Int J Clin Exp Med 2017;10(4):7030-7039
www.ijcem.com /ISSN:1940-5901/IJCEM0045172

*Original Article*

# Evaluation of root and canal morphology of maxillary molars in a Southern Chinese subpopulation: a cone-beam computed tomographic study

He Wang[1,2], Bo-Wen Ci[1,2], Hai-Yue Yu[1,2], Wei Qin[3,4], Yu-Xia Yan[5], Bu-Ling Wu[1,2], Dan-Dan Ma[1,2,4]

*[1]Department of Stomatology, Nanfang Hospital, Southern Medical University, Guangzhou, China; [2]College of Stomatology, Southern Medical University, Guangzhou, China; [3]Department of Operative Dentistry and Endodontics, Guanghua School and Hospital of Stomatology, Sun Yat-sen University, Guangzhou, China; [4]Guangdong Provincial Key Laboratory of Stomatology, Sun Yat-sen University, Guangzhou, China; [5]Department of Biostatistics, School of Public Health, Southern Medical University, Guangzhou, China*

Received October 29, 2016; Accepted February 14, 2017; Epub April 15, 2017; Published April 30, 2017

**Abstract:** Previous studies using cone-beam computed tomography (CBCT) in different ethnic populations showed generality, similarity and diversity in root and canal morphology. Data about the southern Chinese population is scanty. This study was aimed at investigating the variations in root canal configuration in maxillary first (1 MM) and second molars (2 MM) of a southern Chinese subpopulation using CBCT. A total of 337 male and 310 female adults from a southern Chinese population with healthy, untreated, well-developed maxillary molars were enrolled. All 953 1 MM and 1,066 2 MM were analysed *in vivo* using CBCT scanning. The number of roots and canals, the canal configuration (Vertucci's classification) and the presence of additional mesiobuccal canals (MB2) were recorded. In 1 MM, over 97% had 3 separate roots, 31% had 3 canals and 68.1% had 4. In 2 MM, over 70% had 3 roots and 20% had 2 roots, and 67.1% had 3 canals and 24% had 4 canals. The prevalence of MB2 canals in 1 MM and 2 MM is 68.3% and 23.8%, respectively. When MB2 was present, the most common type of MB root canal configuration of 1 MM and 2 MM was type IV and III. A 22-variant category of root canal system of maxillary molars was devised. In conclusions, Southern Chinese subpopulation had a high MB2 prevalence of 68.3% in 1 MM, with the most common variants being the newly-modified category variant XIV and XV. Some uncommon variants were also found in this study.

**Keywords:** Cone-beam computed tomography, maxillary molars, root canal anatomy, second mesiobuccal canal, southern China

## Introduction

Mastery of root canal anatomy is essential for ensuring a satisfactory outcome of both surgical and nonsurgical root canal treatments. Due to their high anatomical complexity, understanding the anatomical configuration and variations of maxillary molars is important in ensuring that they are treated properly [1]. The canal configuration of maxillary molars is one of the most complex canal configurations in human teeth. For example, the most commonly missed canals are the second canals in the mesiobuccal (MB) root [2]. Misdiagnosis of the MB second canal (MB2) may lead to unfavourable prognosis, failure of treatment and, even loss of the whole tooth. Therefore, the appliance of auxiliary imaging, especially in the diagnosis of teeth with complicated root canal anatomy, is indispensable.

The way to study root canal anatomy can be divided into *in vivo* and *in vitro*. Physical sectioning of the extracted teeth, which is the gold standard of *in vitro* root canal configuration evaluation [3], is limited in practice because of the tortuous processing procedure and small sample size. Thus the data from *in vivo* studies appear to be less convincing, especially in the studies that analyse and estimate root canal configurations from small samples.

In the case of evaluating the root and canal morphology from a particular population, *in vivo*

studies by virtue of advanced imaging techniques allow clinicians to gain insight into the anatomy of teeth. These imaging techniques include tuned aperture computed tomography, magnetic resonance imaging, ultrasound, computed tomography and cone beam computed tomography (CBCT). Of these techniques, CBCT appears to be an effective and safe way to overcome some of the problems associated with conventional radiographs [4].

CBCT appears to be very promising in large-scale use of the CT technique in dento-maxillofacial diagnostic applications [5] and *in vivo* dental anatomy investigation [6], because of the favourable ratio between performance and low cost, together with its low radiation dose and perfect sensitivity, specificity and accuracy [7].

Previous studies have investigated the root and canal morphology of maxillary molars both in a western Chinese [8, 9] and other ethnic populations [10-13] by using *in vivo* CBCT scanning with large samples. However, the enormous population of China calls for more research about root canal configurations of maxillary molars in other regions of this country, such as eastern, northern and southern China. More data will contribute to our knowledge of this field and therefore guide the clinical practice. The aim of this study was to investigate the variations in root canal configuration in maxillary first and second molars in a southern Chinese subpopulation through using CBCT.

## Materials and methods

### *Patients*

CBCT images of 953 maxillary first molars and 1066 maxillary second molars from 647 adults born in southern China (337 males and 310 females) with a mean age of 46.3 years (ranging from 18 to 80 years) who required radiograghic examination by CBCT as part of their dental treatment were identified in the database of the oral radiology department, Nanfang Hospital, Guangzhou, China, between February 2010 and December 2015. The images were taken as part of the routine examination, diagnosis and treatment planning of patients that included those suffering facial trauma or maxillary sinusitis, who required a pre-operative assessment for implants, or who needed orthodontic treatment because of an impacted tooth. Informed consent was obtained from the patients and this study was approved by the Ethics Committee of Nanfang Hospital.

