Pulp chamber bottom have three root canal orifices□then there are merged into two canals at a certain position of the root canal□and ends up with two apical foramens.

Type□(3-2): There are three root canal orifices at the bottom of the pulp chamber, and then they merge into two root canals, and finally come out from two different apical foramens.

Type□(2-3-1): There are two root canal orifices at the bottom of the pulp chamber, then they branch into three independent root canals, and finally they merge into one root canal, and they come out from the same apical foramen.

Type□(2-3-2): The bottom of the pulp chamber begin with two root canal orifices, then branch into three separate root canals, and finally merge into two root canals.

Type□(2-3-2-1): There are two root canals at the beginning of the pulp chamber, which are then branched into three independent root canals, and finally, the same apical foramen is formed.

Type□(1-2-3-2): There is a root canal opening at the bottom of the pulp chamber, which branches into two independent root canals at the upper part of the root canal, then divides into three independent root canals, and finally merges into two root canals.

Type(1-3-4-1): There is only one root canal orifice at the bottom of the pulp chamber, and then it branches into three independent root canals, and then divides into four independent root canals, and finally merges into the same root canal at the apex part of root canal.

Type(3-2-1): There are three different root canal orifices at the bottom of the pulp chamber, and then they merge into two root canals, and finally come out from the same apical foramen.

Type(3-2-3-2): At the bottom of the pulp chamber there are three different root canal orifices, which fuse into two root canals, then branch into three independent root canals, and finally through two different apical holes out of the root canal system.

Type(3-4-3-2-1): There are three root canal orifices at the bottom of the pulp chamber, which are divided into four root canals, and then merged into three independent root canals, during the apical 1/3 of root canal, they are merged into two canals, and finally an apical foramen is formed.

If the types of root canal system found in our experimental sample cannot be found in the Vertucc classification or in the additional root canal classification studied by scholars from all over the world, it will be listed separately (Figure 2-4).

Analysis of the curvature and position of the MMC

In this study, a modified Schneider method was used to measure the curvature of the MMC [26]. The method is: use the 3D reconstruction software of planeca romexis CBCT machine to set the root canal orifice as point a, the apical foramen as point C, draw a straight line along the root canal image from point a, and set the inflection point as point b. The acute angle of ab and bc lines was root canal curvature. The curvature of root canal can be divided into three grades: slight curvature is less than or equal to 10°; medium curvature is between 10°-30°; severely curvature is more than or equal to 30°. Measurement of root canal curved position: referring to the ratio of ab and bc, set P = ab / bc (Figure 1). According to the results of P, the curved regions of root canal can be divided into three categories: $P<0.5$ is class I, the curved region of root canal is upper 1/3; $0.5<P\leq 2$ is class II, the curved region of root canal is middle 1/3; $P > 2$ is class III, the curved region of root canal is apical 1/3.

Statistical Analysis

Statistical analysis was performed using SPSS 21.0, the rate is compared by chi-square test; the mean is compared with t test, with significance set at P0.05

Results

The CBCT images of the MFMs of 1100 patients were observed, and 1750 CBCT images of 875 patients met the inclusion criteria, among which 158 CBCT images contained MMC. The incidence of MMC in our experimental sample was 9.03%. Among them, there were 81 (51.27%) males and 77 (48.73%) females, and the difference between them was not statistically significant($P > 0.05$). The average age of the patients with MMC in males was (37.9 ± 1.76) years old, while that of the females was (33.42 ± 1.52) years old ($P > 0.05$). Moreover, there was no significant difference in the distribution of the MMC between the right and left MFMs,whether males or females (Table 1).

Table 1
The incidence of mesial middle canals in mandibular first molars of different sex

Sex	Single side		Both side	Total
	Left	Right		
Male	39(24.68%)	37(23.42%)	5(3.16%)	81(51.27%)
Female	36(22.78%)	37(23.42%)	4(2.53%)	77(48.73%)
Total	149(94.30%)		9(5.70%)	158(9.03%)

875 patients were divided into group A and group B with the age of 40 years old as the boundary. The group A and group B were observed again with an age gradient of 10 years old,with the minimum age of 18 years and the maximum age of 70 years. In the 18–29 age group of group A, 63 of the 476 teeth contained MMC, and this root canal incidence was 13.24%. It can be seen from Table 2 that with the increase of age, the incidence of the MMC in the MFMs decreased. The difference of MMC's incidence in group A and group B was statistically significant ($P < 0.05$) (Table 3).

