https://doi.org/10.17159/sadj.v78i09.16861

Root and canal morphology of the mandibular first molar: A micro-computed tomography-focused observation of literature with illustrative cases.

Part 1: External root morphology

SADJ October 2023, Vol. 78 No.9 p449-456

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ABSTRACT

The mandibular first molar often requires endodontic intervention, which can be challenging and complex with several variants in the number of canals and roots. Usually, these teeth have a single mesial and distal root, but variants and anomalies have been noted. The incidence of the number of roots can differ between populations. For instance, up to a third of East Asians present with a third root, while the global prevalence is 8.9%. One- and four-rooted first molar teeth are seldom encountered. Over the years different methods have been used to study root and canal morphology, but micro-computed tomography (micro-CT) has provided a non-invasive method to study root and canal morphology in high definition. This paper is the first of two giving an overview of available literature on various aspects of the external and internal root and canal morphology of the mandibular first permanent molar. The aim is to provide an overview of relevant aspects of the external root morphology of the mandibular first molar in different populations. The content is supported by illustrative micro-CT images and a report on clinical cases where anomalies have been treated.

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Acknowledgements

The corresponding author would like to extend his gratitude to Dr Charlotte Theye for technical support in preparation of the manuscript. The corresponding author would like to extend his gratitude to Dr Guy Lambourn, colleague and consultant in Prosthodontics, School of Dentistry, University of Plymouth, for his support and encouragement.

Keywords

Micro-CT, number of roots, radix entomolaris, radix paramolaris

INTRODUCTION

Root canal treatment involves the removal of irreversibly inflamed or infected tissues from a root canal system.[1,2] The endodontic treatment of molars can be particularly challenging due to their root and root canal complexity.[2] Variants in roots or canals can easily be overlooked during clinical investigation and if they remain undiscovered could compromise the treatment outcome. These undiscovered roots potentially harbour infected or inflamed root canals, which can cause re-infection and ultimate treatment failure.[2-4]

The mandibular first molars are often neglected in the early years, placing them at risk of early carious pulpal involvement leading to root canal treatment.[5] They often require endodontic intervention, which can be challenging and complex with several variants in the number of canals and roots.[2,6,7] In most populations the mandibular first molars have one mesial (M) and one distal (D) root with either three or four canals.[7-9] The incidence of the number of roots and root canals can differ between populations.[10-13] An additional root can be present on either the buccal or lingual surface. A radix entomolaris (RE) is an extra root on the disto-lingual side (DL); where an additional root is present on the mesiobuccal side it is referred to as a radix paramolaris (RP).[14,15]

Micro-computed tomography (micro-CT) is a non-invasive method to study root and canal morphology in high definition.[16] Although micro-CT was not originally intended for use in dentistry, Nielsen et al.[16] first used it to describe the root and root canal morphology of a maxillary first molar. Since then it has been used regularly for morphological studies and reporting on complex detail in human dentition; it has therefore been proposed as the most suitable method to describe complexities and fine morphological detail in dental studies.[7,16-19] In combination with suitable software (for example Avizo), all the components of a tooth can be viewed in different colours and isolated from each other in a segmentation process called the watershed.[20,21] Images can also be magnified and rotated for complete observation.

Figure 1 depicts examples of three-rooted mandibular first molars (RE) viewed through micro-CT and Avizo software,

www.sada.co.za / SADJ Vol. 78 No.9
https://doi.org/10.17159/sadj.v78i09.16861

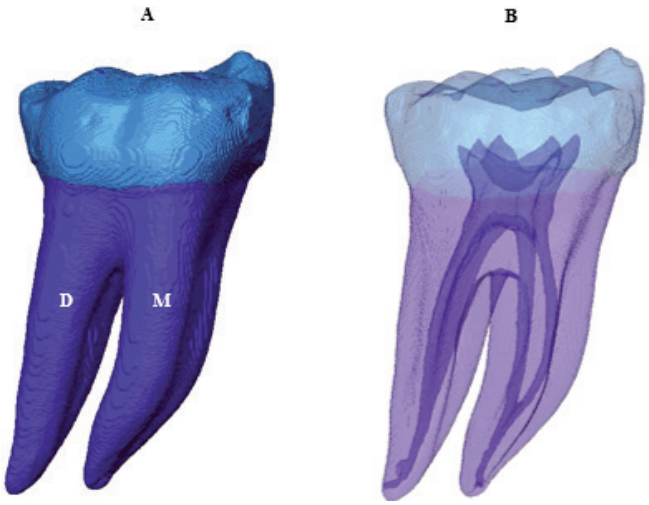

Figure 1: Micro-CT illustrations of a typical two-rooted mandibular first molar; (A) Viewed from mesio-buccal displaying one M and one D root; (B) Adjusted transparency with increased radiolucency illustrating the relationship between the external and internal root and canal morphology. This micro- CT image

while Figure 2 illustrates two clinical cases of South African patients.

