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Root canal morphology of mandibular permanent molars at different ages

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Abstract

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Aim To investigate differences in the root canal morphology of permanent mandibular molar teeth at various ages.

Methodology Four hundred and eighty permanent mandibular first and second molars were examined. First and second molars were divided into six and five groups, respectively, according to the age of the patient at the time of extraction. Root canal morphology was studied using a clearing technique. The canal morphology of the mesial root was classified into three stages depending on its developmental pattern. When the root canal system was completely differentiated, the canal classification and the number of lateral canals and inter-canal communications were recorded. Vertucci's classification was taken as the main reference. Canal morphology was compared amongst age groups.

Results In both first and second molars, developmental stages of canal morphology amongst age groups were significantly different ($P < 0.0001$). The prevalence of inter-canal communications was highly significantly different in the first ($P < 0.0001$) and less significant in the second molar ($P < 0.05$). After completion of the canal differentiation, the mesial roots of first molars had type IV and II canal forms. The majority of the mesial roots of second molars had type I and III canals. C-shaped canals were found in 3% of second molars.

Conclusions Mesial roots of first and second molars mostly had one large canal until 11 and 15 years of age, respectively. In both molars, the canal system was completely defined at 30–40 years. The prevalence of inter-canal communications was low at young and old ages but high at intermediate ages.

Keywords: age changes, inter-canal communications, permanent mandibular molars, root canal morphology.

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Introduction

Root canal morphology changes as the teeth develop. In general, roots in teeth from young individuals have single large canals. With age, deposition of secondary dentine results in the formation of partitions, which often cause extensive differentiation of the root canal system resulting in the development of separate canals and transverse connecting systems (Hess 1925). The differentiation of a simple root canal into a complex form occurs most commonly in roots that are flat or which have external grooves (Hess 1925).

Although several investigations have recorded the canal morphology of the permanent dentition (Walker 1988a,b, Manning 1990a,b, Gulabivala *et al.* 2001, 2002, Sert *et al.* 2004, Peiris *et al.* 2007), age changes in canal morphology has rarely been studied in detail. Hess (1925) was the first to undertake a comprehensive investigation of the root canal system of the human

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permanent dentition. That report described the form and number of root canals in a European white population of different age groups ranging from 6 to 55 years and concluded that age has an influence upon the form and number of the root canals in different tooth types. In another study, Thomas *et al.* (1993) reported the canal anatomy of the mesio-buccal root of maxillary first molars at various ages using a radiographic technique. They reported that differentiation of root canals commenced at an early age but that the rate of progression appeared to be variable. Unfortunately, the limitations of radiographs in studying certain features of the root canal system are prone to a wide range of interpretation (Mueller 1936, Pineda & Kuttler 1972).

Information concerning the age-related changes of root canal morphology in the human dentition is insufficient. In addition, more detailed investigations using a more accurate technique to visualize the root canal system is necessary to make a firm conclusion about these changes. A better knowledge of this changing morphology would assist clinicians in treating teeth, particularly in young patients. It would be expected that the root canal anatomy of the mandibular first and second permanent molar teeth would change with age.

The aim of this study was to investigate the changes that take place in the canal morphology of permanent mandibular molars at different ages. It was hypothesized that in the mesial root of permanent mandibular molar teeth, canal morphology and the prevalence of inter-canal communications (ICC) differed amongst different age groups.

Materials and methods

Two hundred and forty permanent mandibular first and 240 second molar teeth from patients of known age and gender were included. Teeth were collected from the patients who attended for extractions as a result of caries, before prosthodontic treatments, etc. at three dental hospitals in the central province of Sri Lanka. The patients consisted of Sri Lankan Sinhalese and Tamils who are the two major ethnic groups in Sri Lanka. It has been reported that the Sinhalese of Sri Lanka are genetically similar to the Tamils of Sri Lanka who have always been in proximity with each other historically, linguistically, geographically and culturally (Kshatriya 1995, Papiha *et al.* 1996, Peiris *et al.* 2006). All subjects enrolled in the project responded to an informed-consent protocol, which had been approved by the Ethics Committee of the Nihon University School of Dentistry at Matsudo and conformed to the provisions of the World Medical Association Declaration of Helsinki (revised Washington 2002). Only teeth, which could be verified as mandibular permanent first and second molar teeth by crown morphology, were included.