Table 2
Number and percentage of the middle mesial canal in mesial roots of the mandibular first molars by age

	< 40		≥ 40		
	18–29	30–39	40–49	50–59	60–80
Number of specimens/Total	63/476	40/442	30/352	17/286	8/194
Incidence	13.24%	9.05%	8.52%	5.94%	4.12%

Table 3

Comparison of MMC's incidence of the MFMs between the group A and group B

Group	Total number of teeth	Number of teeth with MMC	Incidence
Group A	918	103	11.22%*
Group B	832	55	6.61%
Total	1750	158	9.03%

* Compared with group B, *P*< 0.05

In this study, we classified the types of mesial root canals of 158 MFMs containing the MMC, and named them based on the Vertucci classification,but these classifications are only suitable for the southern Chinese subpopulation. A total of ten types of root canals system were found, the most common type was type II (3 – 2) (53.80%), followed by type IV (2-3-2) (25.32%) and type I (Type VIII) (8.23%), the other seven types were relatively rare.We found that three of these root canal types have not been reported in the previous literature using the CBCT to study the MFMs. So we showed them through CBCT screenshots and 3D reconstruction images. (Table 4□Figure 2,3,4,5). As can be seen from Table 4, most of the MMC was fused in the middle or apical part of the root canal with the mesiobuccal root canals or mesiolingual root canals (92.41%). Only 8.23% of the MMCs were independent from the bottom of the pulp chamber to the apical foramen.

Table 4

Frequency distribution of the improved Vertucci's classifications of middle mesial canal of mandibular first molars in a Southern Chinese subpopulation

Classification	Improved Vertucci's classification	Number of specimens	Incidence
Type□	Type VIII	12	8.23%
Type□	3 – 2	85	53.80%
Type□	2-3-1	4	2.53%
Type□	2-3-2	40	25.32%
Type□	2-3-2-1	5	3.16%
Type□	1-2-3-2	2	1.27%
Type□	1-3-4-1	3	1.90%
Type□	3-2-1*	3	1.90%
Type□	3-2-3-2*	2	1.27%
Type□	3-4-3-2-1*	1	0.63%

* We found that there were three classifications have not been reported by using CBCT.

Among the root canal types found in this experiment, type I (type VIII), type II (type 3 – 2), type VIII (type 3-2-3-2), type IX (type 3-2-3-2) and type X (type 3-4-3-1) all have three root canal orifices at the bottom of the pulp chamber, which are mesiobuccal(MB) root canal orifices, MM root canal orifices and mesiolingual(ML) root orifices. We measured the distance between the mesiobuccal - middle mesial orifices as well as the mesiolingual - middle mesial orifices from the above types in group A and group B respectively. The statistical results showed that, no matter what type of root canal system, there was no significant difference in the distance between the MMC and the two main root canals in group A and B (P[illegible]0.05) .

Table 5
The distance between the mesiobuccal - middle mesial orifices as well as the mesiolingual - middle mesial orifices

Classification	**Improved Vertucci's classification**	**MM-MB distance (Mean ± S)**		**MM-ML distance (Mean ± S)**	
		< 40	≥ 40	< 40	≥ 40
Type[illegible]	Type VIII	1.55 ± 0.30	1.41 ± 0.25	1.56 ± 0.17	1.32 ± 0.20
Type[illegible]	3 – 2	1.44 ± 0.31	1.40 ± 0.28	1.41 ± 0.25	1.49 ± 0.28
Type[illegible]	3-2-1*	1.07 ± 0.27	1.01	1.17 ± 0.38	1.21
Type[illegible]	3-2-3-2*	—	1.93 ± 0.04	—	1.49 ± 0.01
Type[illegible]	3-4-3-2-1*	1.02	—	1.02	—

As shown in Table 6, 95.15% of the MMCs in group A showed a significant curvature of > 10 ° in the mesiodistal directions, and 71.84% in the buccolingual directions; In grope B,96.36% of the MMCs showed a significant curvature of > 10° in the mesiodistal directions, and 85.45% in the buccolingual directions. By Chi-square test, the curvature in the mesiodistal directions was significantly greater than that in the buccolingual directions all in group A and B, and the difference was statistically significant (P < 0.01). The curvature in group A was 29.39 ± 8.53° in mesiodistal direction while group B was 26.06 ± 8.50 °, with statistical differences (P < 0.05). The curvature of group A was 21.34 ± 10.41 ° in buccolingual direction while group B was 22.45 ± 10.67 °, without statistical differences (P > 0.05) (Table 6).

