



Root and canal morphology of maxillary second molars by cone-beam computed tomography in a native Chinese population

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Abstract

Objective: To evaluate the root and root canal morphology of the maxillary second molars (MSMs) in a native Chinese population by cone-beam computed tomography.

Methods: Cone-beam computed tomography images of 2412 MSMs from 1294 Chinese patients were analyzed to determine the number and morphology of the roots, the root canal morphology, the bilateral symmetry, and the correlations of these parameters with sex and age.

Results: The percentage of fused roots increased with age, while the percentage of fused roots in women was higher than that in men. The percentage of second mesiobuccal (MB2) canals in MSMs with three separate roots was higher in men than women. Patients aged 31 to 40 years showed a higher prevalence of MB2 canals, while those aged ≥ 51 years showed the lowest prevalence of MB2 canals among both men and women. There was a significant difference in bilateral symmetry of MSMs between men and women.

Conclusion: Root fusion of MSMs increased with age, while the root canal morphology was more complex in patients of intermediate ages.

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Keywords

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Introduction

A thorough anatomical knowledge of the roots and root canals is an essential prerequisite for successful root canal treatment.¹ Since Hess and Zurcher demonstrated the anatomic complexities of the root canal system, many studies have revealed that the root canal system has complex anatomical characteristics such as main and accessory canals, multiple foramina, isthmuses between canals, and irregularly shaped canals. More importantly, many studies have described different trends in the number and morphology of roots and root canals among different ethnicities, between the two sexes,² and among different ages.³⁻⁶

The maxillary second molars (MSMs) have been frequently investigated because of their complex root and root canal morphology and higher incidence of variations. Most MSMs exhibit a mesiobuccal root (MBR), a distobuccal root (DBR), and a palatal root (PR).⁷ A common anatomic variation in these teeth is root fusion, with a prevalence of 5.90% to 42.25%.^{4,8-13} Yang et al.⁸ indicated that the prevalence of root fusion of MSMs in a Chinese population in Taiwan was 40.1%. Fusion of the PR with the MBR was the most prevalent, followed by fusion of the MBR with the DBR; complete fusion of the three roots into a cone-shaped root was the least common. Other studies of the native Chinese population have revealed that fusion of the two buccal roots (BRs) of MSMs was the most prevalent type of fusion.⁹⁻¹¹ Silva et al.¹² reported that the prevalence of MSMs with three separate roots in a Brazilian population was 79.41%, while the most common anatomic variation was a mesial root (MR)

and a distal root (DR) with one canal in the MR and two canals in the DR. Plotino et al.¹³ found that a BR and PR was the most common anatomic variation in the MSMs in a white population. Kim et al.⁴ found that the incidence of fused roots was 10.71% in MSMs in a Korean population, and four separate roots were identified in four (0.49%) of the MSMs, including three BRs and one PR, two DBRs, one MBR, and one PR. In addition, Kottoor et al.¹⁴ reported an MSM of a 35-year-old man exhibiting two PRs, two MBRs, and one DBR each with its own separate canal. Zeng et al.¹⁵ treated a right MSM exhibiting a C-shaped MBR with two canals, two fused DBRs with two separate canals, and one normal bulky PR with one canal.

Many methods have been used to evaluate the root canal morphology. The most commonly used methods include canal staining and tooth clearing,^{2,16} periapical radiographs,¹⁷ and micro-computed tomography (micro-CT).⁹ The canal staining and tooth clearing technique has generally been considered the gold standard in previous studies.^{2,16} However, this technique cannot be used *in vivo*, and it is not repeatable because of its destruction to teeth. Periapical radiographs have generally been used in clinical examinations, but the defects of anatomical noise, two-dimensionality, and geometric distortion have restricted its application in investigations.^{18,19} Micro-CT imaging has been applied to evaluate the root and root canal anatomy because of its high resolution and lack of specimen destruction.⁹ However, micro-CT cannot be used to scan the head of a living human, which limits its clinic application. Recently, cone-beam computed tomography (CBCT) has been widely used in endodontic

Table 1. Details of patients' maxillary second molars.

