ORIGINAL ARTICLE
Volume 15 Issue 2 2020
DOI: 10.21315/aos2020.15.2.444
ARTICLE INFO
Submitted: 29/02/2020
Accepted: 09/11/2020
Online: 24/12/2020

A Cone-Beam Computed Tomography Study on the Morphometry of the Mandibular Molars and Their Relative Root Lengths to the Mandibular Height

Wei Cheong Ngeow[a]*, Nur Redannia Redzuan[b], Nur Nabilah Aisyah Mat Nawawi[b]

[a]*Department of Oral and Maxillofacial Clinical Sciences, Faculty of Dentistry, University of Malaya, 50603 Kuala Lumpur, Malaysia*

[b]*Faculty of Dentistry, University of Malaya, 50603 Kuala Lumpur, Malaysia*

*Corresponding author: ngeowy@um.edu.my

To cite this article: Ngeow WC, Redzuan NR, Mat Nawawi NNA (2020). A cone-beam computed tomography study on the morphometry of the mandibular molars and their relative root lengths to the mandibular height. *Arch Orofac Sci*, **15**(2): 119–137. https://doi.org/10.21315/aos2020.15.2.444

To link to this article: https://doi.org/10.21315/aos2020.15.2.444

ABSTRACT

The first, second and third mandibular molars (M1, M2, M3) show variations in the number of cusps and some distinction in size, occlusal design, and the relative lengths and number of roots. However, there are also genetic and racial related variations within them. This study determined the tooth length and related root-to-crown ratio (RCR), and root morphology variations in M1 and M2. We also determined the root length relative to the mandibular height of these teeth. Sixty-one cone-beam computed tomography (CBCT) images of patients who had a good set of lower teeth with no sign of mandibular pathology or defect were included. Relevant measurements were made along the axes of the mesial and distal roots of these mandibular molars. The measurements obtained were used to calculate RCR and root-to-mandible (R/M) ratio. The crowns of 226 teeth and 465 roots were reviewed in 61 CBCTs of Malay patients. M1 and M2 were 19.41 mm and 18.15 mm long. The respective anatomical RCR and clinical RCR were 1.90 and 1.59 for M1, and 1.86 and 1.60 for M2. Thirteen molars (5.8%) presented with three roots, with twice the number affecting M1 than M2. More M1 (4.3%) had C-shaped morphology than M2 (1.8%). The R/M ratio at M1 was 42.32% and, at M2 this was 43.94 %. In summary, the morphometric measurements of M1 and M2 in Malay were established. These teeth did not have a high prevalence of supernumerary roots, but there is a high prevalence of C-shaped morphology in M1.

Keywords: *Cone-beam computed tomography; C-shaped root; mandibular molar; morphometry; morphology*

INTRODUCTION

The mandibular molars are larger than any other mandibular teeth. They are three in numbers on each side of the mandible: the first, second and third mandibular molars (M1, M2, M3). They are similar to each other in functional form. However, comparison between them shows variations in the number of cusps with some distinction in size, occlusal design, and the relative lengths, number, and positions of roots. The root and canal anatomy of mandibular first and second molars have in general recurring features, as well as a great number of atypias, which is racially and genetically influenced

(Yaacob *et al.,* 1996; Maggiore *et al.,* 1998). The study of the whole morphology of the mandibular molar teeth is important not only for anthropological and forensic analyses, but also for endodontic, prosthodontic and periodontic treatment, besides dentoalveolar surgery (Tu *et al.*, 2007).

The mandibular molars are usually reported to have two roots, one mesial and another distal, and at least three main canals (Maggiore *et al.,* 1998). The root canal configuration can present in many forms and shapes, either as straight, curved, or fused canals (Vertucci, 2005). Most M1 present with such defined morphology, two roots with three canals (Maggiore *et al.,* 1998). Variations to this are the presence of a single root or the presence of a third root, known as supernumerary lingual root (Abella *et al.*, 2012). However, the presence of up to four roots has also been reported for M1 (Zhang *et al.*, 2011; Shemesh *et al.*, 2015). Similarly, the roots of M2 can vary from one to four in number (Maggiore *et al.,* 1998; Shemesh *et al.,* 2015). In addition, these roots can fuse, resulting in a single-rooted, conical, or "C-shaped" root. C-shaped roots may appear as a single, fused root or as two distinct roots with a communication (Zhang *et al.*, 2011). Because of their unique appearance, Nakayama and Toda (1941) named the C-shaped root as "gutter shaped root".

Genetic influence causes inconsistencies in the morphology of teeth as observed in the mandibular molars of the Chinese population. They typically present with a high prevalence of distolingual roots in M1 and C-shaped morphology in M2. Similar features have been seen in the Korean (Park *et al.,* 2013). It is unknown if such variation also occurs in other groups of Mongoloids, such as the Malay ethnic. A good awareness of these anomalies is important for successful endodontic and periodontic therapy and for dental exodontia where there is a high risk of root fracture involving the supernumerary root (Huang *et al.*, 2007; Chen *et al.*, 2009; Sachdeva and Phadnaik, 2012; Garg *et al.,* 2013).

The root canal morphology of the mandibular molars also varies. The number of canals can vary between three and six (Maggiore *et al.*, 1998). Some of them can present as a single C-shaped canal configuration, an anomaly that was first described from the skeletal remains of the Neanderthals (Keith and Knowles, 1911). The Neanderthals were considered the predecessors of the Mongoloid race that made up most of the current Asian populations (Tratman, 1950). The prevalence of C-shaped canal in mandibular molars varies greatly with a global sample prevalence of 13.9% (von Zuben *et al.*, 2017). Studies have shown considerably higher prevalence of C-shaped canal in M2 of Mongoloids (Zhang *et al.*, 2011; Zheng *et al.*, 2011; Park *et al.,* 2013) compared to Caucasians (Helvacioglu-Yigit and Sinanoglu, 2013; Silva *et al.*, 2013; Torres *et al.*, 2015; Martins *et al.*, 2016). A recent worldwide study reported the prevalence that range from 6.8% to 44.0% (von Zuben *et al.*, 2017).

The average length of the M1 is 21.0 mm, while the M2 is 19.8 mm (Carrotte, 2004). A comprehensive list of tooth lengths of Caucasians have been published almost four decades ago, but a literature search found only little data on Asians, mostly limited to Korean and Bangladeshi (Verhoeven *et al.*, 1979; Alam *et al.*, 2004; Kim *et al.*, 2005).

Accurate knowledge of the crown to root apex length of the mandibular molars in Mongoloids is crucial for determining accurate working length for root canal treatment. The working length is defined as the distance from a coronal reference point to the point at which canal preparation and obturation should terminate. The most accurate way to determine a root canal working length is by using an apex locator. However, an anatomical length reference must be known either from previous references or via the use of periapical radiography (Rodríguez-Niklitschek *et al.*, 2015).

The understanding of the length of roots of mandibular molars is important for dental exodontia because the root portion of these teeth can be firmly encased in its socket, and made worse if the root is slender and long. Excessive force used or excessive removal of bone surrounding these roots may result in weakening the mandible and lead to iatrogenic fracture of the body of the mandible. Although fractures associated with exodontia is uncommon, incidence ranging from 0.0034% to 0.0075% has been reported. The extractions of the M3 accounted for 75% of these fractures, followed by the M2 (8%), second premolar (8%), M1 (6%), and canine (3%). It may occur either as an instant or as a late complication, usually within the first four weeks after extraction (Joshi *et al.*, 2016). It has been speculated that the relative risk of fractures arising from mandibular third molar extraction is associated with force exerted and the weakening of the mandible. We think that one contributing factor to the weakening of the mandible is a high root length relative to the mandibular height. So far, no studies have been undertaken to determine the normal root-to-mandible (R/M) ratio of M1 and M2.