The aim of this paper is to provide an overview of available literature on root morphology of the mandibular first molar supported by illustrative images in micro-CT and clinical cases. Authors report on different methods and populations that are included in the review, but this paper focuses on the use of micro-CT.

Number of roots

The consensus is that the mandibular first molar has two roots[7] and the prevalence can range between 73.5%[12] and 100%.[9] 10% nitric acid, and 99% methyl salicylate. India ink was coronally injected into the pulp chamber and withdrawn apically by suction. The teeth were viewed under a magnifying lens and the numbers of root canals and their configurations, lateral canals, intercanal communications, and multiple apical foramina were recorded, along with the number of roots and their morphology. Student's t test for independent samples was used to assess significant differences in the root canal system. All specimens were tworooted with one mesial and one distal root. Root fusion was more frequent in the second than in the first molar: 3.2% versus 0.4%. Vertucci type IV canal configuration was most frequently recorded in the mesial root of the first (44.6% Figure 1 illustrates the root and canal morphology of a typical mandibular first molar with a single M and D root using micro-CT and Avizo software.

Variants are single-rooted, three-rooted and four-rooted teeth. In a recent meta-analysis of available literature, a group of authors determined that, globally, the prevalence of two-rooted first molars was 90.2% and 8.9% for three-rooted teeth. They also did a geographic analysis of the prevalence of three-rooted first molars and found that the distribution was 12.2% in Asia, 3.2% in Africa and 3.2% in Europe.[22] Only a few studies on African subjects could be found in the literature reviewed. Subjects from Uganda, Tanzania and Kenya all had two roots,[9,23,24] 10% nitric acid, and 99% methyl salicylate. India ink was coronally injected into the pulp chamber and withdrawn apically by suction. The teeth were viewed under a magnifying lens and the numbers of root canals and their configurations, lateral canals, intercanal communications, and multiple apical foramina were recorded, along with the number of roots and their morphology. Student's t test for independent samples was used to assess significant differences in the root canal system. All specimens were tworooted with one mesial and one distal root. Root fusion was more frequent in the second than in the first molar: 3.2% versus 0.4%. Vertucci type IV canal configuration was most frequently recorded in the mesial root of the first (44.6%[23,24]University of Nairobi\nResults: The mesial root of mandibular first molars had two canals in 96.3% of the teeth in both males and females and type IV canal configuration was most prevalent in the mesial root. The distal root of the mandibular first molar had one canal in 57.7% of the teeth in males and females. There were significant gender variations in the number of canals and canal configurations in the distal root. Two canals were more prevalent in females (53.6% while in Egypt, 99.5% of teeth were two-rooted and 0.5% were three-rooted.[25] In a South African study investigating a mixed population, the authors reported an incidence of two roots in 98.7%, 1% of three-rooted first molars, 0.3% for single-rooted teeth and no teeth with four roots.[8]

There are several papers available on the number of roots in different populations and most used cone-beam computed tomography (CBCT), but few authors reported on root numbers in their micro-CT investigations. In a Chinese population where 122 first molars were observed using this technology, Gu et al.[26] found 1.6% of teeth were single-rooted, 66.4% were two-rooted and approximately 32% were three-rooted. A prevalence of approximately 2.6% with a third root was reported in a Brazilian population also using micro-CT.[27] An overview of investigations that reported on the number of roots in different populations is given in Table I.

Radix entemolaris (RE) and radix paramolaris (RP)

Several studies report different prevalence of RE and RP. The differences in prevalence noted could be ascribed to variations between populations. A number of investigators used CBCT and other techniques used include *in vivo* radiographic observations[61,62] or *in vitro* observations of extracted teeth.[29,42,54] Examining literature from different studies using different modalities, a group of authors in 2012 calculated an average of 14.4% of RE.[63] A population-specific report published in 2022 found an average prevalence of RE of 5.6% on 23 nations from five continents using CBCT. The findings ranged from 0.9% in Venezuela to 22.4% in China.[64] On the other hand, a literature review and meta-analysis in the same year (2022) of 72 available studies on 33 populations worldwide focusing on CBCT as the main methodology determined that the RE was present on average in 12.3% of teeth, ranging between 0% and 29% in 72 studies originating from 33 populations. On average, RP was present in 0.1% of teeth ranging between 0% and 2%.[65] There was also a rare clinical case of a first molar that had both RE and RP.[66]