Age (y)	No. of patients	Men		No. of patients	Women	
		Right	Left		Right	Left
20–30	181	177	178	315	307	311
31–40	123	114	116	146	141	138
41–50	131	125	115	130	120	122
≥51	125	102	104	143	118	124
Total	560	518	513	734	686	695

regions because it provides improved accuracy, higher resolution, and lower effective radiation doses than does conventional CT.²⁰ CBCT images can display the axial, sagittal, and coronal planes of the roots and root canals, reducing the superimposition of surrounding structures.²¹ Studies have confirmed that CBCT images are as accurate as the modified staining technique in identifying the root canal system and much more accurate than periapical radiographs.²² CBCT as a nondestructive scanning technique has become a powerful tool in endodontic diagnosis, treatment planning, and follow-up.²³

Previous studies have reported the number of root canals of MSMs in native Chinese populations^{9–11,15}; however, few studies have explicitly investigated the morphological characteristics of the MSMs according to the sex and age of the patients. Therefore, the objective of this study was to investigate the root and root canal morphology of MSMs in a large sample of a native Chinese population according to sex and age using CBCT images.

Patients and methods

Patients

This study was approved by the Ethical Committee Department, Affiliated Hospital of Stomatology, Nanjing Medical University (PJ2014-031-001), and written informed consent was obtained from the patients. High-quality CBCT images were

randomly collected from the Department of Radiology, Affiliated Hospital of Stomatology, Nanjing Medical University from July 2014 to December 2015. The reasons for CBCT scanning included management of impacted teeth before orthodontic treatment, preoperative assessment for dental implants, treatment planning before nonsurgical and surgical endodontic treatment, and diagnosis of facial trauma. The CBCT images fulfilled the following inclusion criteria: the presence of MSMs; MSMs with fully formed apices; and no root canal fillings, posts, coronal restorations, fractures, root resorption, apical periodontitis, or any other odontogenic or nonodontogenic pathology.

CBCT images of 2412 MSMs of 560 men and 734 women were selected. The details of the selected specimens are shown in Table 1. The mean age of the men and women was 39.5 ± 14.4 (range, 20–78) years and 36.8 ± 13.9 (range, 20–75) years, respectively.

Image acquisitions and evaluations

CBCT images were obtained using a CBCT device (NewTom 5G; QR s.r.l., Verona, Italy) with the following parameters: 110 kVp and 10 mA, a basic voxel size of 0.16 mm, and scanning time of 18 s. The field of view (8×12 cm or 18×16 cm) was selected according to the examination requirements. The as-low-as-reasonably-achievable principle was strictly followed, exposing patients to the least amount of

radiation while still obtaining the most useful information for a proper diagnosis. All images were acquired by an experienced radiologist according to the manufacturer's instructions.

Two endodontists were calibrated based on the criteria and variants established before the experimental reading. The inter-examiner and intraexaminer reliability were assessed by statistical analysis using Cohen's kappa. The endodontists then simultaneously evaluated the CBCT images with NNT software version 4.6 (ImageWorks, Elmsford, NY). All MSMs were analyzed using serial axial, sagittal, and coronal planes with a slice thickness of 0.3 mm, and the contrast and brightness of the images could be adjusted using the software to ensure optimal visualization. After 2 weeks, the two endodontists evaluated the CBCT images again, and a radiologist with endodontic experience resolved any disagreements. The following observations were recorded:

(1) Number and morphology of roots

The number and morphology of roots were classified into the following categories, modified from the method described by Yang et al.⁸:

Category I: One root

Subdivision 1: Cone-shaped root

Subdivision 2: B-shaped root

Subdivision 3: V-shaped root

Category II: Two roots

Subdivision 1: BR (MBR fused with DBR) + PR

Subdivision 2: MR (MBR fused with PR) + DBR

Subdivision 3: MBR + DR (DBR fused with PR)

Category III: Three roots: MBR + DBR + PR

Category IV: Four roots: MBR + DBR + mesio palatal root + distopalatal root

(2) Root canal morphology

The root canal morphology of every root of the MSMs was analyzed according to Vertucci's classification.¹ The incidence of additional canals was also determined.

(3) Symmetry of MSMs

The symmetry in the root and the root canal morphology of the MSMs on the opposite side were evaluated.