The CBCT images were selected for enrollment in this investigation based on the following criteria: (i) maxillary permanent molars without periapical lesions; (ii) teeth that had not been endodontically treated; (iii) no root canals with open apices, absorption or calcification; and (iv) CBCT images of good quality [9].

### *Radiographic techniques*

The CBCT images were taken using a Planmeca Romexis 3D CBCT scanner (Planmeca, Finland) operating at 84 kV and 14 mA, and the exposure time was 12 s. The voxel size was 200 μm × 200 μm and the minimum slice thickness was 0.2 mm. The detector resolution was 1024 × 1024 pixels and the pixel size was 127 μm × 127 μm. Scans were made according to the manufacturer's recommended protocol. All the CBCT examinations were carried out by an appropriately licensed radiologist with the minimum exposure necessary for adequate image quality. The lowest effective dose of radiation and radiation field were guaranteed.

### *Evaluation of the images*

The CBCT images were 3D-reconstructed by using a patented Feldkamp reconstruction algorithm, analysed with inbuilt software and ran in a 32-bit Windows 7 system. All the images were analysed by a Lenovo LCD screen with a resolution of 1280 × 1024 pixels in a dark room. Contrast and brightness of images was adjusted using the software's image processing tool to ensure optimal visualisation. Examiners could scroll through the axial, coronal and sagittal views. Frequencies and descriptives of all the data were recorded using the SPSS 13.0 software. Two professional oral radiologists evaluated all the images separately. These two groups of raw data were matched and compared, and the inconsistent data were second-checked and evaluated by two oral radiologists and an experienced endodontist concurrently to reach consensus in the interpretation of the radiographic findings. A second analysis was performed one month after the first one, using approximately 20% of the images for intraobserver reliability assessment.

**Table 1.** Twenty-two-variant category of root canal system of maxillary molars

| Variant | Root number | Canal number | Distribution of root canals | Abbreviation |
|---|---|---|---|---|
| I | 1 | 1 | - | 1-1 |
| II | 1 | 2 | - | 1-2 |
| III | 1 | 3 | - | 1-3 |
| IV | 1 | 4 | - | 1-4 |
| V | 2 | 2 | A mesial and a distal, with 1 canal in each root | 2-2, M1D1 |
| VI | 2 | 2 | A buccal and a palatal, with 1 canal in each root | 2-2, B1P1 |
| VII | 2 | 3 | A mesial and a distal, with 1 canal in distal and 2 canals in mesial | 2-3, M2D1 |
| VIII | 2 | 3 | A mesial and a distal, with 2 canals in distal and 1 canal in mesial | 2-3, M1D2 |
| IX | 2 | 3 | A buccal and a palatal, with 2 canals in buccal and 1 canal in palatal | 2-3, B2P1 |
| X | 2 | 3 | A buccal and a palatal, with 1 canal in buccal and 2 canals in palatal | 2-3, B1P2 |
| XI | 2 | 4 | A mesial and a distal, with 2 canals in mesial and 2 canals in distal | 2-4, M2D2 |
| XII | 2 | 4 | A mesial and a distal, with 3 canals in mesial and 1 canal in distal | 2-4, M3D1 |
| XIII | 2 | 4 | A buccal and a palatal, with 3 canals in buccal and 1 canal in palatal | 2-4, B3P1 |
| XIV | 3 | 3 | MB, distobuccal, and palatal, with 1 canal in each root | 3-3 |
| XV | 3 | 4 | With 1 canal in each of the distobuccal and palatal roots and 2 canals in the MB root | 3-4, MB2 |
| XVI | 3 | 4 | With 1 canal in each of the MB and palatal roots and 2 canals in the distobuccal root | 3-4, DB2 |
| XVII | 3 | 4 | With 1 canal in each of the distobuccal and MB roots and 2 canals in the palatal root | 3-4, P2 |
| XVIII | 3 | 5 | With 1 canal in each of the distobuccal and palatal roots and 3 canals in the MB root | 3-5, MB3 |
| XIX | 4 | 4 | MB, distobuccal, mesiopalatal and distopalatal, with 1 canal in each root | 4-4 |
| XX | 4 | 5 | With 1 canal in each of the distobuccal, mesiopalatal, and distopalatal roots and 2 canals in the MB root | 4-5, MB2 |
| XXI | 4 | 5 | With 1 canal in each of the distobuccal, mesiopalatal, and MB roots and 2 canals in the distopalatal root | 4-5, DP2 |
| XXII | - | - | Other variants with irregular fused roots | Irregular |

Notes: 1. Variant types are presented as (root number-root canal number, root canal distribution), 'M', 'D', 'B' and 'P' represents 'mesial', 'distal', 'buccal' and 'palatal', respectively. 2. Variant I-XXI are all separate roots.