First and second molars were divided into six and five groups, respectively, according to the age of the patient at the time of extraction (Tables 1 and 2). Teeth were washed immediately after extraction and stored in 10% formalin until the collection was completed. They were boiled in 5% NaOH for 5 min and then cleaned with 10% NaOCl for 40 min in an ultrasonic cleaner to remove surface organic debris on the surface. Any further deposits calculus and bone fragments were removed subsequently. The vacuum injection protocol described by Yoshiuchi *et al.* (1972) was then used to inject ink into the root canal system and make the tooth transparent to visualize the canal system. Briefly, a conservative coronal access was made into the pulp chamber with a carbide bur in a high-speed handpiece. China ink was then injected into the pulp cavity using a vacuum injector two or three times. Teeth were thoroughly cleaned with water to remove surface stains. Teeth were then demineralized for five days in

Table 1 Age groups and the prevalence of developmental stages of root canal morphology in the mesial root of mandibular first molars

Age group of patients at extraction (years)	*n*	Root canal stages S1	S2	S3
6–11	19	17 (89.5)	2 (10.5)	–
12–15	46	7 (15.2)	20 (43.5)	19 (41.3)
16–20	58	3 (5.2)	9 (31.0)	46 (63.8)
21–30	66	–	4 (15.1)	62 (84.9)
31–40	19	–	1 (5.26)	18 (94.73)
41 and over	32	–	–	32 (100)

Figures in parentheses denote percentages.

Table 2 Age groups and the prevalence of developmental stages of root canal morphology in the mesial root of mandibular second molars

Age group of patients at extraction (years)	*n*	Root canal stages S1	S2	S3
12–15	30	28 (93.3)	2 (6.7)	–
16–20	42	20 (47.6)	6 (14.3)	16 (38.1)
21–30	68	8 (11.8)	6 (8.8)	54 (79.4)
31–40	48	–	–	48 (100)
41 and over	52	–	–	52 (100)

Figures in parentheses denote percentages.

5% nitric acid at room temperature (20 °C); the nitric acid solution was changed each day. To learn the reliability of the demineralization procedure, teeth were tested for softness by inserting a needle in the coronal region. After demineralization, the teeth were rinsed in running water for 24 h and then dehydrated using ascending concentrations of ethanol (70%, 80%, 90%, 95% and 100%) for 5 days. Finally, the teeth were rendered transparent by immersion in a solution containing benzoic acid mixed with benzene and methylsalycylate for 2–3 days. At the end of this procedure, all specimens were transparent, and with no sign of opacity on their surfaces at the end of a 3-day period. Furthermore, it was noticed that the samples, taken out of the solution lost their transparency rapidly.

The cleared specimens were examined under a dissecting microscope at 10× magnification by one investigator. Depending on the pattern of development, canal morphology of the mesial (M) root was classified into three stages (Hess 1925) (Fig. 1): stage 1, single large canal from pulp chamber to the apex without secondary dentine deposition; stage 2, commencement of canal differentiation with the appearance of isolated secondary dentine depositions and/or secondary dentine deposition increases, so that bifurcations appear; stage 3, canal differentiation is completed with complete division of the root canal system. When the root canal system was fully differentiated, the type of canals, the number and position of lateral canals and ICC were recorded. During the evaluation of the samples, the classification of Vertucci (1984) was taken as the main reference. Vertucci (1984) classified root canal configuration of human permanent teeth into eight types (Figs 2 and 3a): type 1 (1) – a single canal extends from the pulp chamber to the apex; type II (2-1) – two separate canals leave the pulp chamber

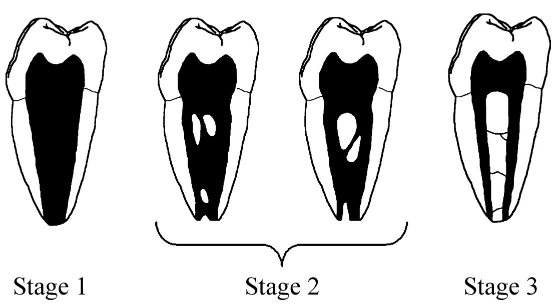

Figure 1 Diagrammatic representation of the different stages of development of canal morphology in the mesial root of Ml and M2 (modified from Hess 1925).