Statistical analysis

Statistical analyses were performed using SPSS 19.0 (IBM Corp., Armonk, NY) at a significance level of $P < 0.05$. The association between the root/canal morphology and the patient's sex and age was assessed using the chi-square test and the Kruskal-Wallis test.

Results

The kappa values for interexaminer agreement were 0.9017 and 0.8665 for the first and second assessments, respectively. The kappa value for the intraexaminer agreement of each examiner was 0.9684. These values indicated good interexaminer and intraexaminer agreement.

Number and morphology of roots

The CBCT axial and three-dimensional images of the root morphology of the MSMs are shown in Figures 1 and 2. The distribution of the root morphology according to patient age and sex is shown in Table 2.

Of the men, 702 (68.09%) MSMs had separate roots (695 three-rooted and 7 four-rooted MSMs), and 329 (31.91%) had fused roots (129 one-rooted and 200 two-rooted MSMs). Of the women, 712 (51.56%) MSMs had separate roots (700 three-rooted and 12 four-rooted MSMs), and 669

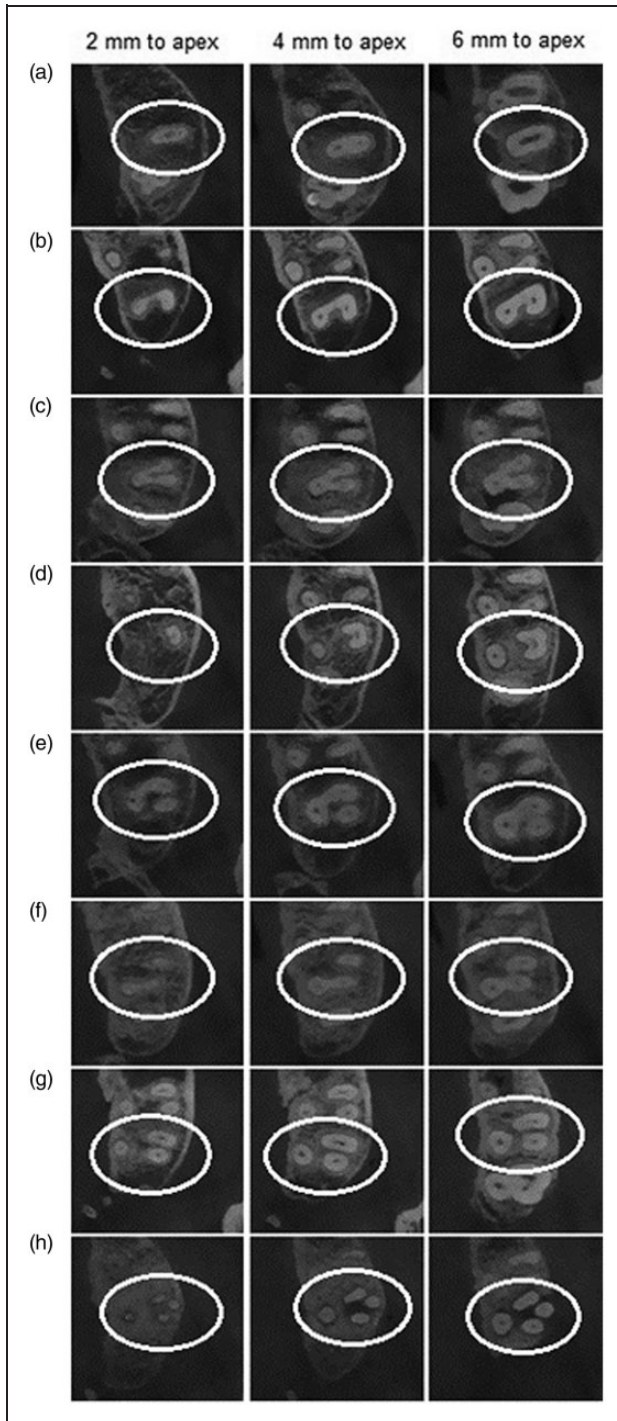


Figure 1. Axial cone-beam computed tomography images showing the root morphology of left maxillary second molars (at 2, 4, and 6 mm to apex). (a) Category I, Subdivision 1. (b) Category I, Subdivision 2. (c) Category I, Subdivision 3. (d) Category II, Subdivision 1. (e) Category II, Subdivision 2. (f) Category II, Subdivision 3. (g) Category III. (h) Category IV.