**Table 2.** Age distribution of 2,019 Maxillary Molars

| Age group | Number of patients | Number of teeth |
|---|---|---|
| 18-29 | 100 | 332 |
| 30-39 | 112 | 322 |
| 40-49 | 141 | 370 |
| 50-59 | 133 | 317 |
| 60-80 | 161 | 346 |

The teeth included were radiographically examined by CBCT to determine (i) the number of roots and their morphology, (ii) the number of canals per root and the presence of MB2, (iii) the MB root canal configuration classified using Vertucci's classification [14] and (iv) variations of root and canal anatomy modified from the classification of Peikoff et al. [15], Zhang et al. [9] and Silva et al. [12]. The new classification is described in **Table 1**.

## Results

Totally, 2019 maxillary molars were recorded in this study (**Table 2**). In all these maxillary molars, 991 teeth (49.1%) were from female patients and 1028 teeth (50.9%) were from male patients. Intraobserver reliability was satisfactory for both observer 1 (R = 0.85) and observer 2 (R = 0.89), and the interobserver reliability as assessed by the Cohen kappa was excellent (R = 0.88).

*The number of roots and their morphology*

Over 97% of 953 maxillary first molars had three separate roots (**Table 3**). The other maxillary first molars had one, two or four roots, and their roots could be fused with different variants (**Table 4**). In the maxillary second molars, the number of roots and their morphology had a wide range of variation. Over 70% of them had three roots and 20% had two roots; others had either one or four roots (**Table 3**). Consistent with this, only 70% of maxillary second molars had all separate roots; the other had all fused or partly fused roots. Particularly, irregular fused roots that could not be classified as any of the five categories [8] were classified as "irregular fused roots" (**Table 4**).

*The number of canals per tooth*

In maxillary first molars, except in the fused teeth and one five-root tooth, 31% of the teeth

**Table 3.** Frequency of Root Number and Root Canal Number in 953 Maxillary First and 1,066 Second Molars

| | No. of roots | | | | No. of canals | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 5 |
| Right maxillary first molar | 2 (0.4) | 9 (1.9) | 465 (97.7) | - | 1 (0.2) | 4 (0.8) | 181 (38.0) | 290 (60.9) | - |
| Left maxillary first molar | - | 10 (2.1) | 465 (97.5) | 2 (0.4) | - | 3 (0.6) | 114 (23.9) | 359 (75.3) | 1 (0.2) |
| Maxillary first molar Total | 2 (0.2) | 19 (2.0) | 930 (97.6) | 2 (0.2) | 1 (0.1) | 7 (0.7) | 295 (31.0) | 649 (68.1) | 1 (0.1) |
| Right maxillary second molar | 41 (7.8) | 105 (20.0) | 378 (72.0) | 1 (0.2) | 8 (1.5) | 36 (6.9) | 373 (71.0) | 108 (20.6) | - |
| Left maxillary second molar | 51 (9.4) | 109 (20.1) | 379 (70.1) | 2 (0.4) | 13 (2.4) | 38 (7.0) | 342 (63.2) | 148 (27.4) | - |
| Maxillary second molar Total | 92 (8.6) | 214 (20.1) | 757 (71.0) | 3 (0.3) | 21 (2.0) | 74 (6.9) | 715 (67.1) | 256 (24.0) | - |

Notes: Data are presented as frequency and percentage, i.e., n (%).

**Table 4.** Frequency distribution of root morphology in maxillary first and second molars

| Root morphology | 1 MMR (n = 476) | 1 MML (n = 477) | 1 MM Total (n = 953) | 2 MMR (n = 525) | 2 MML (n = 541) | 2 MM Total (n = 1066) |
|---|---|---|---|---|---|---|
| All roots separate | 466 (97.9) | 466 (97.7) | 932 (97.8) | 377 (71.8) | 381 (70.4) | 758 (71.1) |
| MBR fused with DBR | 8 (1. 7) | 8 (1.2) | 16 (1.7) | 74 (14.1) | 75 (13.9) | 149 (14.0) |
| MBR fused with PR | - | 2 (0. 3) | 2 (0.2) | 29 (5.5) | 31 (5.7) | 60 (5.6) |
| DBR fused with PR | - | 1 (0.2) | 1 (0.1) | 2 (0.4) | 4 (0.7) | 6 (0.6) |
| All roots fused | 2 (0.4) | - | 2 (0.2) | 41 (7. 8) | 50 (9.2) | 91 (8.5) |
| Irregular fused roots | - | - | - | 2 (0.4) | - | 2 (0.2) |

Notes: 1. '1 MMR', '1 MML', '1 MM', '2 MMR', '2 MML' and '2 MM' represents 'right maxillary first molars', 'left maxillary first molars', "maxillary first molars', 'right maxillary second molars', 'left maxillary second molars' and 'maxillary second molars', respectively. 2. Data are presented as frequency and percentage, i.e., n (%).

had 3 canals and 68.1% of them had 4 canals. Among these teeth, all the palatal and distobuccal roots had one canal, and the additional canals were all in the MB roots (**Table 3**).

In maxillary second molars, over 90% of the teeth had three or four canals, 67.1% had three canals and 24% had four. None of the maxillary second molars had 5 canals; however, compared with maxillary first molars, a higher prevalence of one canal (2%) and two canals (6.9%) per tooth were found (**Table 3**).

*The prevalence of MB2 canals in maxillary molars*

In maxillary first molars, 68.3% had MB2 canals, among which the prevalence of MB2 in right and left molars was 60.9% and 75.7%, respectively. In maxillary second molars, 23.8% of them had MB2 canals, among which the prevalence of MB2 in right and left molars was 20.2% and 27.4%, respectively.