Table 6
Curvature in the mesiodistal and buccolingual direction of the MMCs of mandibular first molars

Age	Direction	Slight (≤ 10°)	Medium (10°-30°)	Severely (> 30°)	Mean ± S
<40	Mesiodistal	5(4.85%)	62(60.19%)	36(34.95%)	29.39 ± 8.53
n = 103	Buccolingual	29(28.16%)	54(52.43%)	20(19.42%)	21.34 ± 10.41
≥ 40	Mesiodistal	2(3.64%)	37(67.27%)	16(29.09%)	26.06 ± 8.50
n = 55	Buccolingual	8(14.55%)	30(54.55%)	17(30.91%)	22.45 ± 10.67

The incidence of mesiodistal and buccolingual curved regions of the MMCs were significantly higher in the middle 1/3 of the root canal than in the upper 1/3 and apical 1/3 of the root canal in group A and B (Table 7).

Table 7
The curved regions of of mesiodistal and buccolingual directions of the MMCs of the mandibular first molars

Age	Direction	Upper 1/3(P ≤ 0.5)	Middle 1/3(0.5 < P ≤ 2)	Apical 1/3(P > 2)
<40	Mesiodistal	9(8.74%)	80(77.67%)	14(13.59%)
n = 103	Buccolingual	5(4.85%)	92(89.32%)	6(5.83%)
≥ 40	Mesiodistal	2(3.64%)	53(96.36%)	0(0%)
n = 55	Buccolingual	1(1.82%)	51(92.73%)	3(5.45%)

Discussion

The MMC, typically described as the presence of an additional canal in mesial root, is an anatomic variant in MFMs. In accordance with previous studies, it showed that there have noted considerable difference of the MMC frequency. The detection rate of MMCs in mandibular first molars ranged from 0.26–46.15%, it is considered to be a racial trait. CBCT images are used to analyze in this experiment, there were 1100 patients, total in 1750 CBCT images, we found the incidence of MMC in mandibular first molars was 9.03%, the result is also within this range. There were no significant differences in the prevalence of MMC in MFMs between men and women. But the results expressed that the incidence of MMC in the mesial root of mandibular first molars decreases with age. With age, the teeth will have age-related changes, such as tooth wear, periodontal degeneration, Secondary dentin, calcification of root canal, thickening of cementum, root resorption and increase of transparent dentin in root caused by external stimuli such as caries and trauma. In this study, the high prevalence of MMC among over

40 years old subpopulation was in line with previous studies. Navid and other[27] articles showed that the incidence of coronal calcification of the root canal was higher than that of less than 40 after the age of the patient was over 40 years old. This was also the reason why the experiment was divided into two groups at the age of 40. But the detection rate of MMC decreased significantly after 40 years old, not because of the decrease in the actual existence rate of MMC, but because of calcification of root canal and secondary dentin hyperplasia, which caused the diameter of MMC root canal to become smaller[28]. It increases the difficulty of MMC probe, which will also increase the difficulty of CBCT scan observation in this experiment[29].

The mesial root of mandibular first molars poses significant variations, various studies have investigated the morphology and anatomic complexity of the mesial root of mandibular first molars [7][11][30]. However, only a few studies used CBCT images to examine the prevalence and configuration of MMCs. Some research articles report the middle mesial canals to be located equidistant to both the main canals, while others report it to be closer to one of the main canals. The results of this study also showed that there were no marked difference in the distance between the mesiobuccal - middle mesial orifices and the mesiolingual - middle mesial orifices from the above classifications, the result is same of the previous study[31]. This measurement might help clinicians in locating the MMCs position. Locating of MMCs based on midpoint distance between MB and ML root canal orifice.

The results showed that the mean curvature of MMC in different age groups was in the range of moderate and severe curvature, and the root canal with large curvature caused great difficulties in clinical operation. However, the root canals curvature of mesiodistal direction decreased with the increase of age, which may be related to the increase of calcification degree of root canals with the increase of age. All the above studies have proved the correlation between MMC and age. Therefore, clinicians can design different treatment schemes according to patients' age before treatment. In our study, a high proportion of patients of all ages were found to have mesiodistal and buccolingual direction, as described by Perlea[32]. It is suggested that the curvature of the root canal is usually three-dimensional. Clinicians should pay attention to the possibility of mesiodistal and buccolingual direction curvature of the teeth, not only one direction.