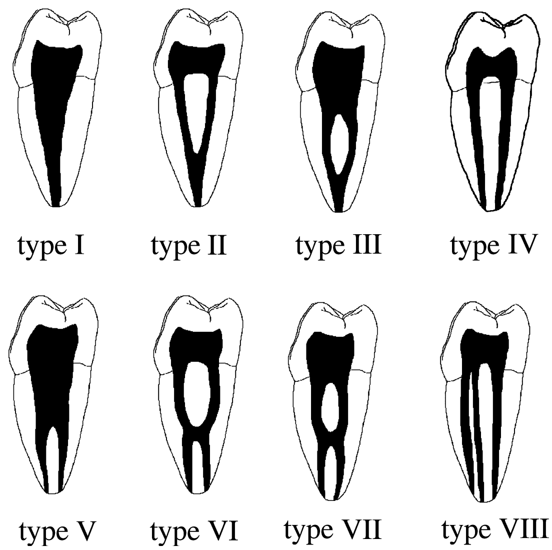

Figure 2 Vertucci's classification of root canal types (reproduced from Peiris *et al.* 2007, with permission).

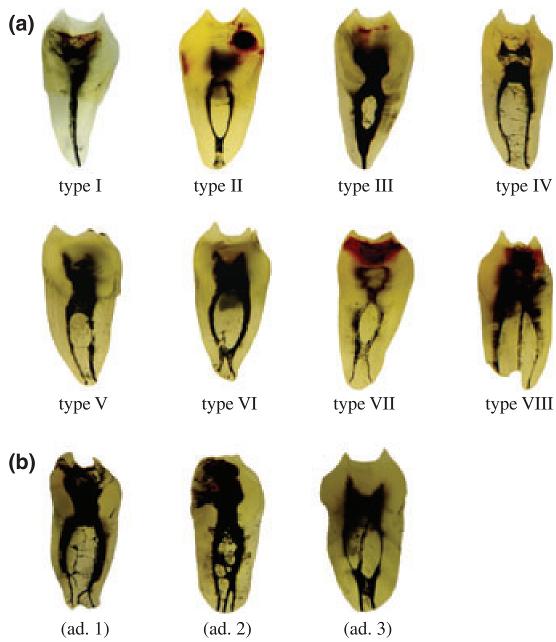

Figure 3 Transparent root canal appearance of mandibular permanent molars with completely differentiated canal systems in this study. (a) Examples for each type of Vertucci's classification: type I, 1; type II, 2-1; type III, 1-2-1; type IV, 2; type V, 1-2; type VI, 2-1-2; type VII, 1-2-1-2; type VIII: 3. (b) Additional canal configurations, commonly found: (ad. 1), 2-3; (ad. 2), 1-2-3; (ad. 3), 3-1-2 (reproduced from Peiris *et al.* 2007, with permission.).

and join short of the apex to form one canal; type III (1-2-1) – one canal leaves the pulp chamber, divides into two within the root and then merges to exit as one canal; type IV (2) – two separate and distinct canals extend from the pulp chamber to the apex; type V (1-2) – one canal leaves the pulp chamber and divides short of the apex into two separate and distinct canals with separate apical foramina; type VI (2-1-2) – two separate canals leave the pulp chamber, merge within the body of the root and redivide short of the apex to exit as two distinct canals; type VII (1-2-1-2) – one canal leaves the pulp chamber, divides and then rejoins within the body of the root and finally redivides into two distinct canals short of the apex; type VIII (3) – three separate canals extend from the pulp chamber to the apex. Aberrant forms of root canals that did not fit Vertucci's classification were also evaluated.