In normal circumstances, the root length of a tooth is generally longer than its crown height. Their relative lengths are reported as the crown-to-root ratio (CRR), or root-to-crown ratio (RCR), depending on the type of literature one reads. The CRR may be studied either as an anatomical or a clinical ratio. The anatomical CRR is obtained by using the cemento-enamel junction (CEJ) as a reference point while the clinical CRR is obtained by using a reference line drawn from the mesial to the distal crestal bone level (Yun *et al.*, 2014).

Clinical CRR reflects the alveolar bone support that exists around the tooth (Yun *et al.*, 2014; Kung *et al.*, 2016). It is intended to serve as a guide in predicting the prognosis of teeth. The term CRR is often used in prosthodontic articles for this purpose (von Arx *et al.*, 2015). It is one of the primary variables used to evaluate the suitability of a tooth as an abutment for a fixed or removable partial denture (Grossmann and Sadan, 2005). Instead, the term RCR is commonly used in orthodontic literatures when dealing with root resorption where a normal ratio can be compromised following treatment. A normal RCR indicates adequate support for teeth to function under acceptable physiologic stress. Unfavourable RCR as caused by short dental roots may affect the long-term retention of teeth (von Arx *et al.*, 2015). A ratio of two is considered ideal with 1.5 acceptable, while a ratio of one is suggested as the minimal acceptable ratio (Kung *et al.*, 2016). Crowned molar with RCR of 1.49 is generally observed and well accepted (Kung *et al.*, 2016). However, values below the norms may complicate treatment planning. In orthodontics, there may be issue of anchorage while in prosthodontics, there is concern of the ability of a tooth to carry masticatory forces.

So far, only one study has been performed to determine the RCR of Malaysian subjects (Othman *et al.*, 2011). They reported an anatomical RCR of 2.42 for M1, and 2.24 for M2 in males. The RCR in females was of 2.48 for M1 and 2.20 for M2. They reported that there was no significant difference between RCRs of male and female groups, but the mandibular teeth have a higher RCR than their maxillary antagonist. Similar finding has been observed in the Iranian female. However, unlike the Malays, the mean RCRs of Iranian males were notably higher than that of their females' (Haghanifar *et al.*, 2014).

Proper knowledge and awareness of the anatomical and clinical crown lengths, bone-supported root length, and number of roots present are crucial to arrive at the most appropriate treatment plan. In addition, R/M ratio, CRR and RCR are important in ensuring successful dental treatment outcome. The study of the R/M ratio is important in accessing the difficulty of a mandibular molar extraction and predicting the possibility of weakening the mandible following such procedures. The study of the two latter ratios (CRR and RCR) will be crucial in the provision of appropriate prosthetic devices and in ensuring successful orthodontic treatment, respectively. All parameters described above can nowadays be investigated using cone-beam computed tomography (CBCT), without the need to measure or section teeth or mandible (Cotton *et al.*, 2007). It was the aim of this study to review CBCTs of selected patients to determine the morphometry of the M1 and M2 molars, and to determine CRR, RCR and relative root length to the mandibular height (the R/M ratios) in a group of selected Malay subjects.

MATERIALS AND METHODS

Data Source

This research received the relevant Institutional Board of Study approval (DF OS 1703/0016[U]). About 129 CBCT images of patients taken between the year 2010 and 2016 were obtained from the Oral and Maxillofacial Radiology Unit of the Faculty of Dentistry, University of Malaya.

These CBCT scans were captured using i-CAT imaging system (Imaging Sciences International, Inc. Hatfield, USA) with all patients giving their informed consent for having CBCT taken for their dental investigations. These scans were medically justified and were done to diagnose conditions such as impacted teeth, maxillofacial skeletal fractures and the presence of cysts or tumours of the jaws. All images were taken following a standard protocol for patient positioning, and exposure parameter (120 KvP, 3-7 mA, 20 sec). The image acquisition was done at 0.3 mm voxel size by the same radiographer. The images were obtained from scans acquired with the field of view (FoV) of 16 cm (diameter) and 13 cm (height), and the Digital Imaging and Communications in Medicine (DICOM) was reconstructed using proprietary i-CAT image reconstruction software.

The criteria for subject selection are as follows:

1. Malay adult individual regardless of gender, age range from 18–60 years;
2. Presence of a fully erupted set of teeth with two mandibular permanent molars intact at least in one quadrant;
3. The first and second permanent mandibular molars must have fully formed apices;
4. Molars with deep caries, root canal treatment or various restorations were excluded because of possible altered coronal size or defect and/or associated periapical radiolucency or radiological artefact arising from metal restorative material;
5. Images must be free from any radiolucent or radiopaque lesion in the mandible. There should be no evidence of jaw fracture around the mandibular molar region;
6. Images with supernumeraries and unerupted teeth were excluded because the impacted or unerupted teeth might displace the molars from the original locations;
7. Images where the lower anterior teeth and/or premolars were missing were excluded because of the possibility of mesial drift of the molars, hence affecting its relation within the mandible;
8. Images where the upper molars were missing were excluded because of the possibility of over-eruption of the lower molars.

The CBCT images were analysed using a 3D software generic for the CBCT system. The images were reformatted according to axial, sagittal and coronal planes. Using the panoramic window of this software, the crown and root length, the tooth length and mandibular height were measured (Figs. 1, 2 and 3). For descriptive analysis, the crown height and root length were compared to average measurements as previously reported (Nelson and Ash, 2010). The number of roots present on these molars was counted by viewing all the coronal, axial and sagittal planes made available by the software. The presence of a C-shaped morphology (root and canal) was determined using the axial plane. The criteria of a C-shaped morphology were based on the description by Zhang *et al.* (2011) that C-shaped roots may appear as a single, fused root or as two distinct roots with a communication. Effort was undertaken to confirm the presence of a C-shaped canal within these roots using the axial view.

Except for molars with fused roots, in M1 and M2 that have two roots, morphometric (anatomic) measurements were obtained at both mesial and distal roots (Fig. 1) and averaged into one measurement when these two measurements were confirmed to be not statistically different. These measurements were used to arrive at the *anatomical* CRR (Fig. 1) which serves as a baseline data for normal morphometry of the Malay's molar teeth.

For the purpose of this study, the anatomical CRR is defined as the relative value between the anatomical crown and the root lengths. This ratio uses the CEJ as the reference landmark separating the crown from its roots.

A is the mesial crown height of the tooth at right angle to the CEJ

B is the distal crown height of the tooth at right angle to the CEJ

C is the mesial root length of the tooth at right angle to the CEJ

D is the distal root length of the tooth at right angle to the CEJ

Formula for CRR = [A/C + B/D]/2

The official definition of the CRR is the physical relationship between the portions of the tooth not within the alveolar bone, as determined by a radiograph, compared with the portion of the tooth within alveolar bone (The Glossary of Prosthodontic Terms, 2017). In essence, it is the clinical CRR but is often described as the RCR. This ratio is derived using another set of measurements obtained following the method shown in Fig. 2.

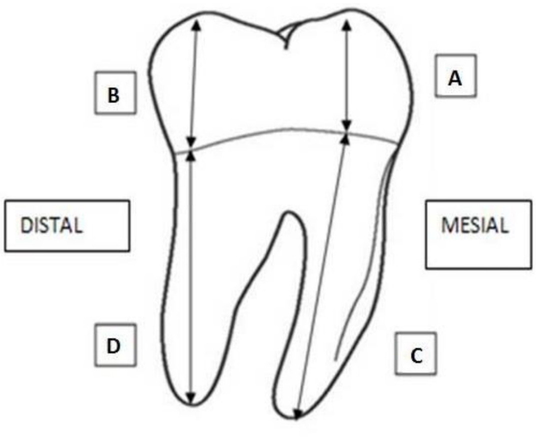

Fig. 1 Landmarks used to calculate the anatomical CRR.