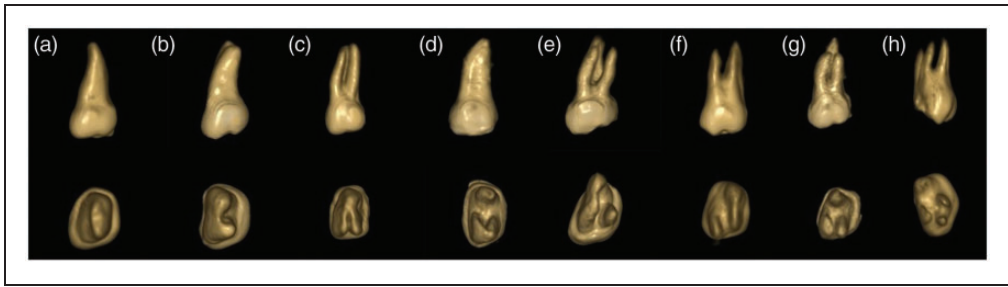


Figure 2. Cone-beam computed tomography three-dimensional reconstructions of the root morphology of left maxillary second molars (upper row: buccal view of roots; bottom row: apical view of roots). (a) Category I, Subdivision 1. (b) Category I, Subdivision 2. (c) Category I, Subdivision 3. (d) Category II, Subdivision 1. (e) Category II, Subdivision 2. (f) Category II, Subdivision 3. (g) Category III. (h) Category IV.

Table 2. Distribution of root anatomy of maxillary second molars.

Age (y)	Men				Women			
	C1	C2	C3	C4	C1	C2	C3	C4
20–30	11.27	16.34	71.83	0.56	19.42	27.18	52.10	1.29
31–40	9.57	19.57	69.57	1.30	24.73	24.37	50.54	0.36
41–50	12.92	21.67	65.00	0.42	16.94	32.64	50.00	0.41
≥51	17.48	21.84	60.19	0.49	28.51	22.73	47.93	0.83
Total	12.51	19.40	67.41	0.68	21.65	26.79	50.69	0.87

Values are presented as percentages.

(48.44%) had fused roots (299 one-rooted and 370 two-rooted MSMs). The percentage of fused roots increased with age in both men and women, while the percentage of fused roots was higher in women than men in each age group ($P < 0.05$). The Kruskal–Wallis test showed significant associations between the percentage of fused roots and sex ($P < 0.05$).

For one-rooted MSMs, a cone-shaped root was the most prevalent while a B-shaped root was the least prevalent in both men and women. For two-rooted MSMs, Subdivision 1 roots were the most prevalent in men, while Subdivision 2 roots were the most prevalent in women. Subdivision 3 roots were the least prevalent in both men and women.

Number and morphology of root canals

The root canal morphology of one-rooted MSMs included Vertucci’s Type I, II, IV, V, and VIII (Figure 3a and b) and five additional canal types identified as follows: 1-2-3, 3-1, 3-2, 3-2-1, and 2-3 (Tables 3 and 4).

For two-rooted MSMs, all nonfused roots had Vertucci’s Type I canals, whereas the fused roots showed complex root canal morphologies. For Subdivision 1, the BRs had Vertucci’s Type I, II, III, IV, V, VIII, and 3-2 type. Type IV canals were the most common in men, while Type I canals were the most common in women. For Subdivisions 2 and 3, most of the fused roots had Type IV canals in both men and women (Figure 3c, Tables 3 and 4).



Figure 3. Cone-beam computed tomography images showing the root canal morphology of left maxillary second molars. (a) Coronal plane: Category I, Subdivision 1 root; 1-2 type canal. (b) Sagittal plane: Category I, Subdivision 2 root; 1-2-1 type canal in the buccal root. (c) Coronal plane: Category II, Subdivision 3 root; 2-2 type canal in the mesiobuccal root. (d) Coronal plane: Category III root; 2-1 type canal in the mesiobuccal root.

Table 3. Number and types of canals of maxillary second molars in men.