A test of the consistency of the observer in assessing developmental stages of canal morphology and canal types was undertaken by re-examining the mesial roots of 100 randomly selected first molars and then comparing the results with the original canal assessment. Sri Lankan Sinhalese and Tamil data were combined for the analysis because no statistically significant difference was observed in canal morphology between these two population groups. In addition, these parameters did not significantly differ between male and female; thus, these groups were also combined. JMP (Version 3; SAS Institute, North Carolina, USA) software was used for the statistical analysis. The Kruskal–Wallis test was applied to examine any statistically significant difference and a P-value of less than 0.05 was considered significant.

Results

Concordance for the test of consistencies of the observer in assessing canal morphology was 92% for canal stages and 96% for canal types, indicating that using the present classification, canal morphology could be scored with high reliability.

The data for different developmental stages of canal morphology in the mesial root of mandibular molars are presented in Tables 1 and 2. In both first and second molars, canal morphology amongst age groups was significantly different ($P < 0.0001$). There was a decline of stage 1 and increase of stage 3 canal forms with the advancement of the age. After 30 years of age, the majority of teeth had stage 3 canal morphology. Furthermore, in first molars, a greater percentage of teeth in the 6–11 years age group had stage 1 canal form. Stage 2 and stage 3 were commonly seen in the 12–15 and 16–20 years age groups (Table 1). On the other hand, in second molars, the 12–15 years age group typically presented with stage 1 canal morphology. A high prevalence of stage 1 and stage 3 was observed in the 16–20 years age group (Table 2).

The distribution of canal differentiation and ICC in mesial roots of first and second molars is shown in Fig. 4(a,b). Prevalence of ICC between age groups was significantly different in first molars ($P < 0.0001$) and less significant in second molars ($P < 0.05$). In both

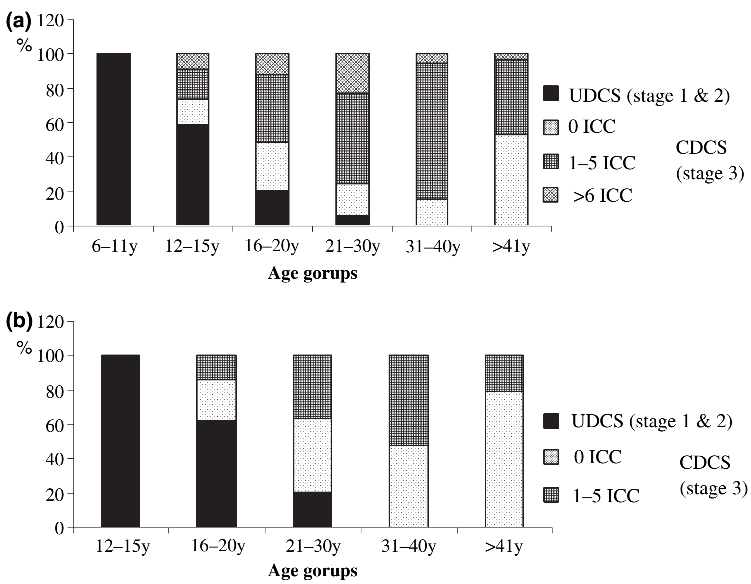

Figure 4 (a) Prevalence of canal differentiation and ICC at different age groups in Ml. (b) Prevalence of canal differentiation and ICC at different age groups in M2. ICC, inter-canal communications; UDCS, undifferentiated canal system; CDCS, completely differentiated canal system.

first and second molars, with the establishment of canal system, the prevalence of mesial roots with 1–5 ICC gradually increased with age up to 31–40 years. Meanwhile, comparatively high and low incidence of mesial roots without ICC (0 ICC) and 1–5 ICC, respectively was observed in >40 years age group. Furthermore, in first molars, occurrence of ≥6 ICC increased with the advancing age up to 21–30 years and then decreased gradually. In this study, 6–11 and 12–15 years age groups, respectively, in first and second molars did not show any completely differentiated canal systems and therefore, no ICC.

The results of the evaluation of the root canal system of first and second molars after completion of canal differentiation (stage 3) are given in Table 3. Mesial roots of first molars typically had two canals and two apical foramina of type IV and two canals and one apical foramen of type II canal configuration. Furthermore, additional canal types were found in 3.4% of first molars studied. Most of the distal roots of first molars had type I canal configurations. The remainder was distributed mainly between type V, type IV and type III. In second molars, the majority of the mesial roots had one or two canals with one apical foramen of type I and type III canal morphologies. The distal root commonly presented with type I canal configurations. In addition, C-shaped canals were found in 3% of the cases.