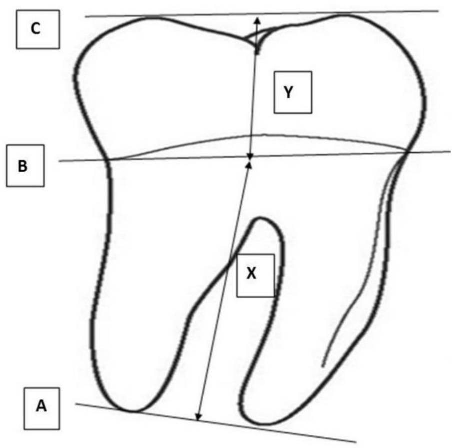

Fig. 2 Landmarks used to calculate the clinical RCR.

The RCR uses the alveolar bone as the reference landmark separating the crown from the root; (A) is the line that connects the apices of the two roots, (B) is the line that connects the mesial and distal alveolar bone, and (C) is the line that connects the two cusps on the crown.

Y is the crown height of the tooth. It connected the middle of the crown at right angle from Line C to Line B.

X is the root length of the tooth, as supported within the alveolar bone. It connected the middle of the tooth at right angle from Line B to Line C.

Formula for RCR = X/Y

Based on the criteria developed by Hölttä *et al.* (2002), the CRR was recalculated as anatomical RCR to determine if they were subjected to disturbance in root development. The different abnormality ratios are summarised in Table 1. The mandibular heights were obtained by extending the Line X as illustrated in Fig. 2 to the end at the lower border (Fig. 3). The obtained morphometric measurements of the root and mandibular height were used to calculate the R/M ratio using the formula:

$$\text{R/M ratio} = \frac{\text{Root length (X)} \times 100\%}{\text{Mandibur height}}$$

The R/M ratio is calculated for each mandibular molar tooth. The effect of jaw side on the morphometric measured was statistically tested, and when found to be not statistically significant, the data was pooled and reported as an average for M1 and M2.

Table 1 The abnormality ratios of different anatomical RCR

RCR	Disturbance in root development
>1.6	No disturbance
1.2–1.6	Mild
0.9–1.1	Moderate to severe
<0.9	Very severe disturbance or arrested root development

Fig. 3 The method to obtain R/M ratio, by extrapolating a line from X all the way to the lower border of the mandible (shown as a yellow line with double arrows ends).

Data Analysis

The patients' demographic data and the assigned measurement scores were recorded in a Microsoft Excel 2007 database (Microsoft®, USA). Frequency, mean and standard deviation values were calculated using the SPSS Statistics 12.0 for Windows software (IBM, USA). The crown and root lengths of different gender and at different side of the mandible were compared using *t*-tests. Statistically significant differences were set at $p < 0.05$.

RESULTS

Only 61 CBCTs of Malay patients fulfilled the selection criteria. The sample size calculation indicated a minimum of 60 CBCTs were needed. Thirty-five (58.3%) of the patients were male, with the remaining 41.7% being females. Their mean age was 29.8 ± 9.6 years. Altogether the crowns of 226 teeth and 465 roots were reviewed. The measurements were obtained by two co-authors. To ensure inter-examiner reliability, re-measurements were carried out on all samples. The Bland and Altman calculation showed 10.58% difference between both examiners, which is considered reliable and acceptable.

Morphometric Measurements of M1 and M2

Table 2 shows the distribution of measurements obtained for the anatomical crown heights and root lengths of the M1 and M2. Statistical analyses showed no difference between mesial and distal crown heights (independent *t*-test; $p > 0.05$) and root lengths (independent *t*-test; $p > 0.05$) and between measurements obtained from the right and left sides (independent *t*-test; $p > 0.05$). There was also no gender difference (independent *t*-test; $p > 0.05$). Hence, the results were pooled to produce an average crown height, root length and tooth length for M1 and M2, as shown in Table 2.

In general, it was observed that M1 are slightly longer than M2, both at their anatomical crown heights and root lengths. However, this difference was not statistically significant (independent *t*-test; $p > 0.05$). The tooth lengths for M1 and M2 were 19.41 ± 1.54 mm and 18.15 ± 1.77 mm, respectively (Table 2). The average crown height of M1 was 6.74 ± 0.93 mm, while that of M2 was 6.41 ± 0.86 mm. Similarly, the average root length of M1 was 12.59 ± 1.63 versus 11.73 ± 2.01 mm for M2. Both crown heights and root lengths of these teeth showed a large range of measurements, as shown in Table 2. The anatomical crown height measured between 4.83 mm and 9.69 mm for M1, and 4.02 mm and 8.74 mm for M2, while their respective root lengths had a range of 8.45 mm to 16.11 mm, and 4.92 mm to 16.66 mm.

CRR

The anatomical CRR for M1 was 0.54 ± 0.09; for M2, it was 0.56 ± 0.13 (Table 3). This becomes anatomical average RCRs of 1.90 ± 0.31 for M1 and 1.86 ± 0.36 for M2 when recalculated individually based on root length/crown height formula (Table 3). It was found that 15% of M1 and 16.7% of M2 of Malay patients had higher anatomical RCRs than the average of ~1.86 that was derived from this pool of patients (data distribution not shown). Most of them were found to have short crown (<7.5 mm) with standard root length (~14.0 mm) when compared to the measurements that was previously reported by Nelson and Ash (2010). When the anatomical RCRs were further categorised according to the abnormality ratio (Hölttä *et al.*, 2002), it suggests that between 20% and 25% of the molars appear to suffer from some form of disturbance in root development (Table 3). In M1, 78.6% had normal root, but 21.4% appeared to suffer from mild disturbance in the root development. In M2, 74.5% showed no root development disturbance, but 23.5%

Table 2 The anatomical crown heights and root lengths of the M1 and M2

Parameter	Anatomical crown height			Anatomical root length		
	Mesial*	Distal*	Average (SD) [min–max] in mm	Mesial*	Distal*	Average (SD) [min–max] in mm
	M1			M1		
Right**	6.89 ± 0.94	6.48 ± 0.83	6.74 ± 0.93 (4.83–9.69)	12.67 ± 1.67	11.96 ± 1.53	12.59 ± 1.63 (8.45–16.11)
Left**	7.07 ± 1.00	6.53 ± 0.83		13.33 ± 1.49	12.41 ± 1.54	
Mean	6.98 ± 0.97	6.51 ± 0.82		12.99 ± 1.62	12.19 ± 1.55	
Tooth length = 19.41 ± 1.54 mm						
	M2		Average (SD) [min–max] in mm	M2		Average (SD) [min–max] in mm
Right**	6.16 ± 0.85	6.32 ± 0.84	6.41 ± 0.86 (4.02–8.74)	12.19 ± 1.95	11.02 ± 2.00	11.73 ± 2.01 (4.92–16.66)
Left**	6.43 ± 0.83	6.69 ± 0.87		12.27 ± 1.93	11.42 ± 1.95	
Mean	6.30 ± 0.85	6.51 ± 0.87		12.23 ± 1.93	11.22 ± 1.97	
Tooth length = 18.15 ± 1.77 mm						

Notes: *Independent *t*-test $p > 0.05$ when comparing mesial and distal crown and root lengths.
**Independent *t*-test $p > 0.05$ when comparing right and left crown and root lengths.

suffered from mild disturbance, and 2.0% from moderate to severe disturbance.

The clinical crown heights and root lengths (supported alveolar bone) and the clinical RCRs of M1 and M2 are shown in Table 4. Because measurements were done at alveolar bone level, the clinical crown height increased, while the clinical root lengths reduced when compared to their anatomical counterparts. Statistical analysis showed no difference in the crown height and root length between the right and left side (independent *t*-test; $p > 0.05$). The clinical RCR was 1.59 for M1 and 1.60 for M2.