*Root canal configuration of MB root classified by Vertucci's classification*

The root canal configuration of the MB root of maxillary first molars when MB2 was present was 36.3% type IV, 28.4% type II, 18.6% type V and 14.1% type III; others were type VI or VII.

When MB2 was present, the configuration of the MB root of maxillary second molars was 33.9% type III, 24.4% type IV, 21.3% type II, 19.3% type V; others were type VI or VII.

The distribution and percentage of first and second molars in the 8 categories of Vertucci's classification [14] are described in **Table 5**. No type VIII teeth were found.

*Variations in the morphology of the root canal systems modified from reported classifications*

In maxillary first molars, 30% were variant XIV and 67.6% were variant XV. In maxillary second molars, 50.7% were variant XIV and 20.1% were variant XV. There were 6, 8 and 11 categories in Peikoff et al.'s [15], Zhang et al.'s [9] and Silva et al.'s [12] classifications, respectively. Many types of variants in the present study and other reported studies, however, could not be classified as any of the known variant types in these categories; therefore, a modified classification was devised. The distribution and percentage of first and second molars in the 22 categories

**Table 5.** Configuration of separated mb root canal systems in maxillary first and second molars

| | Type I (1) | Type II (2-1) | Type III (1-2-1) | Type IV (2) | Type V (1-2) | Type VI (2-1-2) | Type VII (1-2-1-2) | Type VIII (3) | Total |
|---|---|---|---|---|---|---|---|---|---|
| Right maxillary first molar | 178 (38.0) | 75 (16.0) | 39 (8.3) | 110 (23.5) | 58 (12.4) | 7 (1.5) | 1 (0.2) | - | 468 (100) |
| Left maxillary first molar | 110 (23.4) | 110 (23.4) | 53 (11.3) | 126 (26.8) | 63 (13.4) | 7 (1.5) | 2 (0.4) | - | 471 (100) |
| Maxillary first molar Total | 288 (30.7) | 185 (19.7) | 92 (9.8) | 236 (25.1) | 121 (12.9) | 14 (1.5) | 3 (0.3) | - | 939 (100) |
| Right maxillary second molar | 292 (73.4) | 24 (6.0) | 35 (8.8) | 27 (6.8) | 19 (4.8) | 1 (0.3) | - | - | 398 (100) |
| Left maxillary second molar | 263 (64.0) | 30 (7.3) | 51 (12.4) | 35 (8.5) | 30 (7.3) | 1 (0.2) | 1 (0.2) | - | 410 (100) |
| Maxillary second molar Total | 555 (68.6) | 54 (6.7) | 86 (10.6) | 62 (7.7) | 49 (6.1) | 2 (0.2) | 1 (0.1) | - | 809 (100) |
| Total | 843 (48.2) | 239 (13.7) | 178 (10.2) | 298 (17.0) | 170 (9.7) | 16 (0.9) | 4 (0.2) | - | 1748 (100) |

Notes: Data are presented as frequency and percentage, i.e., n (%).

**Table 6.** Frequency distribution of the 22 categories of variant of root canal anatomy of maxillary first and second molars

| Variant | 1 MMR | 1 MML | 1 MM | 2 MMR | 2 MML | 2 MM | Total |
|---|---|---|---|---|---|---|---|
| I | 1 (0.2) | - | 1 (0.1) | 8 (1.5) | 13 (2.4) | 21 (2.0) | 22 (1.1) |
| II | - | - | - | 12 (2.3) | 12 (2.2) | 24 (2.3) | 24 (1.2) |
| III | 1 (0.2) | - | 1 (0.1) | 22 (4.0) | 23 (4.3) | 45 (4.1) | 46 (2.2) |
| IV | - | - | - | - | 3 (0.6) | 3 (0.3) | 3 (0.1) |
| V | - | - | - | - | - | - | - |
| VI | 4 (0.8) | 3 (0.6) | 7 (0.7) | 24 (4.6) | 26 (4.8) | 50 (4.7) | 57 (2.8) |
| VII | - | - | - | 21 (4.0) | 19 (3.5) | 40 (3.8) | 40 (2.0) |
| VIII | - | - | - | 1 (0.2) | 1 (0.2) | 2 (0.2) | 2 (0.1) |
| IX | 4 (0.8) | 5 (1.0) | 9 (0.9) | 45 (8.6) | 43 (8.0) | 88 (8.3) | 97 (4.8) |
| X | - | - | - | - | - | - | - |
| XI | - | 1 (0.2) | 1 (0.1) | 1 (0.2) | 3 (0.6) | 4 (0.4) | 5 (0.2) |
| XII | - | - | - | 8 (1.5) | 11 (2.0) | 19 (1.8) | 19 (0.9) |
| XIII | 1 (0.2) | 2 (0.4) | 3 (0.3) | 4 (0.8) | 6 (1.1) | 10 (1.0) | 13 (0.7) |
| XIV | 176 (37.0) | 110 (23.1) | 286 (30.0) | 285 (54.3) | 256 (47.4) | 541 (50.6) | 827 (41.0) |
| XV | 289 (60.7) | 355 (74.4) | 644 (67.6) | 91 (17.3) | 123 (22.8) | 214 (20.1) | 858 (42.5) |
| XVI | - | - | - | - | - | - | - |
| XVII | - | - | - | - | - | - | - |
| XVIII | - | - | - | - | - | - | - |
| XIX | - | 1 (0.2) | 1 (0.1) | 1 (0.2) | 1 (0.2) | 2 (0.2) | 3 (0.1) |
| XX | - | - | - | - | - | - | - |
| XXI | - | - | - | - | - | - | - |
| XXII | | | | 2 (0.4) | | 2 (0.2) | 2 (0.2) |