Table 3 Root canal types of mandibular first and second molars

		First		Second	
n		177		165	
Canal configuration	Canal type	MR	DR	MR	DR
1	I	5 (2.8)	127 (71.8)	51 (30.9)	159 (96.4)
2-1	II	44 (24.9)	2 (1.1)	24 (14.6)	1 (0.6)
1-2-1	III	6 (3.4)	12 (6.8)	42 (25.5)	2 (1.2)
2	IV	107 (60.5)	14 (7.9)	25 (15.1)	–
1-2	V	3 (1.7)	18 (10.2)	20 (12.1)	3 (1.8)
2-1-2	VI	3 (1.7)	2 (1.1)	1 (0.6)	–
1-2-1-2	VII	1 (0.5)	1 (0.5)	–	–
3	VIII	2 (1.1)	–	–	–
Additional canal configurations	A	6 (3.4)	1 (0.5)	2 (1.2)	–

Figures in parentheses denote percentages.

Three additional canal configurations beyond Vertucci's classification were identified (Fig. 3b). In one case, two canals exit the pulp chamber and the buccal canal divided into two at the apical third to make three separate canals at the apex. In the second case, a wide single canal exit of the pulp chamber and separated into two in the cervical third. The buccal canal then branched in the apical third to exit as three canals at the apex. A third case had three canals leaving the pulp chamber that merged in the middle third and separated into two canals again to exit as two foramina at the apex.

The percentages and location of the ICC and lateral canals are presented in Tables 4 and 5. ICC were more common in the mesial roots of first and second molars; the prevalence was lower in second molars. In both first and second molars, they were seen less frequently in the distal root than in the mesial root. ICC were found mostly in the middle third and less frequently in the apical and cervical third of the root, respectively. Moreover, in many cases, they were observed in all positions simultaneously. In addition, a variable number of communications was found at each position. For example, the number of ICC in the middle third varied from 1–11 canals. There was an increasing prevalence of lateral canals towards the apical part of the root. The apical third of the root had a higher prevalence of lateral canals than the middle, cervical and furcation regions combined. Lateral canals were more frequently seen in first rather than in second molars.

Discussion

It has been suggested that although various techniques have been used to evaluate root canal morphology, the most detailed information is obtained by demineralization and staining (Vertucci 1984, Omer *et al.* 2004),

Table 4 Number and position of inter-canal communications in mandibular molars

				Position of inter-canal communications						
Tooth	Root	*n*	Inter-canal communi -cations	C	M	A	C + M	C + A	M + A	C + M + A
First molar	MR	177	137(77.4)	11(6.2)	19(10.7)	7(4.0)	23(13.0)	2(1.1)	16(9.0)	59(33.3)
	DR	177	20(11.3)	2(1.1)	8(4.5)	3(1.7)	1(0.6)	–.	4(2.3)	2(1.1)
Second molar	MR	165	63(38.2)	6(3.6)	16(9.7)	1(0.6)	14(8.5)	–	13(7.9)	13(7.9)
	DR	165	2(1.2)	1(0.6)	1(0.6)	–	–	–	–	–

Figures in parentheses denote percentages.
C, cervical third of the root; M, middle third of the root; A, apical third of the root.

Table 5 Number and position of lateral canals in mandibular molars

				Position of lateral canals				
Tooth	Root	*n*	Lateral canals	C	M	A	C+A	M+A
First	MR	177	92 (52.0)	–	3 (1.7)	80 (45.2)	–	9 (5.1)
molar	DR	177	60 (33.9)	–	6 (3.4)	52 (29.4)	–	2 (1.2)
Second	MR	165	62 (37.5)	–	6 (3.6)	54 (32.7)	–	2 (1.2)
molar	DR	165	51 (30.9)	–	6 (3.6)	44 (26.7)	–	1 (0.6)

Figures in parentheses denote percentages.
C, cervical third of the root; M, middle third of the root; A, apical third of the root.

which is excellent for three-dimensional evaluation of root canal morphology. It was anticipated that examination of fine details (ICC, lateral canals) would require ink penetration; however, the quality of clearing was sufficient to visualize such details without staining.