Root Anomalies

There were 13 teeth that presented with three roots (Table 5). This gives an overall prevalence of 5.8% for the presence of additional roots. Two of these root anomalies were observed on the left side of the same patient. Bilateral occurrence of 3-rooted molars was observed in one patient. More M1 (7.8%) presented with three roots in comparison to M2 (3.6%). The prevalence of three roots was higher on the right side (7.1%) than the left side (4.4%). There was no gender difference in the prevalence of 3-rooted molars, with six female and seven male patients affected.

Seven teeth were found to manifest C-shaped morphology at the coronal part, although all of them were 2-rooted (Table 5). Five (4.3%) cases involved M1 and two (1.8%) cases involved M2, giving rise to an overall prevalence of 3.1%. This anomaly was found in three female and four male patients. There was one patient who presented with bilateral occurrence of C-shaped morphology. The right side had a higher occurrence of more C-shaped morphology than the left side. There was no C-shaped morphology present at left M2 (Table 5).

Table 3 CRR and recalculation as anatomical RCR with distribution in different types of root development disturbances

Teeth	CRR	Recalculated as anatomical RCR	Cases with disturbance in root development
M1 *N* = 115	0.54 ± 0.09	1.90 ± 0.31	Normal: RCR >1.6 = 78.6%
			Mild: RCR 1.2–1.6 = 21.4%
			Moderate–severe: RCR 0.9–1.1 = 0%
			Very severe: RCR <0.9 = 0%
M2 *N* = 111	0.56 ± 0.13	1.86 ± 0.36	Normal: RCR >1.6 = 74.5%
			Mild: RCR 1.2–1.6 = 23.5%
			Moderate–severe: RCR 0.9–1.1 = 2.0%
			Very severe: RCR <0.9 = 0%

Table 4 The clinical crown heights and root lengths, and their corresponding RCRs

Parameter	Mean (SD)		
	Crown height	Root length	RCR**
M1			
Right* (*N* = 58)	7.50 ± 0.80	11.52 ± 1.41	1.55 ± 0.26
Left* (*N* = 57)	7.46 ± 0.96	11.92 ± 1.63	1.63 ± 0.33
Average	7.48 ± 0.88	11.71 ± 1.53	1.59 ± 0.30
M2			
Right* (*N* =54)	7.00 ± 1.07	11.18 ± 1.89	1.63 ±0.37
Left* (*N* = 57)	7.15 ± 0.96	10.87 ± 2.12	1.56 ± 0.43
Average	7.08 ± 1.02	11.02 ± 2.01	1.60 ± 0.40

Notes: * Independent *t*-test $p > 0.05$ when comparing right and left crown and root lengths.
** These ratios were derived from the mean of each individual crown height vs. root length ratio of 61 patients.

The Relative Root Lengths to the Mandibular Height

The left mandible height at M1 and M2 were 26.21 ± 5.88 mm and 25.57 ± 5.33 mm, respectively (Fig. 4). In contrast, the respective mandible heights at the right side were slightly lower at 23.58 ± 5.61 mm and 22.95 ± 4.87 mm. However, these differences were not statistically significant (independent *t*-test; $p > 0.05$). Hence, when the data are pooled, the overall mandible height at M1 was 25.89 ± 5.60 mm (range 11.37 mm to 35.42 mm), and 23.27 ± 5.25 mm (range 8.61 to 32.10 mm) at M2 (Fig. 4).

The R/M ratio is used to determine the relative length of roots embedded in the mandible, as measured using the mandibular height. The R/M ratios at these four sites were 42.0% (left M1), 42.7% (right M1), 43.1% (left M2) and 44.8% (right M2) (Fig. 4). These differences were not statistically significant (independent *t*-test; $p > 0.05$). Therefore, it can be summarised that the R/M ratio at M1 was 42.32 ± 9.10% (range 20.25% to 57.55%). The R/M ratio at M2 was 43.94 ± 10.55% (11.65% to 61.80%). It was observed that there were 10.0% and 26.7% of patients with R/M ratio of more than 50% for M1 and M2 (Fig. 4), and occured more often in female than male patients.

Table 5 Distribution shows the teeth and sites with root anomalies

Parameter		M1 N (%) Right	M1 N (%) Left	M2 N (%) Right	M2 N (%) Left
3-rooted tooth	Individual	6 (10.2%)	3 (5.3%)	2 (3.7%)	2 (3.6%)
	Combined	9 (7.8%)		4 (3.6%)	
	Overall	13 (5.8%)			
C-shaped morphology	Individual	3 (5.1%)	2 (3.5%)	2 (3.7%)	Not present
	Combined	5 (4.3%)		2 (1.8%)	
	Overall	7 (3.1%)			

DISCUSSION

CBCT was the method of choice for the present study as it offers rapid acquisition of a data set of the entire FoV while using a comparatively less extensive radiation detector when compared to conventional CT. It provides a shorter scanning time, has increased image sharpness, reduces image distortion that usually results from internal patient movements, and has increased X-ray tube effectiveness (Cotton *et al.*, 2007).

The approach of measurement undertaken in this study was similar to that reported by Eliasson *et al.* (1986). This is different from that reported by Othman *et al.* (2011) who obtained a single measurement for the crown height and root length using panoramic radiographs. Othman *et al.* (2011) measured the root length as a measured perpendicular distance from the apical tangent to the midpoint of intersection between the crown and root. Their crown height was measured as a perpendicular distance from the midpoint of intersection between the crown and root to the occlusal reference. This approach was adopted from the methodology used by Lind (1972). We thought that such approach will introduce a number of errors when adapted to a CBCT study. Firstly, the use of longest root will cause over reporting and possible complication when applied clinically, especially when this information is translated for root canal treatment. As CBCTs allowed clear identification and full viewing of all roots present, morphometric measurements were obtained at both mesial and distal roots to reflect the real situation. These measurements were averaged into one single measurement only after they were confirmed to be not statistically different.

Tooth dimensions are one of the parameters used in the investigation of hominid evolution and pattern of variation among different population groups (Kupczik and Hublin, 2010). They are affected by genetic influence and changes in environment and diet. A study has shown that tooth length has decreased from Neanderthals to Homo sapiens and attributed this to the space available in the mandible during molar growth and development (Kupczik and Hublin, 2010). The tooth length for M1 and M2 in the Malay are 19.41 ± 1.54 mm and 18.15 ± 1.77 mm, respectively. This is similar to the lengths in the Korean molars (Kim *et al.*, 2005) and shorter than the average reported for the Caucasians (Verhoeven *et al.*, 1979). This finding is consistent with the notion that smaller mandible yields shorter teeth, as Malay have been reported to have smaller jaw size compared to the Caucasians (Ngeow and Aljunid, 2009).