Notes: 1. '1 MMR', '1 MML', '1 MM', '2 MMR', '2 MML' and '2 MM' represents 'right maxillary first molars', 'left maxillary first molars', "maxillary first molars', 'right maxillary second molars', 'left maxillary second molars' and 'maxillary second molars', respectively. 2. Data are presented as frequency and percentage, i.e., n (%).

of variants of root canal anatomy are described in **Table 6**. Fifteen variants found in the present study are shown in **Figure 1**.

Two special teeth were found, and they were classified as variant XXII (irregular fused variant). They were all maxillary second right molars. These two teeth showed the MB root fused with the mesiopalatal root. (This tooth had two separate palatal roots; see **Figure 1**).

*Symmetry in the bilateral homonymous teeth*

Of 369 patients who had bilateral homonymous teeth in maxillary first molars, 277 (75.1%) had symmetry in the root and canal morphology of homonym teeth on the opposite side. When considering MB root canal configuration (Vertucci's classification), however, only 196 (53.1%) had perfect symmetry. In the presence of MB2 (269 subjects), 199 (74%) had symme-

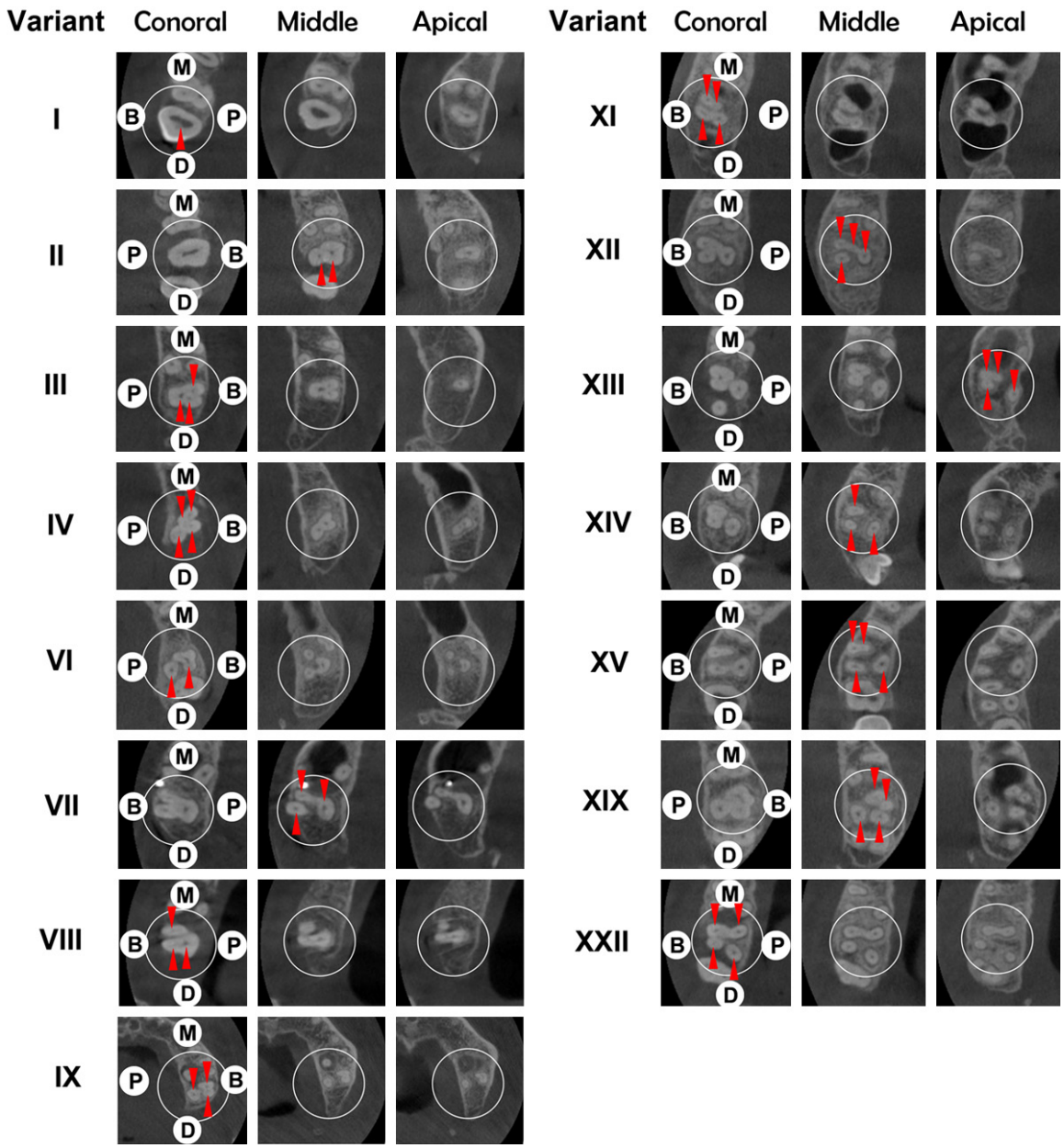


**Figure 1.** CBCT images showing the fifteen variants in maxillary molars found in this study according to the 22-variant category. 'Coronal', 'Middle' and 'Apical' represents the coronal, middle and apical cross slice of each case, respectively. 'M', 'D', 'B' and, 'P' represents 'mesial', 'distal', 'buccal' and 'palatal', respectively. Red triangles indicate the detected canals.

try regardless of the root canal type classification, and 118 (43.9%) had perfect symmetry including the root canal type classification.