Root type	Locations of canal	20-30 y							31-40 y							41-50 y							≥51 y								
		I	II	III	IV	V	VIII	Others	I	II	III	IV	V	VIII	Others	I	II	III	IV	V	VIII	Others	I	II	III	IV	V	VIII	Others		
1	One	1	4	0	8	0	21	6	3	0	0	6	0	9	4	6	3	0	3	0	3	0	13	6	4	1	0	7	0	16	8
2	B	8	5	2	12	2	0	1	5	5	0	12	0	1	0	3	6	1	12	0	1	0	1	0	5	4	0	7	0	2	0
	P	30	0	0	0	0	0	0	23	0	0	0	0	0	0	23	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0
2	M	0	0	0	24	0	1	3	0	0	0	19	0	1	2	1	2	0	22	0	2	2	2	2	1	1	0	24	0	1	0
	D	26	0	0	2	0	0	0	22	0	0	0	0	0	0	28	0	0	1	0	0	0	0	0	26	0	0	1	0	0	0
3	MB	169	38	15	28	5	0	0	93	18	14	34	1	0	0	98	13	10	30	5	0	0	0	0	101	5	8	10	0	0	0
	DB	255	0	0	0	0	0	0	160	0	0	0	0	0	0	156	0	0	0	0	0	0	0	0	124	0	0	0	0	0	0
	P	255	0	0	0	0	0	0	160	0	0	0	0	0	0	156	0	0	0	0	0	0	0	0	124	0	0	0	0	0	0
4	MB	2	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	DB	2	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	MP	2	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
	DP	2	0	0	0	0	0	0	3	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

Table 4. Number and types of canals of maxillary second molars in women.

Root type	20-30 y					31-40 y					41-50 y					≥51 y												
	I	II	III	IV	V	VIII	Others	I	II	III	IV	V	VIII	Others	I	II	III	IV	V	VIII	Others							
1 One	12	9	0	13	2	44	40	7	5	0	21	0	18	18	2	3	0	9	0	21	6	12	3	0	17	0	25	12
2 B	32	13	3	34	3	2	2	17	6	0	15	1	1	0	30	2	1	13	0	1	0	11	0	0	15	0	1	0
P	89	0	0	0	0	0	0	40	0	0	0	0	0	0	47	0	0	0	0	0	0	27	0	0	0	0	0	0
2 M	3	2	0	63	0	7	4	4	2	0	20	0	2	0	3	2	0	26	0	1	0	5	1	0	22	0	0	0
D	72	0	0	7	0	0	0	24	0	0	3	0	1	0	27	0	0	5	0	0	0	23	0	0	5	0	0	0
3 MB	226	20	17	50	3	0	0	103	13	8	23	0	0	0	93	6	2	20	0	0	0	95	7	5	9	0	0	0
DB	322	0	0	0	0	0	0	141	0	0	0	0	0	0	121	0	0	0	0	0	0	116	0	0	0	0	0	0
P	322	0	0	0	0	0	0	141	0	0	0	0	0	0	121	0	0	0	0	0	0	116	0	0	0	0	0	0
4 MB	8	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0
DB	8	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0
MP	8	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0
DP	8	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0

For three-rooted MSMs, all DR and PR canals were Vertucci's Type I. The percentages of second mesiobuccal (MB2) canals in the MBR was significantly higher in men than women in every age group except the ≥ 51 -year group (Table 5, Figure 3d). The 31- to 40-year age group showed a higher prevalence of MB2 canals than the other age groups ($P < 0.05$), while MB2 canals were more frequently absent in the ≥ 51 -year group in both men and women ($P < 0.05$).

For four-rooted MSMs, each of the four roots had only one canal.

Symmetry in the bilateral MSMs

Of 471 men and 654 women with both bilateral MSMs, 311 men and 382 women had perfect symmetry in the root and root canal morphology on the opposite side. Men had higher symmetry than women ($P < 0.05$) (Table 6). Among men, the 31- to 40-year and 41- to 50-year age groups had lower symmetry than the other age groups

($P < 0.05$), while in women, there were no significant differences among the age groups (Table 6).