First and second molars erupt around 6–11 years and apical closure is completed around 9–14 years of age, respectively (Hillson 1998). Hess (1925) explained that differentiation of the root canals appears only after the growth of the root is completed (after the closing of the apical foramen). The findings of this study are in agreement with these previous investigations and confirm that mesial roots of first and second molars have most often one large canal until 11 and 15 years of age, respectively. In addition, in first and second molars, completion of canal differentiation commences at about 3–6 and 2–6 years after root completion, respectively. Furthermore, ages 12–20 years in first and 16–30 years in second molars had mixed patterns of canal morphology and therefore, these periods seem to be a transition period for canal differentiation (Tables 1 and 2). During this period, secondary dentine deposition in the mesio-distal direction within the canal at the cervical, middle and apical thirds causes canal separation. It has been suggested that the form and number of root canals are principally determined by the deposition of secondary dentine and these partitions cause extensive differentiation in root canals, which were originally in simple form (Hess 1925, Thomas *et al.* 1993).

Thomas *et al.* (1993) suggested that secondary dentine appeared initially to be deposited in the mid root where the root was constricted. Hess (1925) reported that differentiation might commence either at the end or on the middle of the root. Meanwhile, in this study, it was noted that islands of secondary dentine depositions occurred mostly in the apical and middle third of the root. It would appear that if a single partition is formed in the cervical third, a single root canal becomes separated coronally forming Vertucci's type II canal form. Similarly, when two partitions are formed at cervical and apical thirds of the root, type VI canal configuration results. However, if numerous partitions form, extensive differentiation of the root canal system results in a reticular form in which three or more vertical canals are present with lateral interconnections resulting in type VIII or additional canal types (Fig. 3). This study further confirmed that canal differentiation was completed around 30–40 years of age in both first and second molars. However, the rate of progression of secondary dentine deposition was variable as evidenced by the fact that all developmental stages of root canal morphology were represented in younger age groups (up to 30 years of age).

The occurrence of ICC increased with age up to 31–40 years in both first and second molars. Hess (1925) noted that extensive differentiation of the root canal system with age was characterized by the appearance of spaces, transverse ICC and especially by the division of the root canal into two separate canals. He further mentioned that after completion of canal development, continuous deposition of secondary dentine caused numerous intervening stages, which resulted in a network of transverse anastomosis and communications between the separate canals. These findings are consistent with those of Hess (1925) and confirmed increasing numbers of ICC between 16 and 40 years of age in both first and second molars (Fig. 4a,b). Meanwhile, with advancing age further deposition of secondary dentine, which is a slow continuous process, results in narrowing of canals, disappearance of transverse anastomosis and lateral canals (Hess 1925, Thomas *et al.* 1993). This finding is further supported by our study and shows a sudden decrease in the prevalence of 1–5 ICC and increase in occurrence of no ICC in the mesial root of first and second molars after 40 years of age.

This investigation confirmed that root canal morphology of completely differentiated mandibular molars is complex. Although the distal root canals had simple structures, the mesial canals exhibited many complex configurations. Furthermore, additional canal configurations that did not fit Vertucci's classification were more frequently found in mesial roots than in distal and in first compared with second molars. For example, 72% of distal root of first molars had type I canal morphology and prevalence of type IV and type II canal configuration in the mesial root was 61% and 25%, respectively. The result of this study of Sri Lankan first molars compares with those of American Caucasians (Vertucci 1984) and Turkish (Sert *et al.* 2004) populations. However, they differ from those of Thai (Gulabivala *et al.* 2002), Burmese (Gulabivala *et al.* 2001) and Chinese (Walker 1988a) populations who had a higher prevalence of two canals and apical foramina in the distal roots of first molars. These findings are consistent with the frequent occurrence of three-rooted (one mesial and two distal) first molars in Thai and Burmese populations, which represent a culture mix of people of Chinese and Indian origin (Gulabivala *et al.* 2002,2001) and in Chinese populations (Walker 1988a).