From the results of Table 7, it can be seen that the curved region of MMC mostly occurs in the middle 1/3 of the canal, so this part should be focused on with the treatment process. However, the curved region of the root canal is also at upper 1/3 and apical 1/3 of this root canal and these regions not only curved but narrow, and are easy to break endodontic instruments during root canal therapy[33]. Therefore, clinicians can improve the success rate of root canal therapy by knowing the shape and curvature of root canal in advance. Because few scholars at home and abroad study the curvature and curved region of MMCs, it cannot be referred to, which shows the necessity and importance of our results.

The presence of the MMCs should be considered before treatment. We found that there consist of 10 classification of mesial roots in the mandibular first molars with middle mesial root canals. Although most current articles study for MMCs were classified according to Pomeranz et al. [9], then we classified these 10 classification of root canals based on improved Vertucci's classification. This category had several merits. This category contained information about root number and the distribution of root canals. This classification of root canals can accurately and clearly present the trend of root canals. Our results revealed that the majority classifications of MMC was type II (3 − 2), which was consistent with previously reported studies of western Chinese [34], Korean[11], and Brazilian[28] populations. Then a higher prevalence of type IV (2-3-2) were found in our study was also similar to western Chinese[34], Korean[11], but the incidence of this classification is lower in Brazilian and Turk. These differences in root canal anatomy maybe influence of ethnic background on mandibular first molars root morphology. In the present investigation, we detected that Type VIII, type II (3 − 2), type IV (2-3-2) were the most common classifications. The clinician should be taken into consideration these classifications during root canal treatments. A total of 27 variants were found in the present study[35], which used by micro CT, these difference may be caused by different study method. There variants revealed a complex variation of MMCs, and they may bring challenge to dental operation both in surgical and non-surgical treatments. The presence of 3 canals merged before the apical foramen and join in 1 or 2 apical foramen will lesser affect the treatment outcome. Ali's research showed MMC orifices were at the CEJ level between the MB and ML canal orifices, which means they would not require troughing in order to be located. The MMCs would require troughing with a 1–2 mm depth in order to be accessed. But the MMC orifices were deeper than 2 mm and could not be accessed via troughing preparation[36]. The chance of failure increases because of the remaining organic tissue and microorganisms close to the apical foramen[37]. Detecting an extra mesial canal is also important for the success of nonsurgical and surgical root canal treatment. So we should know about the root canal configuration of MMC. Although the experimental methods for evaluating root canal morphology are clearing and staining, sectioning, conventional radiographs, magnification, micro–computed tomographic imaging, and mixed methods. In this study, we found 3 new root canal classifications in Southern Chinese subpopulation by using CBCT. Using CBCT's reconstruction software to slowly move the cross-section of each layer screenshots, can very clearly see the root canal branch and fusion. The advantages of CBCT in noninvasive observation of root canal system are fully reflected. We don't rule out the existence of more new root canal classifications. We should study them more deeply. Nevertheless, clinicians can find this kind of complex root canal classification with the help of CBCT so as to adopt more suitable treatment plan and not omit root canal treatment failure.

Conclusion

In the present CBCT study and the results of this experiment, the root canal configurations of mandibular first molars in a Chinese population demonstrated to have a certain proportion incidence of MMC. Moreover the results present new information on how to locate the MMC. Clinicians must consider the possibility of such anatomic variations.

Abbreviations

CBCT: Cone-beam computed tomography; MMC: Middle mesial canal; MFMs Mandibular first molars; DLR: Distolingual root; MB: mesiobuccal; ML: mesiolingual

Declarations

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Author contributions

Yeqing Yang: contributed to data collection, data analysis, manuscript writing. Ming Chen: contributed to data collection, manuscript editing. Junkai Zeng: contributed to manuscript editing. Buling Wu: contributed to protocol/project development, manuscript editing.

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Consent for publication

Not applicable.

Conflict of interest

The authors have stated explicitly that there is no conflict of interests in connection with this article.