Discussion

Many studies have revealed that the presence of three separate roots is the most common morphology in MSMs (incidence of 66.10%–94.60%), while four-rooted MSMs are very rare (incidence of 0.06%–1.20%).^{4,10,11} The results of the present study revealed that 67.41% and 50.69% of MSMs had three separate roots and that 0.68% and 0.87% of MSMs had four separate roots in men and women, respectively. The prevalence of root fusion in women (48.44%) was significantly higher than that in men (31.91%), and the percentage of fused roots increased with age in both men and women. Additionally, the form of root fusion was not the same between men and women. Possible explanations for these observations are that (1) the cementum deposition with time differs between men and women, resulting in different forms and prevalences of root fusion, and (2) the cementum deposition with time is not uniform in people of the same sex and peaks in old age, resulting in a complex and changeful root morphology in old age.

The incidence of MB2 canals in MSMs varies from 13.87% to 78.90%.^{10,11,24} Zhang et al.¹⁰ reported that MB2 canals were present in 18% of the MSMs in a Chinese population, and Weng et al.²⁴ reported that MB2 canals were present in 14% in the MSMs in subjects of Han ethnicity in the same Chinese population. In the present study, the prevalences of MB2 canals in three-rooted MSMs in men and women were 33.67% and 26.14%, respectively. The prevalence of MB2 canals was significantly different between men and women ($P < 0.05$). Men in the 31- to 40-year age group showed the highest prevalence of MB2 canals, but both men and women in the ≥ 51 -year age groups showed the lowest

Table 5. Prevalence of second mesiobuccal canals in three-rooted maxillary second molars.

Age (y)	Men	Women	P
20–30	33.73%	27.95%	>0.05
31–40	41.88%	31.00%	<0.05
41–50	37.18%	23.14%	<0.05
≥ 51	18.55%	18.10%	>0.05
Total	33.67%	26.14%	<0.05

Table 6. Bilateral symmetry of roots and root canals of maxillary second molars.

Age (y)	Men	Women	P
20–30	72.00%	61.37%	<0.05
31–40	60.75%	57.58%	>0.05
41–50	60.55%	57.14%	>0.05
≥ 51	67.50%	57.14%	<0.05
Total	66.03%	59.22%	<0.05

prevalence of MB2 canals. These results are consistent with previous reports in Korean⁴ and Brazilian⁵ populations, in which the prevalence of MB2 canals was found to be associated with patient age. The present results are also consistent with a previous report in a Japan population, which confirmed that canal differentiation was completed around 30 to 40 years of age for the deposition of secondary dentin, resulting in a low prevalence of intercanal communications at young and old ages but a high prevalence at intermediate ages.³ These results confirm the above-mentioned possible explanations for why the deposition of secondary dentin with time differs between men and women and is not uniform in people of the same sex. In general, the root canal morphology of MSMs changes as age advances, but it becomes more complex at intermediate ages.

Bilateral symmetry of the presence or absence of MB2 canals of MSMs was found in 82.07% of a Korean population.⁴ Zhang et al.¹⁰ and Tian et al.¹¹ reported that bilateral homonymous MSMs were present in 84.0% and 82.3% of people in a Chinese population, respectively. In addition, Plotino et al.¹³ observed symmetry in 79.6% of white patients. In the present study, bilateral symmetry of the MSM root and root canal morphology was found in 66.03% of men and 59.22% of women, and the main pattern of asymmetry was the presence of a single canal in each root of three-rooted MSMs. The highest symmetry was found in the 20- to 30-year age group, and lower bilateral symmetry was found in the 31- to 40-year and 41- to 50-year age groups; this may have been caused by the simple root canal morphology at young ages and complicated morphology at intermediate ages.

This study has provided a detailed description of the root and canal morphologies of MSMs in a large sample of a Chinese population. These findings are very important for clinicians because they will help to increase the success rates for

endodontic treatment of patients of different sexes and ages. However, accessory canals may not be readily identified because of the resolution of CBCT. In addition, the higher radiation and higher cost of CBCT scanning compared with periapical radiography hinder its clinical application, especially for endodontic treatment.

Conclusions

The root and root canal morphology of MSMs in a Chinese population showed associations with sex and age. Root fusion was increased with age, while root canal morphology was more complex at intermediate ages.

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Declaration of conflicting interest

The Authors declare that there is no conflict of interest.

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