Nelson and Ash (2010) reported that the average crown height and root length of

Parameter	Location	Side		Mean (SD) [Min – Max]
		Right	Left	
Mandible height (mm)	M1	23.58 ± 5.61	26.21 ± 5.88	25.89 ± 5.60 (11.37 to 35.42)
	M2	22.95 ± 4.87	25.57 ± 5.33	23.27 ± 5.25 (8.61 to 32.10)
R/M Ratio (%)	M1	42.7	42.0	42.32 ± 9.10 (20.25 to 57.55)
	M2	44.8	43.1	43.94 ± 10.55 (11.65 to 61.80)

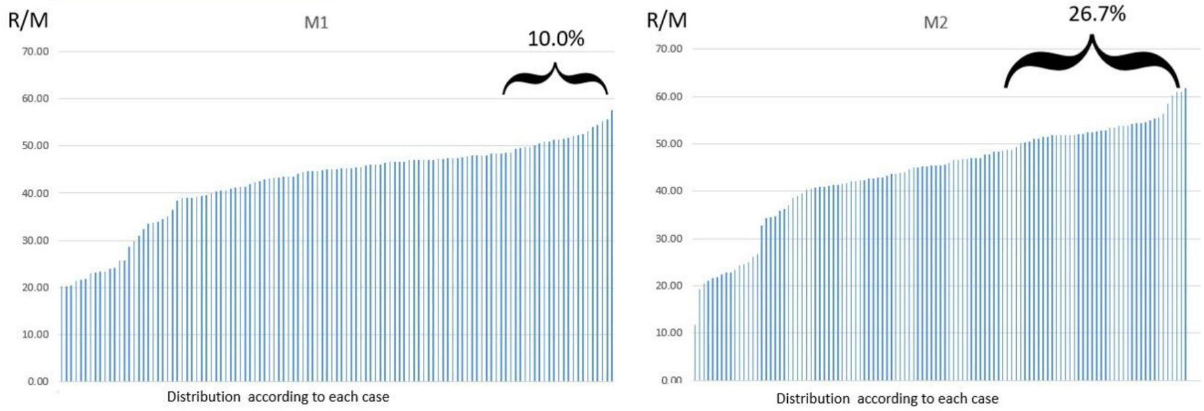

Fig. 4 Details of mandibular height, root to mandible height ratio, and their distribution.

M1 is 7.5 mm and 14.0 mm, respectively; this gives M1 the length of 21.5 mm. M2 has been reported to have a crown height of 7.0 mm and root length of 13.0 mm; this then gives it the tooth length of 20.0 mm. Overall, Kim *et al.* (2005) found that tooth lengths of Asian (Korean) were shorter than Caucasians. The mesial and distal roots of the M1 were between 1.5 mm and 1.8 mm shorter than their Caucasoid counterparts. For M2, their roots were 1.5 mm to 2.3 mm shorter. Eliasson *et al.* (1986) reported slightly longer M1 and M2 of between 21.5 mm and 22.5 mm in the Swedish population, which they attributed to radiographic elongation as their method of study was via the use of periapical radiographs.

A comparison of tooth lengths in the present study against two reports from the Caucasian population is shown in Table 6. The tooth lengths in the present study are lower than that reported by Black (1892) and Bjorndal *et al.* (1974) for the Caucasians.

The teeth/roots in the Malay patients of the present study, which are shorter, concurs with other reports on Asians. Yaacob *et al.* (1996) reported that the anatomical roots of the Mongoloids are shorter, but the root trunks are better developed. However, they did not specifically report the exact difference compared to Caucasians. With regard to root length, M1 in the present study is approximately similar to mesial and distal root lengths of 12.19 ± 1.13 mm and 11.53 ± 1.32 mm as reported for the Chinese subjects (Gu *et al.*, 2011). In contrast, the M1 and M2 root length of Homo sapiens of Caucasoid origin have been reported to be 14.17 ± 1.16 mm and 14.06 ± 1.63 mm, respectively for M1 and M2 (Kupczik and Hublin, 2010). This finding suggests that the root lengths of the Malay's molars is similar to the lengths seen in Asians, thus treatment such as root canal therapy and post placement in fixed prosthodontics can be done using standard instruments. In comparison, the tooth length of M1 in the present study was shorter than the 20.28 mm length reported by Alam *et al.* (2004).

The CRR has been analysed using two formulae in this study. The first approach was purely anatomical in nature to allow us to determine if the anatomical ratios match those reported in standard textbooks. Using reference value obtained from Nelson and Ash (2010), the CRR of both M1 and M2 is ≈0.54 (or in another word, RCRs of M1 is ≈1.87 and for M2, it is ≈1.86). The selected Malay patients with a CRR ratios of 0.54 (or RCRs 1.90 ± 0.31) for M1 and 0.56 (or RCR 1.86 ± 0.36) shows close similarity with standard ratio derived by Nelson and Ash (2010). The anatomical RCRs reported in the present study are lower than that reported by Othman *et al.* (2011) on the Malays. This may arise because of the difference between their use of conventional orthopantomographs and the use of reconstructed panoramic view in this study.

When the anatomical RCRs were further categorised according to the abnormality ratio (Hölttä *et al.*, 2002), it was found that between 20% and 25% of the molars appear to suffer from some form of disturbance in root development. This may alerts us that some patients may experience root development disturbance due to other causes. This may result from local factor such as trauma, or episodes of disease e.g., leukaemia (Rohilla, 2017). Unfortunately, their medical status was not available from the radiographic database to enable us to cross check.

In comparison, studies in other Mongoloids, such as the Koreans' study found that the clinical RCR of M1 as 1.64 ± 0.19 and M2 as 1.47 ± 0.23 (Yun *et al.*, 2014). The clinical RCR for M1 in the subjects of the present study was approximately similar to the ratios reported in the Korean. However, the clinical RCR of M2 in the patients of the present study is higher than that reported by Yun *et al.* (2014). It is apparent that the RCR of some Mongoloids (including the Malay ethnic of the present study) did not reach the recommended two as suggested by some prosthodontic textbooks (Grossmann and Sadan, 2005). Shillingburg *et al.* (1997) suggested a RCR of 1.5 as optimum for a fixed partial denture abutment, while a ratio of one can be accepted as the minimum ratio for a prospective abutment under normal circumstances, especially if the opposing occlusion is composed of tissue supported prosthesis. In general, the patients in this study conformed to recommendation by Shillingburg *et al.* (1997).

Table 6 Comparison of tooth measurements from present study with two reported references from the Caucasian populations

Tooth	Mean length (SD) [min–max] in mm		
	Black (1892)	Bjorndal *et al.* (1974)	Present study (2020)
M1	*N* = Not reported	*N* = 45	*N* = 115
Tooth length	21.0 (18.0–24.0)	22.0 ± 1.4 (19.3–25.0)	19.41 ± 1.54
Crown height	7.7 (7.0–10.0)	8.3 ± 0.7 (6.4–10.2)	6.74 ± 0.93 (4.83–9.69)
Mesial root length	13.2 (11.0–15.0)	15.1 ± 1.2 (11.9–17.3)	12.99 ± 1.62
Distal root length	–	13.6 ± 1.2 (10.9–16.1)	12.19 ± 1.55
M2	*N* = Not reported	*N* = 60	*N* = 111
Tooth length	19.8 (18.0–22.0)	21.7 ± 1.5 (19.0–25.8)	18.15 ± 1.77
Crown height	6.9 (6.0–8.0)	8.7 ± 0.9 (6.8–13.1)	6.41 ± 0.86 (4.02–8.74)
Mesial root length	12.9 (12.0–14.0)	13.8 ± 1.3 (10.3–17.6)	12.23 ± 1.93
Distal root length	–	13.4 ± 1.3 (10.3–17.0)	11.22 ± 1.97

An in-depth knowledge of root morphology, the variability of the root canal system, and the features in different races is imperative to achieve successful root canal treatment, periodontal treatment as well as other aspects of clinical dentistry (Tu *et al.*, 2007). Most M1 present with two well-defined roots (one mesial and one distal) with three canals (two mesial and one distal) (Maggiore *et al.*, 1998; Zhang *et al.*, 2015). A major variant to this is the presence of a third root, or a supernumerary lingual root, called radix entomolaris. A review on M1 with disto-lingual roots reported an average prevalence of 14.4% (Abella *et al.*, 2012). Ethnicity and genetic predisposition influence the number of roots present on M1 (Bjorndal *et al.*, 1974). In Caucasians, the occurrence of three roots in M1 is low, with a prevalence of 0% to 5.97%, while Mongoloids presents with a higher prevalence of 3.0% to 33.1% (Abella *et al.*, 2012). In comparison, the prevalence in Negroids ranged from 0% to 3.1% (Abella *et al.*, 2012). The presence of a third root is considered a normal morphologic variant in Mongoloids (Calberson *et al.*, 2007) and is referred as an Asiatic trait (Turner, 1971; Yew and Chan, 1993; Tu *et al.*, 2007; Ishii *et al.*, 2016). The present study found a prevalence of 7.8% for the presence of three roots in M1 of the Malays. This prevalence falls within the range reported for the Mongoloids elsewhere and is quite similar to the 7.9% reported on Singaporean Chinese (Loh, 1990).