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Figures

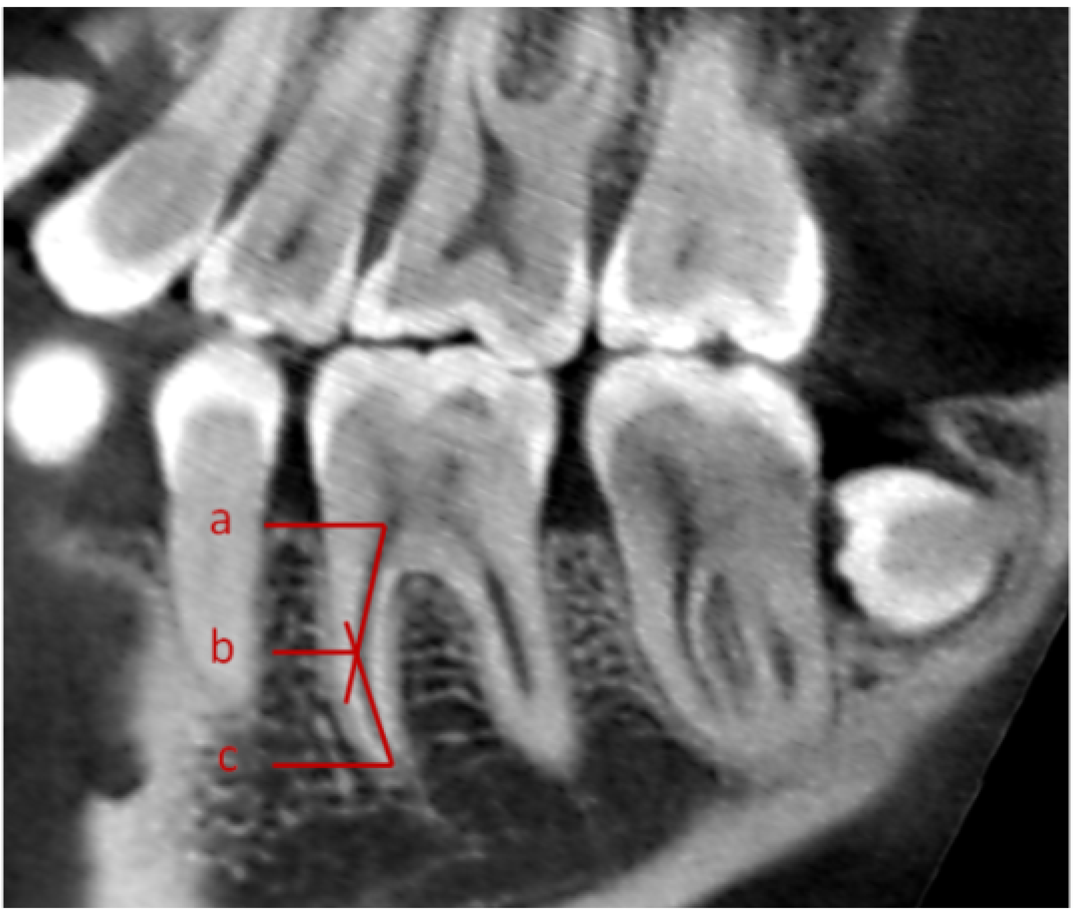

Figure 1

The measurement method for the curvature of root canal a: Root canal orifice; b: ab and bc linear inflection point; c: apical foramen