Of 456 patients who had bilateral homonymous teeth in maxillary second molars, 280 (61.4%) had symmetry in the root and canal morphology of homonym teeth on the opposite side. When considering MB root canal configuration, however, only 253 (55.5%) had perfect symmetry. In the presence of MB2 (109 subjects), 56 (51.4%) had symmetry regardless of the root canal type classification, and 29 (26.6%) had perfect symmetry including the root canal type classification.

## Discussion

The present study provides a detailed anatomic description of maxillary first and second molars

**Table 7.** Prevalence of the MB2 canal in the mesiobuccal root of maxillary first and second molar in previously published *in vivo* studies by using CBCT scanning (n>200)

| Author(s) | Year | Age | Population | Sample (n) | MB2 canal |
|---|---|---|---|---|---|
| Maxillary first molar | | | | | |
| Georgia, N. E. et al. [11] | 2015 | 18-80 | Greek | 410 | 53.41% |
| Silva, E. J. et al. [12] | 2014 | Unreported | Brazilian | 314 | 42.63% |
| Lee, J. H. et al. [13] | 2011 | 18-76 | Korean | 458 | 71.8% |
| Zhang, R. et al. [9] | 2011 | 17-60 | Chinese | 299 | 52% |
| Zheng, Q. H. et al. [8] | 2010 | 10-86 | Chinese | 775 | 52.24% |
| Present study | 2016 | 18-80 | Chinese | 953 | 68.3% |
| Maxillary second molar | | | | | |
| Betancourt, P. et al. [10] | 2015 | 16-75 | Chilean | 225 | 48% |
| Georgia, N. E. et al. [11] | 2015 | 18-80 | Greek | 402 | 40.29% |
| Silva, E. J. et al. [12] | 2014 | Unreported | Brazilian | 306 | 34.32% |
| Lee, J. H. et al. [13] | 2011 | 18-76 | Korean | 467 | 42.2% |
| Zhang, R. et al. [9] | 2011 | 17-60 | Chinese | 210 | 22% |
| Present study | 2016 | 18-80 | Chinese | 1066 | 23.8% |

from a southern Chinese subpopulation based on a retrospective analysis of CBCT images. This is one of the largest sample size studies, as far as we know. The observations made here provide a more precise understanding of maxillary molar roots and root canal systems. Together with other similar studies from different populations, such data not only guide dental clinical practitioners with generality and specialty of tooth anatomy, but also provide evidential support for human teeth morphological evolution, with respect to both ethnical and regional distribution.

Our results revealed that the majority of maxillary first molars had three separate roots, which was consistent with previously reported studies of western Chinese [8], Korean [13], Brazilian [12] and Ugandan [16] populations. However, other large sample size studies [9, 17-19] found that 100% of maxillary first teeth had three separate roots. A lower percentage of three separate roots in maxillary first molars were found in a Greek population [11] and 78% of four separate-rooted maxillary first molars were found in an Irish population [20]. For maxillary second molars, the present study showed that the number of roots and their morphology had a wide range of variation. Moreover, a high percentage of fused roots were found. The results were consistent with previous findings of Chinese [9], Greek [11], Indian [17] and Ugandan [16] populations, though they had different proportions. Nevertheless, studies of Burmese [19] and Thai [18] populations revealed that all maxillary second molars had three separate roots. In general, maxillary second molars are more variable in root number as well as root morphology than maxillary first molars. Besides differences in study methodology (e.g., *in vivo* and *in vitro*) and sample size, these differences in root canal anatomy highlight the influence of ethnic background on maxillary molar root morphology.

Almost all the maxillary first molars in our study had 3 or 4 canals. For the teeth which had three separate roots, all the palatal and distobuccal roots had one canal, and the additional canals were all in the MB roots. In maxillary second molars, 91.1% of the teeth had 3 or 4 canals, and a higher prevalence of one canal or two canals per tooth were found. Most of the mesiobuccal roots had 1 to 2 canals, and each of the distobuccal and palatal root had 1 root; these results were consistent with previously reported studies in Chinese [8, 9, 21] and other ethnic populations [11, 12, 18, 19, 22].

Remarkably, we devised a root and canal category, which consists of 22 variants, modified from previously reported studies [9, 12, 15]. Consistently, the majority of maxillary first and second molars were variant 14 and variant 15, though with different proportions in these studies [9, 12, 15]. A total of 17 variants were found in the present study and maxillary second molars had more variants than maxillary first molars. There variants revealed a complex variation of maxillary second molars, and they may pose challenge to dental practitioners both in surgical and non-surgical treatments.