In contrast, study on the prevalence of 3-rooted M1 among the Malays was reported to range between 8.6% and 16.0% (Jones, 1980). On the other hand, the Mongoloids residing in North-eastern Asia has a prevalence exceeding 20% while those residing in Southeast Asia have a lower prevalence of between 8% and 16% (Ishii *et al.*, 2016). This may be related to their different Mongolian origin with the Sinodont type of teeth being common among North-Eastern Asians, and the Sundadont type being common among South-Eastern Asians (Turner, 1971). Malaysia, Singapore, and Thailand are situated in Southeast Asia, and their populations have Sundadont type teeth, hence explaining their lower prevalence of a third root (Loh, 1990; Gulabivala *et al.*, 2002). Several studies found a predominance on the right side (Jayasinghe and Li, 2007; Tu *et al.*, 2007; Tu *et al.*, 2009; Song *et al.*, 2010; Garg *et al.*, 2013; Ishii *et al.*, 2016), which the present study agrees with.

Not many studies have determined the presence of a third root in the second molar. The prevalence of 3-rooted M2 has been reported to range from 0% to 9.0% (Peiris *et al.* 2007; Neelakantan *et al.*, 2010). Their mesial and distal roots are usually located closer with a long root trunk and are more frequently fused. Root fusion that becomes a single-rooted, conical, or 'C-shaped' form has a reported incidence of approximately 21.8% in one study (Nayak *et al.*, 2014). Similar to M1, tendency to develop a third root has genetic influence, and is more prevalent among Mongoloids (Ferraz and Pécora, 1993). The present study found a prevalence of 3.6%, which is relatively higher than in other Mongoloid ethnics (Ferraz and Pécora, 1993; Peiris *et al.*, 2007; Neelakantan *et al.*, 2010; Zhang *et al.*, 2011; Park *et al.*, 2013; Silva *et al.*, 2013; Felsypremila *et al.*, 2015; Shemesh *et al.*, 2015; Madani *et al.*, 2017; Pawar *et al.*, 2017; von Zuben *et al.*, 2017).

In comparison to M1, there is a high prevalence of single rooted second molar, ranging from 8.7% to 21.8% (Nayak *et al.*, 2014; Felsypremila *et al.*, 2015). As generally acknowledged, M2 with single root morphology is often associated with the presence of C-shaped canal. Felsypremila *et al.* (2015) reported that 92.8% of their single rooted M2 had C-shaped canal configuration. C-shaped canal is an anatomical variation mostly found in mandibular M2 with prevalence between 2.7% to 52% in different populations (Walker, 1988; Weine *et al.*, 1988; Yang *et al.*, 1988; Al-Fouzan, 2002; Cheung *et al.*, 2006; Zheng *et al.*, 2011; Silva *et al.*, 2013). The prevalence of C-shaped morphology in second mandibular molars in the Malay ethnic is low in comparison to other ethnic groups, as this study found only less than 2% of the patients presented with this anomaly.

One unexpected finding of this study is the high prevalence of C-shaped morphology found in M1 (4.3%), which is higher than that reported elsewhere. So far, this prevalence is higher than those reported for the Korean (0.67%), Indian (0.7%), Iranian (1.2%) and Israeli (0.16%) populations (Kim *et al.*, 2005; Felsypremila *et al.*, 2015; Madani *et al.*, 2017; Shemesh *et al.*, 2017). More study is needed to verify the exact prevalence of C-shaped morphology in the Malays as the number of subjects in the present study is low.

This study found that the R/M ratio at M1 was 42.32% and 43.94% at M2. However, there were 10.0% and 26.7% of patients with R/M ratio of more than 50% for M1 and M2 with this happening more often in female than male patients. This may be the result of smaller jaw size in some female patients in comparison to their normal size molars. A study on the craniofacial norms of the Malays confirmed female has smaller jaw size compared to male (Ngeow and Aljunid, 2009). Clinically, this indicates that extra care must be rendered when removing the second molar of Malay females as this procedure may weaken the mandible, causing it susceptible to fracture.

Lastly, to recapitulate, the main purpose of this study was to investigate the root morphometry and morphology of the Malays' mandibular molars. However, the findings can be used to determine the relationship of these morphological variations to people of European (Caucasoid) and Asian (Mongoloid) origin. In summary, M1 and M2 of Malays are shorter than that reported for the Caucasoid but are more similar to the Mongoloid's. They do not have a high prevalence of a third root. Among M1, only 7.8% were 3-rooted, but there is a high prevalence of C-shaped morphology (4.3%). Among M2, 3.6% had three roots, while C-shaped morphology was found in only 1.8% of teeth. All in, it appears that the lengths, anatomical CRR and clinical RCR of M1 and M2 resemble those observed in Mongoloids; but their root morphology has closer tendency to resemble those observed in people of European than of East Asian origin. The exception is the high prevalence of C-shaped morphology seen in M1, which has not been observed before in other ethnic groups.

CONCLUSION

The morphometric measurements of M1 and M2 in Malays were established. M1 and M2 were 19.41 mm and 18.15 mm long. There was no gender and site difference in these morphometric measurements. The respective anatomical RCR and clinical RCR were 1.90 and 1.59 for M1, and 1.86 and 1.60 for M2, respectively. The majority of molars (M1 = 78.6%; M2 = 74.5%) have RCR >1.6 indicative of their normal root development process. The molars did not have a high prevalence of supernumerary roots with only 13 teeth (5.8%) presented with three roots. There were more than twice as many accessory roots affecting M1 (7.8%) than M2 (3.6%). Also, more M1 (4.3%) had C-shaped morphology than M2 (1.8%). The R/M ratio at M1 was 42.32% and, at M2 this was 43.94%.

REFERENCES

Abella F, Patel S, Durán-Sindreu F, Mercadé M, Roig M (2012). Mandibular first molars with disto-lingual roots: Review and clinical management. *Int Endod J*, **45**(11): 963–978. https://doi.org/10.1111/j.1365-2591.2012.02075.x

Alam MS, Aziz-us-salam, Prajapati K, Rai P, Molla AA (2004). Study of tooth length and working length of first permanent molar in Bangladeshi people. *Bangladesh Med Res Counc Bull*, **30**(1): 36–42.

Al-Fouzan KS (2002). C-shaped root canals in mandibular second molars in a Saudi Arabian population. *Int Endod J*, **35**(6): 499–504. https://doi.org/10.1046/j.1365-2591.2002.00512.x

Bjorndal AM, Henderson WG, Skidmore AE, Kellner FH (1974). Anatomic measurements of human teeth extracted from males between the ages of 17 and 21 years. *Oral Surg Oral Med Oral Pathol*, **38**(5): 791–803. https://doi.org/10.1016/0030-4220(74)90402-2

Black GV (1892). *Descriptive Anatomy of the Human Teeth*, 2nd edn. Philadelphia: Wilmington Dental Manufacturing Co., p. 15.

Calberson FL, De Moor RJ, Deroose CA (2007). The radix entomolaris and paramolaris: Clinical approach in endodontics. *J Endod*, **33**(1): 58–63. https://doi.org/10.1016/j.joen.2006.05.007

Carrotte P (2004). Endodontics: Part 4. Morphology of the root canal system. *Br Dent J*, **197**(7): 379–383. https://doi.org/10.1038/sj.bdj.4811711

Chen YC, Lee YY, Pai SF, Yang SF (2009). The morphologic characteristics of the distolingual roots of mandibular first molars in a Taiwanese population. *J Endod*, **35**(5): 643–645. https://doi.org/10.1016/j.joen.2009.01.020

Cheung LH, DL, Cheung GS (2006). Root morphology – A study of the mandibular second molar of ethnic Chinese. *Ann R Australas Coll Dent Surg*, **18**: 47–50.