In second molars, 66% of Sri Lankans had three canals and two canals were seen in 31% of the teeth examined. These results are consistent with previous findings of second molar canal morphology in American Caucasians (Vertucci 1984) but differ from those of Thai (Gulabivala *et al.* 2002), Burmese (Gulabivala *et al.* 2001) and Chinese (Walker 1988b) populations. Walker (1988b) recorded a high prevalence (55%) of two canals and a low prevalence (45%) of three canals in southern Chinese people. Moreover, Thai (Gulabivala *et al.* 2002) and Burmese (Gulabivala *et al.* 2001) had three canals in 55% and 43% of teeth, respectively. In addition, they had one root canal in 3% and 10% of teeth, respectively. Studies of canal anatomy of second molars in Japanese (Kotoku 1985), Chinese (Yang *et al.* 1988) and Hong Kong Chinese (Walker 1988b) reported a high incidence of C-shaped canals. Meanwhile, amongst Europeans and recently in Sri Lankans, an absence (Tamse & Kaffe 1981, Vertucci 1984) or near absence (Weine *et al.* 1988, Peiris *et al.* 2007) of C-shaped canals in second molars has been described. In this study, the prevalence of 3% in Sri Lankan second molars is in agreement with later findings.

Many investigations have revealed the age-related changes of the root canal system and the importance of a better understanding that these changes influence the provision of restorative and endodontic care (Smith *et al.* 1993, Walton 1997, Basmadjian-Charles *et al.* 2002, Murray *et al.* 2002, Dammaschke *et al.* 2003). This study further reinforces these findings and shows distinct developmental patterns of canal morphology, especially in young and intermediate age groups. Therefore, it is suggested that for successful root canal treatment, the dentist should be aware of these developmental variations in the root canal morphology. Meanwhile, reports of the effect of a patient's age on the outcome of endodontic treatment are contradictory. The observation that age made no difference to the outcome was reported by Ingle (1965), Storms (1969) and Swartz *et al.* (1983). However, Grossman *et al.* (1964) and Seltzer *et al.* (1963) both reported better outcomes in younger patients.

Conclusions

The mesial roots of mandibular first and second molars had mostly one large canal until 11 and 15 years of age, respectively. In both teeth, the canal system was completely established at 30–40 years of age. This findings further support the concept that rate of progress of secondary dentine deposition, which differentiate the canal system is variable. The prevalence of ICC was low at young and old ages but high at intermediate ages. It is therefore important to be familiar with these age-related variations in the root canal system because such knowledge can aid in the location and negotiation of canals as well as their subsequent management in clinical practice.

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References

Basmadjian-Charles CL, Farge P, Bourgeois DM, Lebrun T (2002) Factors influencing the long-term results of endodontic treatment: a review of the literature. *International Dental Journal* **52**, 81–6.

Dammaschke T, Steven D, Kaup M, Ott KHR (2003) Long-term survival of root canal treated teeth: a retrospective study over 10 years. *Journal of Endodontics* **29**, 638–43.

Grossman LI, Shepard LI, Pearson LA (1964) Roentgenologic and clinical evaluation of endodontically treated teeth. *Oral Surgery, Oral Medicine and Oral Pathology* **17**, 368–74.

Gulabivala K, Aung TH, Alavi A, Ng YL (2001) Root and canal morphology of Burmese mandibular molars. *International Endodontic Journal* **34**, 359–70.

Gulabivala K, Opasanon A, Ng YL, Alavi A (2002) Root and canal morphology of Thai mandibular molars. *International Endodontic Journal* **35**, 56–62.

Hess W (1925) *The Anatomy of the Root Canals of the Teeth of the Permanent Dentition*, 1st edn. London, UK: John Bale, Sons and Danielsson Ltd, pp. 4–49.

Hillson S (1998) *Dental Anthropology*, 1st edn. Cambridge, UK: Cambridge University press.

Ingle JI (1965) *Endodontics*, Philadelphia, USA: Lea & Febiger, pp. 54–76.

Kotoku K (1985) Morphological studies on the roots of the Japanese mandibular second molars. *Shikwa Gakuho* **85**, 43–64 (in Japanese).