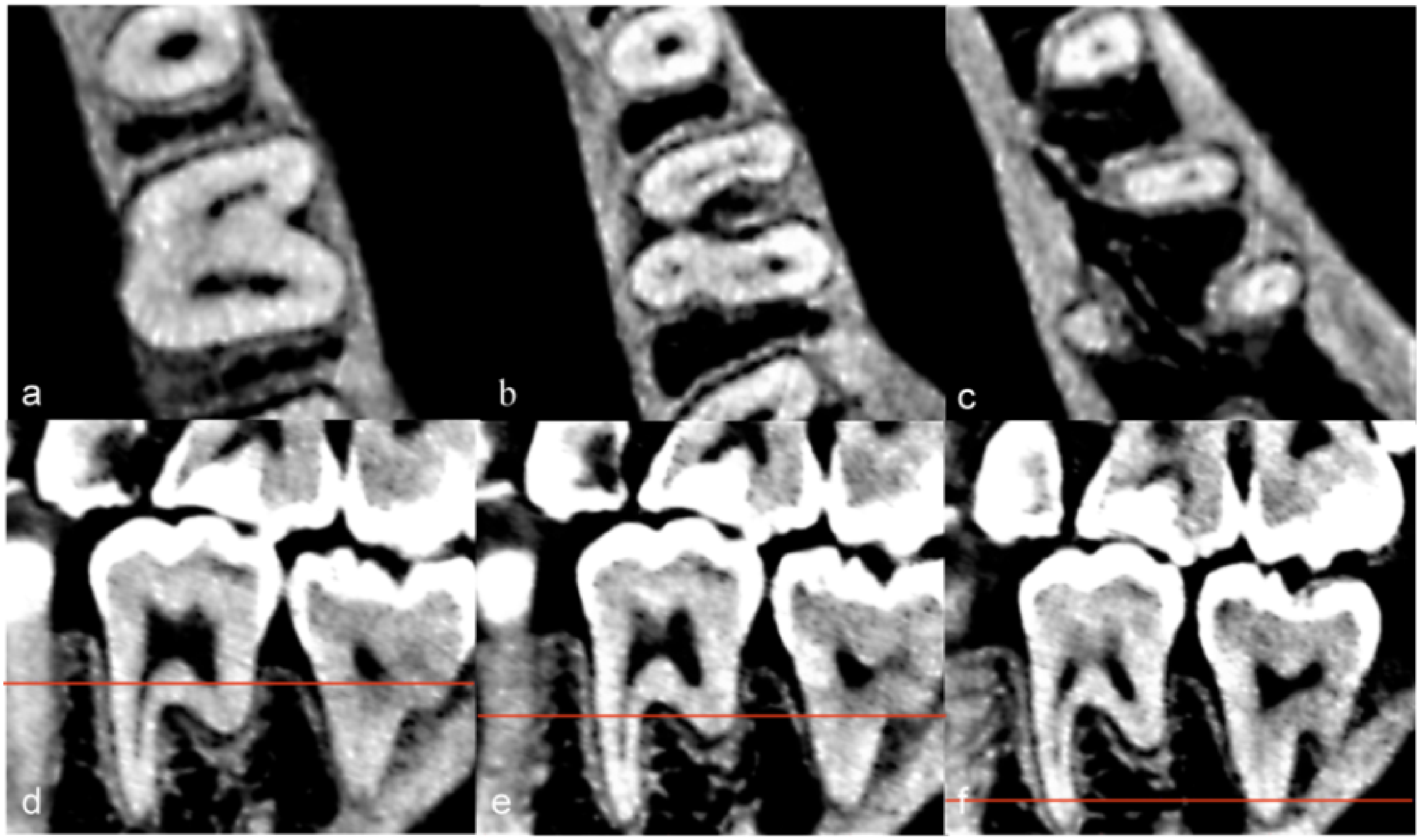

Figure 2

CBCT images of the 3-2-1 root canal system type a, b, c were CT images with different cross sections: a: Three canals can be seen at upper 1/3 of root canal; b: There were two canals at middle1/3 of root canal; c: Two root canals eventually fused into one apical foramen; d, e, f are sagittal images.