Cotton TP, Geisler TM, Holden DT, Schwartz SA, Schindler WG (2007). Endodontic applications of cone-beam volumetric tomography. *J Endod*, **33**(9): 1121–1132. https://doi.org/10.1016/j.joen.2007.06.011

Eliasson S, Lavstedt S, Ljungheimer C (1986). Radiographic study of alveolar bone height related to tooth and root length. *Community Dent Oral Epidemiol*, **14**(3):169–171. https://doi.org/10.1111/j.1600-0528.1986.tb01525.x

Felsypremila G, Vinothkumar TS, Kandaswamy D (2015). Anatomic symmetry of root and root canal morphology of posterior teeth in Indian subpopulation using cone beam computed tomography: A retrospective study. *Eur J Dent*, **9**(4): 500–507. https://doi.org/10.4103/1305-7456.172623

Ferraz JA, Pécora JD (1993). Three-rooted mandibular molars in patients of Mongolian, Caucasian and Negro origin. *Braz Dent J*, **3**(2): 113–117.

Garg AK, Tewari RK, Agrawal N (2013). Prevalence of three-rooted mandibular first molars among Indians using SCT. *Int J Dent*, **2013**: 183869. https://doi.org/10.1155/2013/183869

Grossmann Y, Sadan A (2005). The prosthodontic concept of crown-to-root ratio: A review of the literature. *J Prosthet Dent*, **93**(6): 559–562. https://doi.org/10.1016/j.prosdent.2005.03.006

Gu Y, Zhou P, Ding Y, Wang P, Ni L (2011). Root canal morphology of permanent three-rooted mandibular first molars: Part III – An odontometric analysis. *J Endod*, **37**(4):485–490. https://doi.org/10.1016/j.joen.2011.01.013

Gulabivala K, Opasanon A, Ng YL, Alavi A (2002). Root and canal morphology of Thai mandibular molars. *Int Endod J*, **35**(1): 56–62. https://doi.org/10.1046/j.1365-2591.2002.00452.x

Haghanifar S, Moudi E, Abbasi S, Bijani A, Mir APB, Ghasemi N (2014). Root-crown ratio in permanent dentition using panoramic radiography in a selected Iranian population. *J Dent (Shiraz)*, **15**(4): 173–179.

Helvacioglu-Yigit D, Sinanoglu A (2013). Use of cone-beam computed tomography to evaluate C-shaped root canal systems in mandibular second molars in a Turkish subpopulation: A retrospective study. *Int Endod J*, **46**(11): 1032–1038. https://doi.org/10.1111/iej.12094

Hölttä P, Alaluusua S, Saarinen-Pihkala UM, Wolf J, Nyström M, Hovi L (2002). Long-term adverse effects on dentition in children with poor-risk neuroblastoma treated with high-dose chemotherapy and autologous stem cell transplantation with or without total body irradiation. *Bone Marrow Transplant*, **29**(2): 121–127. https://doi.org/10.1038/sj.bmt.1703330

Huang RY, Lin CD, Lee MS, Yeh CL, Shen EC, Chiang CY *et al.* (2007). Mandibular disto-lingual root: A consideration in periodontal therapy. *J Periodontol*, **78**(8): 1485–1490. https://doi.org/10.1902/jop.2007.060419

Ishii N, Sakuma A, Makino Y, Torimitsu S, Yajima D, Inokuchi G *et al.* (2016). Incidence of three-rooted mandibular first molars among contemporary Japanese individuals determined using multidetector computed tomography. *Legal Med (Tokyo)*, **22**: 9–12. https://doi.org/10.1016/j.legalmed.2016.07.004

Jayasinghe RD, Li TK (2007). Three-rooted first permanent mandibular molars in a Hong Kong Chinese population: A computed tomographic study. *Hong Kong Dent J*, **4**(2): 90–93.

Jones AW (1980). The incidence of the three-rooted lower first permanent molar in Malay people. *Singapore Dent J*, **5**(1): 15–17.

Joshi A, Goel M, Thorat A (2016). Identifying the risk factors causing iatrogenic mandibular fractures associated with exodontia: A systemic meta-analysis of 200 cases from 1953 to 2015. *Oral Maxillofac Surg*, **20**(4): 391–396. https://doi.org/10.1016/10.1007/s10006-016-0579-9

Keith A, Knowles FH (1911). A description of teeth of Palaeolithic man from Jersey. *J Anat Physiol*, **46**(Pt 1): 12–27.

Kim E, Fallahrastegar A, Hur YY, Jung IY, Kim S, Lee SJ (2005). Difference in root canal length between Asians and Caucasians. *Int Endod J*, **38**(3): 149–151. https://doi.org/10.1111/j.1365-2591.2004.00881.x

Kung A, Lam AK, Lay NF, Leung J, Lim YM, Abduo J (2016). Evaluation of the selected root-to-crown ratio of crowned teeth in a hospital setting: A cross-sectional study. *Br J Med Med Res*, **18**(12): 1–8.

Kupczik K, Hublin JJ (2010). Mandibular molar root morphology in Neanderthals and Late Pleistocene and recent Homo sapiens. *J Human Evol*, **59**(5): 525–541. https://doi.org/10.1016/j.jhevol.2010.05.009

Lind V (1972). Short root anomaly. *Scand J Dent Res*, **80**(2): 85–93. https://doi.org/10.1111/j.1600-0722.1972.tb00268.x

Loh HS (1990). Incidence and features of three-rooted permanent mandibular molars. *Aust Dent J*, **35**(5): 434–437. https://doi.org/10.1111/j.1834-7819.1990.tb05426.x

Madani ZS, Mehraban N, Moudi E, Bijani A (2017). Root and canal morphology of mandibular molars in a selected Iranian population using cone-beam computed tomography. *Iran Endod J*, **12**(2): 143–148. https://doi.org/10.22037/iej.2017.29

Maggiore C, Gallottini L, Resi JP (1998). Mandibular first and second molar. The variability of roots and root canal system. *Minerva Stomatol,* **47**(9): 409–416.

Martins JN, Mata A, Marques D, Caramês J (2016). Prevalence of C-shaped mandibular molars in the Portuguese population evaluated by cone-beam computed tomography. *Eur J Dent*, **10**(4): 529–535. https://doi.org/10.4103/1305-7456.195175

Nakayama A, Toda Y (1941). Clinical observation of gutter shaped root canal. *Kokubyo Gakkai Zasshi*, **15**: 118–123.

Nayak G, Shetty S, Shekhar R (2014). Asymmetry in mesial root number and morphology in mandibular second molars: A case report. *Restor Dent Endod*, **39**(1): 45–50. https://doi.org/10.5395/rde.2014.39.1.45

Neelakantan P, Subbarao C, Subbarao CV, Ravindranath M (2010). Root and canal morphology of mandibular second molars in an Indian population. *J Endod*, **36**(8): 1319–1322. https://doi.org/10.1016/j.joen.2010.04.001

Nelson SJ, Ash MM Jr (2010). Chapter 12. The permanent mandibular molars. In: *Wheeler's Dental Anatomy, Physiology and Occlusion*. 9th edn. St. Louis: Elsevier Saunders, pp. 189–209.

Ngeow WC, Aljunid ST (2009). Craniofacial anthropometric norms of Malays. *Singapore Med J*, **50**(5): 525–528.

Othman N, Taib H, Mokhtar N (2011). Root-crown ratios of permanent teeth in Malay patients attending HUSM Dental Clinic. *Arch Orofac Sci*, **6**(1): 21–26.