An important standard of this classification was that when the root furcation is more than one-third of the overall length of the root, it should be treated as two separate roots; otherwise, it should be treated as one root (e.g. C-shaped molars [1]) [23]. This category had several merits. First, this category consisted not only of the

variants we had found in the present study, but also the variants reported in other studies [9, 12, 22, 24], i.e., variant V, X, XVI, XVII, XVIII, XX and XXI. Second, this category contained not only basic information about root number and root canal number, but also contained information about the distribution of root and root canals. Thus, the readers could easily understand the three-dimensional structure of the tooth. Third, the variants were arranged and numbered according to root number, canal number and root canal distribution in an ascending order. Thus, other researchers can record data or modify this category in a simple way. Last but not least, this category covers all the variants reported in both the present and previous studies, as far as we know. Specifically, some reported variants that cannot be categorised in variant I to XXI are categorised as variant XXII, which represents an irregular variant. For instance, Gopikrishna et al. [25] presented a maxillary first molar with an unusual morphology of 2 palatal roots and a single fused buccal root, Yilmaz et al. [26] reported an unusual C-shaped root canal system in a maxillary first molar tooth and some case reports [27, 28] showed 6 or 7 canals in maxillary molars. To sum up, this category is more comprehensive, is well organised and can be recommended in similar studies in the future.

The present study revealed that 68.3% and 23.8% of maxillary first and second molars had MB2 canals. In order to exclude the methodological differences among similar studies, only studies using CBCT imaging and having a large sample size (n>200) were listed in **Table 7**. Compared with previous studies [8, 9] of a western Chinese population (about 52%), the present study (63.8%) showed a higher prevalence of MB2 canals in maxillary first molars in a southern Chinese subpopulation. However, the present study (23.8%) and a previous study [9] (22%) showed a similar prevalence of MB2 canals in maxillary second molars. These differences and similarities suggested that root canal anatomy can be variable in a large area of country. According to **Table 7**, there was a wide range of prevalence of MB2 in both maxillary first and second molars. On the whole, maxillary first molars possessed a much higher prevalence of MB2 canals than maxillary second molars. The Chinese population had the lowest MB2 prevalence of maxillary second molars, compared with other ethnic populations.

The most common MB root canal configuration of maxillary first molars when MB2 was present was type IV and type II in the present study, which was in line with most of the literatures [13, 18, 19, 22]. Zhang et al. [9], however, reported a main canal configuration of type IV, V, and II in maxillary first molar MB roots from a western Chinese population. Singh et al. [17] reported a higher incidence of type II than type IV in Indian maxillary first molar MB roots, which was different from most of the other studies. The root canal configuration was more complicated in maxillary second molars. Our results showed a mixed combination mainly by type III, IV, II, and V in maxillary second molar MB roots from a southern Chinese subpopulation, which is similar to the data from a western Chinese population [9] with a combination of type IV, V, and II. Other combinations can be found in Burmese [19], Korean [13] and Indian [17] populations with a combination of type II and type IV, in other Indian population [22] with a combination of type IV and type II, in a Thai [18] population with a combination of type IV, V, and VI. To sum up, the most common variants of maxillary first and second molar MB roots were type IV and type II in most of the reported studies, though they were in different proportions.

In summary, the present study suggested that there were differences and similarities in root and canal morphology among different Chinese subpopulations. In a southern Chinese population, the root canal system in MB root in maxillary molars was more variable than that in the other roots, and the prevalence of MB2 canals was higher in maxillary first molars. Maxillary second molars had a more variable root and canal system than maxillary first molars. CBCT scanning is effective in studying root canal anatomy. The anatomic variations and differences between different ethnic or regional populations should be taken into consideration during root canal treatments of maxillary molars.

## Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant no. 81400495, D.D.M), Guangdong Natural Science Foundation (2015A03030101, D.D.M and 2015A030310079) and Open Fund of Guangdong Provincial Key Laboratory of Stomatology (KF2015120105). We thank

Hong-Mei Pan, Xiao-Yi Zhang, Yu Lin, Ting-Ting Ning, Shao Hu, Zhi-Wei Lu and Xiao-Hao Liu for their help with the acquisition of the raw data, and we thank Li Cui for his help with literature retrieval. The authors deny any conflicts of interest related to this study.

## Disclosure of conflict of interest

None.

**Address correspondence to:** Drs. Dan-Dan Ma and Bu-Ling Wu, Department of Stomatology, Nanfang Hospital, Guangzhou, China; College of Stomatology, Southern Medical University, No. 1838 North Guangzhou Avenue, Guangzhou 510515, China. Tel: 86-20-62787149; E-mail: mdd@smu.edu.cn (DDM); Tel: 86-20-62787679; E-mail: bulingwu@smu.edu.cn (BLW)

## References

[1] Martins JN, Mata A, Marques D, Anderson C and Carames J. Prevalence and characteristics of the maxillary C-shaped molar. J Endod 2016; 42: 383-389.

[2] Wong R. Conventional endodontic failure and retreatment. Dent Clin North Am 2004; 48: 265-289.

[3] Blattner TC, George N, Lee CC, Kumar V and Yelton CD. Efficacy of cone-beam computed tomography as a modality to accurately identify the presence of second mesiobuccal canals in maxillary first and second molars: a pilot study. J Endod 2010; 36: 867-870.

[4] Patel S, Dawood A, Whaites E and Pitt Ford T. New dimensions in endodontic imaging: part 1. Conventional and alternative radiographic systems. Int Endod J 2009; 42: 447-462.