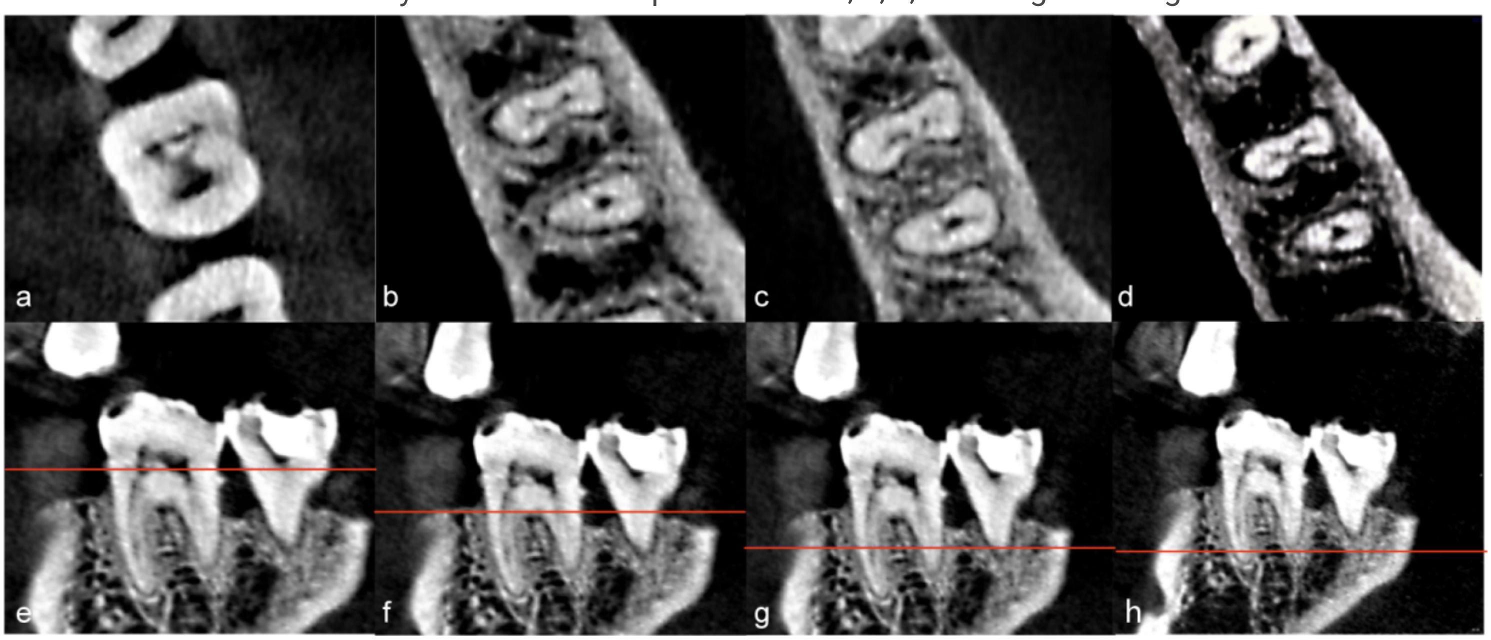

Figure 3

CBCT images of the 3-2-3-2 root canal system type a, b, c, d were CT images with different cross sections: a: There were three canals at pulp chamber floor; b: The root canal can be seen from three canals to two canals; c: Two canals branched into three canals; d: root canals eventually became two different apical foramens; e, f, g, h are sagittal images.