Park JB, Kim N, Park S, Kim Y, Ko Y (2013). Evaluation of root anatomy of permanent mandibular premolars and molars in a Korean population with cone-beam computed tomography. *Eur J Dent*, 7(1): 94–101.

Pawar AM, Pawar M, Kfir A, Singh S, Salve P, Thakur B *et al.* (2017). Root canal morphology and variations in mandibular second molar teeth of an Indian population: An in vivo cone-beam computed tomography analysis. *Clin Oral Investig*, **21**(9): 2801–2809. https://doi.org/10.1007/s00784-017-2082-6

Peiris R, Takahashi M, Sasaki K, Kanazawa E (2007). Root and canal morphology of permanent mandibular molars in a Sri Lankan population. *Odontology*, **95**(1): 16–23. https://doi.org/10.1007/s10266-007-0074-8

Rodriguez-Niklitschek C, Cantín M, Oporto VGH (2015). Comparison of two different methods of average working length determination in second molars and premolars. *Int J Morphol*, **33**(3): 1136–1140.

Rohilla M (2017). Etiology of various dental developmental anomalies: Review of literature. *J Dent Probl Solut*, **4**(2): 19–25. https://doi.org/10.17352/2394-8418.000042

Sachdeva S, Phadnaik MB (2012). Three-rooted mandibular first molar: A consideration in periodontal therapy. *J Indian Soc Periodontol*, **16**(2): 286–289. https://doi.org/10.4103/0972-124X.99279

Shemesh A, Levin A, Katzenell V, Ben Itzhak J, Levinson O, Zini A *et al.* (2015). Prevalence of 3- and 4-rooted first and second mandibular molars in the Israeli population. *J Endod*, **41**(3): 338–342. https://doi.org/10.1016/j.joen.2014.11.006

Shemesh A, Levin A, Katzenell V, Itzhak JB, Levinson O, Avraham Z *et al.* (2017). C-shaped canals-prevalence and root canal configuration by cone beam computed tomography evaluation in first and second mandibular molars: A cross-sectional study. *Clin Oral Investig*, **21**(6): 2039–2044. https://doi.org/10.1007/s00784-016-1993-y

Shillingburg HT, Hobo S, Whitsett LD, Jacobi R, Brackett SE (1997). *Fundamentals of Fixed Prosthodontics*. 3rd edn. Chicago: Quintessence Publishing, pp. 85–103, 191–192.

Silva E, Nejaim Y, Silva AV, Haiter-Neto F, Cohenca N (2013). Evaluation of root canal configuration of mandibular molars in a Brazilian population by using cone-beam computed tomography: An in vivo study. *J Endod*, **39**(7): 849–852. https://doi.org/10.1016/j.joen.2013.04.030

Song JS, Choi HJ, Jung IY, Jung HS, Kim SO (2010). The prevalence and morphologic classification of distolingual roots in the mandibular molars in a Korean population. *J Endod*, **36**(4): 653–657. https://doi.org/10.1016/j.joen.2009.10.007

The Glossary of Prosthodontic Terms: Ninth Edition (2017). *J Prosthet Dent*, 117(5S): e1-e105. https://doi.org/10.1016/j.prosdent.2016.12.001

Torres A, Jacobs R, Lambrechts P, Brizuela C, Cabrera C, Concha G *et al.* (2015). Characterization of mandibular molar root and canal morphology using cone beam computed tomography and its variability in Belgian and Chilean population samples. *Imaging Sci Dent*, **45**(2): 95–101. https://doi.org/10.5624/isd.2015.45.2.95

Tratman EK (1950). A comparison of teeth of people: Indo-European racial stock with the Mongoloid stock. *Dent Rec (London)*, **70**(3): 63–88.

Tu MG, Huang HL, Hsue SS, Hsu JT, Chen SY, Jou MJ *et al.* (2009). Detection of permanent three-rooted mandibular first molars by cone-beam computed tomography imaging in Taiwanese individuals. *J Endod*, **35**(4): 503–507. https://doi.org/10.1016/j.joen.2008.12.013

Tu MG, Tsai CC, Jou MJ, Chen WL, Chang YF, Chen SY *et al.* (2007). Prevalence of three-rooted mandibular first molars among Taiwanese individuals. *J Endod*, **33**(10): 1163–1166. https://doi.org/10.1016/j.joen.2007.07.020

Turner CG 2nd (1971). Three-rooted mandibular first permanent molars and the question of American Indian origins. *Am J Phys Anthropol*, **34**(2): 229–241. https://doi.org/10.1002/ajpa.1330340207

Verhoeven JW, van Aken J, van der Weerdt GP (1979). The length of teeth: A statistical analysis of the differences in length of human teeth for radiologic purposes. *Oral Surg Oral Med Oral Pathol*, **47**(2): 193–199. https://doi.org/10.1016/0030-4220(79)90180-4

Vertucci FJ (2005). Root canal morphology and its relationship to endodontic procedures. *Endod Topics*, **10**(1): 3–29. https://doi.org/10.1111/j.1601-1546.2005.00129.x

von Arx T, Jensen SS, Bornstein MM (2015). Changes of root length and root-to-crown ratio after apical surgery: An analysis by using cone-beam computed tomography. *J Endod*, **41**(9): 1424–1429. https://doi.org/10.1016/j.joen.2015.04.001

von Zuben M, Martins JNR, Berti L, Cassim I, Flynn D, Gonzalez JA *et al.* (2017). Worldwide prevalence of mandibular second molar C-shaped morphologies evaluated by cone-beam computed tomography. *J Endod*, **43**(9): 1442–1447. https://doi.org/10.1016/j.joen.2017.04.016

Walker RT (1988). Root form and canal anatomy of mandibular second molars in a southern Chinese population. *J Endod*, **14**(7): 325–329. https://doi.org/10.1016/S0099-2399(88)80192-4

Weine FS, Pasiewicz RA, Rice RT (1988). Canal configuration of the mandibular second molar using a clinically oriented in vitro method. *J Endod*, **14**(5): 207–213. https://doi.org/10.1016/S0099-2399(88)80171-7

Yaacob H, Nambiar P, Naidu MDK (1996). Racial characteristics of human teeth with special emphasis on the Mongoloid dentition. *Malays J Pathol*, **18**(1): 1–7.

Yang ZP, Yang SF, Lin YC, Shay JC, Chi CY (1988). C-shaped root canals in mandibular second molars in a Chinese population. *Endod Dent Traumatol,* **4**(4): 160–163. https://doi.org/10.1111/j.1600-9657.1988.tb00315.x

Yew SC, Chan K (1993). A retrospective study of endodontically treated mandibular first molars in a Chinese population. *J Endod,* **19(**9): 471–473. https://doi.org/10.1016/S0099-2399(06)80536-4

Yun HJ, Jeong JS, Pang NS, Kwon IK, Jung BY (2014). Radiographic assessment of clinical root-crown ratios of permanent teeth in a healthy Korean population. *J Adv Prosthodont*, **6**(3): 171–176. https://doi.org/10.4047/jap.2014.6.3.171

Zhang R, Wang H, Tian YY, Yu X, Hu T, Dummer PM (2011). Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals. *Int Endod J*, **44**(11): 990–999. https://doi.org/10.1111/j.1365-2591.2011.01904.x

Zhang X, Xiong S, Ma Y, Han T, Chen X, Wan F *et al.* (2015). A cone-beam computed tomographic study on mandibular first molars in a Chinese subpopulation. *PLOS ONE*, **10**(8): e0134919. https://doi.org/10.1371/journal.pone.0134919

Zheng Q, Zhang L, Zhou X, Wang Q, Wang Y, Tang L, Song F, Huang D (2011). C-shaped root canal system in mandibular second molars in a Chinese population evaluated by cone-beam computed tomography. *Int Endod J,* **44**(9): 857–862. https://doi.org/10.1111/j.1365-2591.2011.01896.x