[5] Mozzo P, Procacci C, Tacconi A, Martini PT and Andreis IA. A new volumetric CT machine for dental imaging based on the cone-beam technique: preliminary results. Eur Radiol 1998; 8: 1558-1564.

[6] Baratto Filho F, Zaitter S, Haragushiku GA, de Campos EA, Abuabara A and Correr GM. Analysis of the internal anatomy of maxillary first molars by using different methods. J Endod 2009; 35: 337-342.

[7] Mirmohammadi H, Mahdi L, Partovi P, Khademi A, Shemesh H and Hassan B. Accuracy of cone-beam computed tomography in the detection of a second mesiobuccal root canal in endodontically treated teeth: an ex vivo study. J Endod 2015; 41: 1678-1681.

[8] Zheng QH, Wang Y, Zhou XD, Wang Q, Zheng GN and Huang DM. A cone-beam computed tomography study of maxillary first permanent molar root and canal morphology in a Chinese population. J Endod 2010; 36: 1480-1484.

[9] Zhang R, Yang H, Yu X, Wang H, Hu T and Dummer PM. Use of CBCT to identify the morphology of maxillary permanent molar teeth in a Chinese subpopulation. Int Endod J 2011; 44: 162-169.

[10] Betancourt P, Navarro P, Cantin M and Fuentes R. Cone-beam computed tomography study of prevalence and location of MB2 canal in the mesiobuccal root of the maxillary second molar. Int J Clin Exp Med 2015; 8: 9128-9134.

[11] Nikoloudaki GE, Kontogiannis TG and Kerezoudis NP. Evaluation of the root and canal morphology of maxillary permanent molars and the incidence of the second mesiobuccal root canal in greek population using cone-beam computed tomography. Open Dent J 2015; 9: 267-272.

[12] Silva EJ, Nejaim Y, Silva AI, Haiter-Neto F, Zaia AA and Cohenca N. Evaluation of root canal configuration of maxillary molars in a Brazilian population using cone-beam computed tomographic imaging: an in vivo study. J Endod 2014; 40: 173-176.

[13] Lee JH, Kim KD, Lee JK, Park W, Jeong JS, Lee Y, Gu Y, Chang SW, Son WJ, Lee WC, Baek SH, Bae KS and Kum KY. Mesiobuccal root canal anatomy of Korean maxillary first and second molars by cone-beam computed tomography. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2011; 111: 785-791.

[14] Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 1984; 58: 589-599.

[15] Peikoff MD, Christie WH and Fogel HM. The maxillary second molar: variations in the number of roots and canals. Int Endod J 1996; 29: 365-369.

[16] Rwenyonyi CM, Kutesa AM, Muwazi LM and Buwembo W. Root and canal morphology of maxillary first and second permanent molar teeth in a Ugandan population. Int Endod J 2007; 40: 679-683.

[17] Singh S and Pawar M. Root canal morphology of South Asian Indian maxillary molar teeth. Eur J Dent 2015; 9: 133-144.

[18] Alavi AM, Opasanon A, Ng YL and Gulabivala K. Root and canal morphology of Thai maxillary molars. Int Endod J 2002; 35: 478-485.

[19] Ng YL, Aung TH, Alavi A and Gulabivala K. Root and canal morphology of Burmese maxillary molars. Int Endod J 2001; 34: 620-630.

[20] al Shalabi RM, Omer OE, Glennon J, Jennings M and Claffey NM. Root canal anatomy of maxillary first and second permanent molars. Int Endod J 2000; 33: 405-414.

[21] Weng XL, Yu SB, Zhao SL, Wang HG, Mu T, Tang RY and Zhou XD. Root canal morphology of

permanent maxillary teeth in the Han nationality in Chinese Guanzhong area: a new modified root canal staining technique. J Endod 2009; 35: 651-656.
[22] Neelakantan P, Subbarao C, Ahuja R, Subbarao CV and Gutmann JL. Cone-beam computed tomography study of root and canal morphology of maxillary first and second molars in an Indian population. J Endod 2010; 36: 1622-1627.
[23] Morfis A, Sylaras SN, Georgopoulou M, Kernani M and Prountzos F. Study of the apices of human permanent teeth with the use of a scanning electron microscope. Oral Surg Oral Med Oral Pathol 1994; 77: 172-176.
[24] Ahmad IA and Al-Jadaa A. Three root canals in the mesiobuccal root of maxillary molars: case reports and literature review. J Endod 2014; 40: 2087-2094.
[25] Gopikrishna V, Reuben J and Kandaswamy D. Endodontic management of a maxillary first molar with two palatal roots and a single fused buccal root diagnosed with spiral computed tomography-a case report. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008; 105: e74-78.
[26] Yilmaz Z, Tuncel B, Serper A and Calt S. C-shaped root canal in a maxillary first molar: a case report. Int Endod J 2006; 39: 162-166.
[27] Kim JR, Choi SB and Park SH. A maxillary second molar with 6 canals: a case report. Quintessence Int 2008; 39: 61-64.
[28] Badole GP, Warhadpande MM, Shenoi PR, Lachure C and Badole SG. A rare root canal configuration of bilateral maxillary first molar with 7 root canals diagnosed using cone-beam computed tomographic scanning: a case report. J Endod 2014; 40: 296-301.