Kshatriya GK (1995) Genetic affinities of Sri Lanka populations. *Human Biology* **67**, 843–66.

Manning SA (1990a) Root canal anatomy of mandibular second molars. Part I. *International Endodontic Journal* **23**, 34–9.

Manning SA (1990b) Root canal anatomy of mandibular second molars. Part II. C-shaped canals. *International Endodontic Journal* **23**, 40–5.

Mueller AH (1936) Morphology of root canals. *Journal of American Dental Association* **23**, 1698–706.

Murray PE, Stanley HR, Matthews JB, Sloan AJ, Smith AJ (2002) Age-related odontometric changes of human teeth. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology and Endodontics* **93**, 474–82.

Omer OE, Al Shalabi RM, Jennings M, Glennon J, Claffey NM (2004) A comparison between clearing and radiographic techniques in the study of the root-canal anatomy of maxillary first and second molars. *International Endodontic Journal* **37**, 291–6.

Papiha SS, Mastana SS, Jayasekara R (1996) Genetic variations in Sri Lanka. *Human Biology* **68**, 707–37.

Peiris R, Nanayakkara D, Kageyama I (2006) Crown dimensions of the mandibular molars in two ethnic groups in Sri Lanka. *Anthropological Sciences* **114**, 89–92.

Peiris R, Takahashi M, Sasaki K, Kanazawa E (2007) Root and canal morphology of permanent mandibular molars in a Sri Lankan population. *Odontology* **95**, 16–23.

Pineda F, Kuttler Y (1972) Mesiodistal and buccolingual roentgenographic investigation of 7,275 root canals. *Oral Surgery Oral Medicine and Oral Pathology* **33**, 101–10.

Seltzer S, Bender IB, Turkenkopf S (1963) Factors effecting successful repair after root canal therapy. *Journal of American Dental Association* **67**, 651–62.

Sert S, Aslanalp V, Tanalp J (2004) Investigation of the root canal configurations of mandibular permanent teeth in the Turkish population. *International Endodontic Journal* **37**, 494–9.

Smith CS, Setchell DJ, Harty FJ (1993) Factors influencing the success of conventional root canal therapy – a five-year retrospective study. *International Endodontic Journal* **26**, 321–33.

Storms JL (1969) Factors that influence the success of endodontic treatment. *Journal of Canadian Dental Association* **35**, 83–97.

Swartz DB, Skidmore AE, Griffin JA Jr. (1983) Twenty years of endodontic success and failure. *Journal of Endodontics* **9**, 198–202.

Tamse A, Kaffe I (1981) Radiographic survey of the prevalence of conical lower second molar. *International Endodontic Journal* **14**, 188–90.

Thomas RP, Moule AJ, Bryant R (1993) Root canal morphology of maxillary permanent first molar teeth at various ages. *International Endodontic Journal* **26**, 257–67.

Vertucci FJ (1984) Root canal anatomy of the human permanent teeth. *Oral Surgery, Oral Medicine and Oral Pathology* **58**, 589–99.

Walker RT (1988a) Root form and canal anatomy of mandibular first molars in a southern Chinese population. *Endodontics and Dental Traumatology* **4**, 19–22.

Walker RT (1988b) Root form and canal anatomy of mandibular second molars in a southern Chinese population. *Journal of Endodontics* **14**, 325–9.

Walton RE (1997) Endodontic considerations in the geriatric patient. *Dental Clinics of North America* **41**, 795–816.

Weine FS, Pasiewicz RA, Rice RT (1988) Canal configuration of the mandibular second molar using a clinically oriented *in vitro* method. *Journal of Endodontics* **14**, 207–13.

Yang ZP, Yang SF, Lin YC, Shay JC, Chi CY (1988) C-shaped root canals in mandibular second molars in a Chinese population. *Endodontics and Dental Traumatology* **4**, 160–3.

Yoshiuchi Y, Takahashi K, Yokochi C (1972) Studies on the anatomical forms of the pulp cavities with new method of vacuum injection (II) – accessory canal and apical ramification. *Japanese Journal of Oral Biology* **14**, 156–85 (in Japanese).