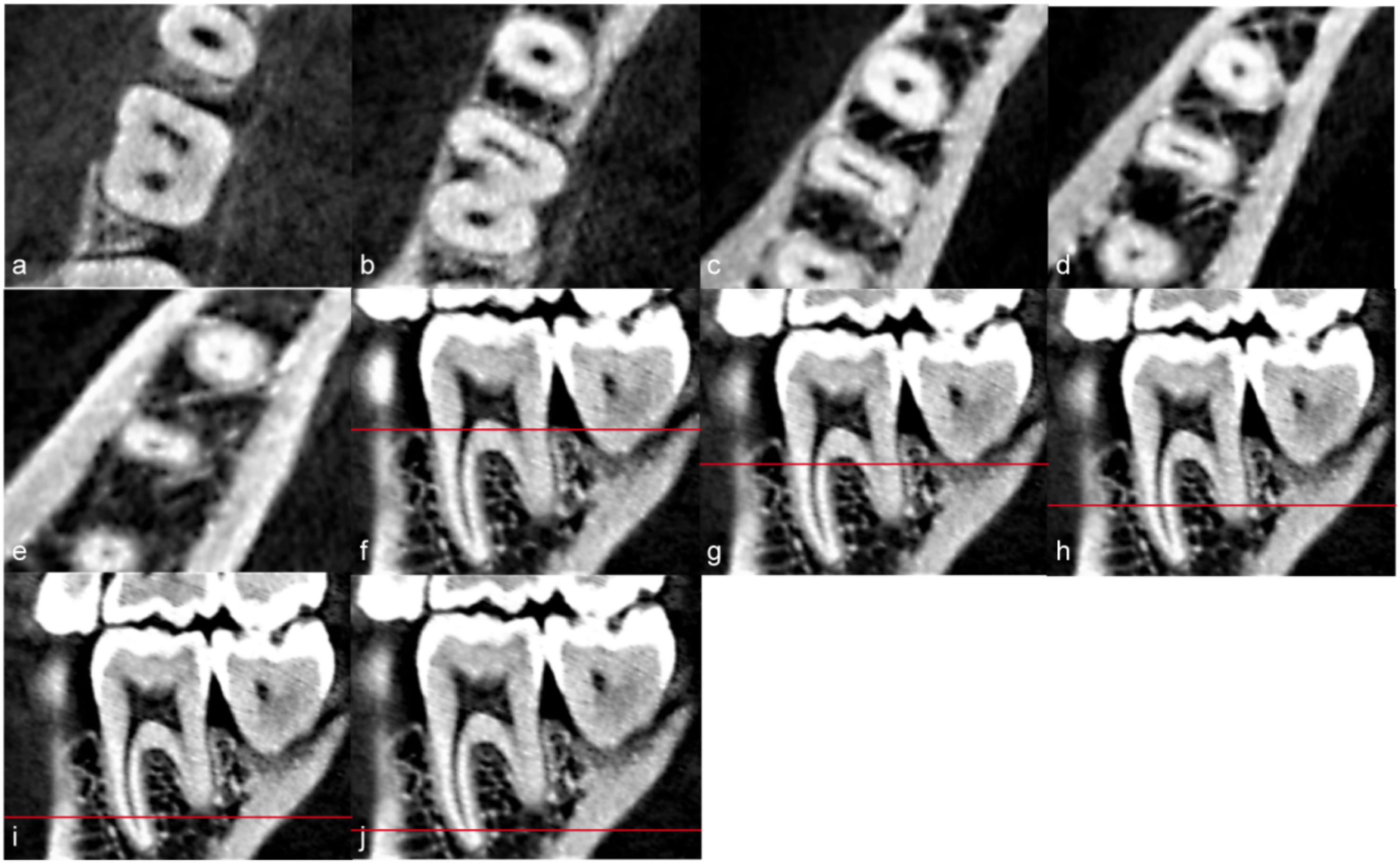

Figure 4

CBCT images of the 3-4-3-2-1 root canal system type a, b, c, d, e were CT images with different cross sections: This type is more complicated, there are three root canals at the bottom of the pulp chamber, then four branches are branched, and fused into three root canals, then two canals can be seen at apical 1/3 of root canal. The root canals eventually fused into one apical foramen; f, g, h, i, j are sagittal images.

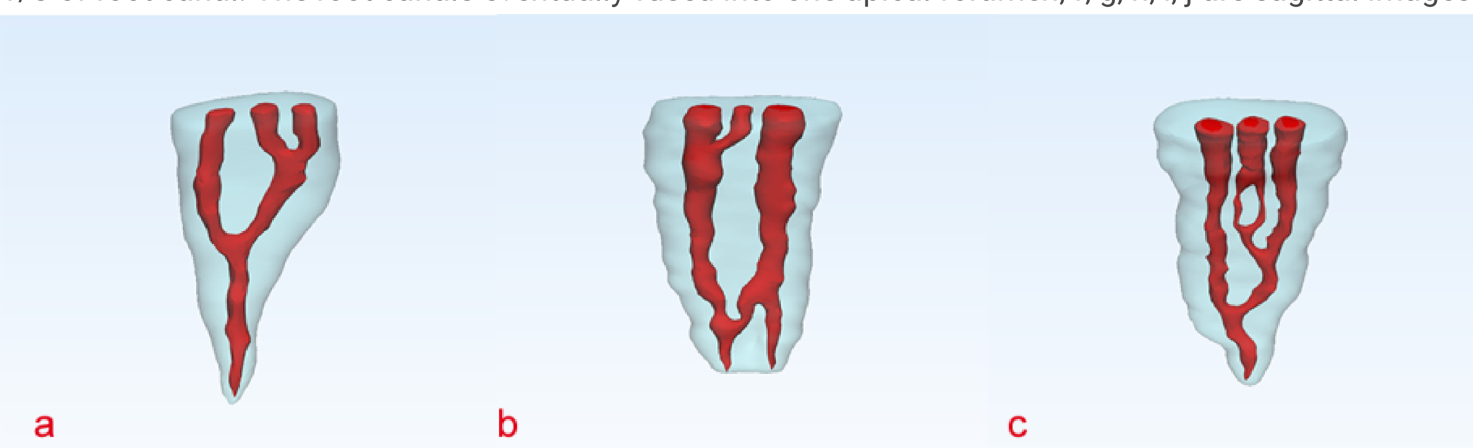

Figure 5

3D reconstruction images a:3D reconstruction images of Type▯(3-2-1); b:3D reconstruction images of Type▯(3-2-3-2); c:3D reconstruction images of Type▯(3-4-3-2-1).