In Africa there were a few reports on RE or RP. In Ugandan, Tanzanian and Kenyan population groups no teeth had RE or RP.[9,23,24]10% nitric acid, and 99% methyl salicylate. India ink was coronally injected into the pulp chamber and withdrawn apically by suction. The teeth were viewed under a magnifying lens and the numbers of root canals and their configurations, lateral canals, intercanal communications, and multiple apical foramina were recorded, along with the number of roots and their morphology. Student's t test for independent samples was used to assess significant differences in the root canal system. All specimens were tworooted with one mesial and one distal root. Root fusion was more frequent in the second than in the first molar: 3.2% versus 0.4%. Vertucci type IV canal configuration was most frequently recorded in the mesial root of the first (44.6% In a Senegalese

https://doi.org/10.17159/sadj.v78i09.16861

Table I: Summary of the number of roots in mandibular first molars identified in different populations.

Country	One root (%)	Two roots (%)	Three roots (%)	Four roots (%)	Number of teeth	Author and date
Belgium	0.7	96.5	2.8	-	145	Torres et al. 2015[28]
Burma	-	89.9	10.1	-	139	Gulabivala et al. 2001[29]
Brazil	3.0	97.0	-	-	234	Silva et al. 2013[30]
Brazil	1.0	94.9	4.1	-	600	Mantovani et al. 2022[31]
Chile	-	93.8	6.2	-	146	Torres et al. 2015[28]
Chile	0.2	99.8	-	-	510	Abarca et al. 2020[32]
China	0.7	73.5	25.8	-	558	Wang et al. 2010[12]
China	-	77.5	22.3	0.2	910	Zhang et al. 2015[33]
China	1.6	66.4	32.0	-	122	Gu et al. 2010[26]
China	-	74.1	25.9	-	466	Martins et al. 2018[34]
Egypt	-	99.5	0.5	-	218	Sharaan and Elrawdy 2017[25]
France	1.5	90.0	7.7	0.8	130	Monsarat et al. 2016[35]
Greece	0.2	96.4	3.3	-	478	Kantilieraki et al. 2019[36]
India	-	94.6	5.3	-	150	Chourasia et al. 2012[13]
India	0.7	93.6	5.7	-	299	Felsypremila et al. 2015[37]
Iran	-	98.6	1.4	-	209	Shahi et al. 2008[38]
Iran	-	96.7	3.3	-	150	Akhlaghi et al. 2017[39]
Iran	1.2	96.8	2.0	-	154	Madani et al. 2017[40]
Italy	-	100	-	-	117	Plotino et al. 2013[41]
Japan	-	68.4	31.6	-	38	Peiris et al. 2008[42]
Jordan	-	96.0	4.0	-	330	Al-Qudah and Awawdeh 2009[10]
Korea	0.7	73.5	25.8	-	1952	Kim et al. 2013[43]
Korea	0.3	77.4	22.3	-	666	Park et al. 2013[44]
Malaysia	0.4	88.1	11.4	-	301	Deng et al. 2018[45]
Palestine	-	96.3	3.7	-	322	Mukhaimer and Azizi 2014[46]
Portugal	0.7	97.3	2.0	-	709	Martins et al. 2016[47]
Portugal	0.7	97.1	2.2	-	450	Martins et al. 2017[48]
Portugal	0.6	96.8	2.6	-	220	Martins et al. 2018[34]
Saudi Arabia	-	97.1	2.9	-	174	Mashyakhy et al. 2019[49]
South Africa	0.3	98.7	1.0	-	371	Tredoux et al. 2021[8]
Spain	1.7	94.2	4.1	-	121	Pérez-Heredia et al. 2017[50]
Sri Lanka	-	97.0	3.0	-	100	Peiris et al. 2007[51]
Sri Lanka	-	95.8	4.1	-	529	Peiris et al. 2015[52]
Sri Lanka	-	94.4	5.6	-	295	Peiris et al. 2008[42]
Tanzania	-	100	-	-	146	Madjapa and Minja 2018[24]
Taiwan	-	74.7	25.3	-	237	Huang et al. 2010[53]
Thailand	0.6	85.6	9.4	0.6	118	Gulabivala et al. 2002[54]
Turkey	-	97.6	2.4	-	533	Miloglu et al. 2013[55]
Turkey	0.3	99.2	0.5	-	966	Nur et al. 2014[56]
Turkey	1.8	95.9	2.1	0.2	823	Demirbuga et al. 2013[57]
Uganda	-	100	-	-	224	Rwenyonyi et al. 2009[9]
UAE	-	96.0	4.0	-	807	Al Shehadat et al. 2019[58]
Vietnam	-	87.7	12.3	-	166	Pham et al. 2019[59]
Yemen	-	96.8	3.2	-	500	Senan et al. 2020[60]

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https://doi.org/10.17159/sadj.v78i09.16861

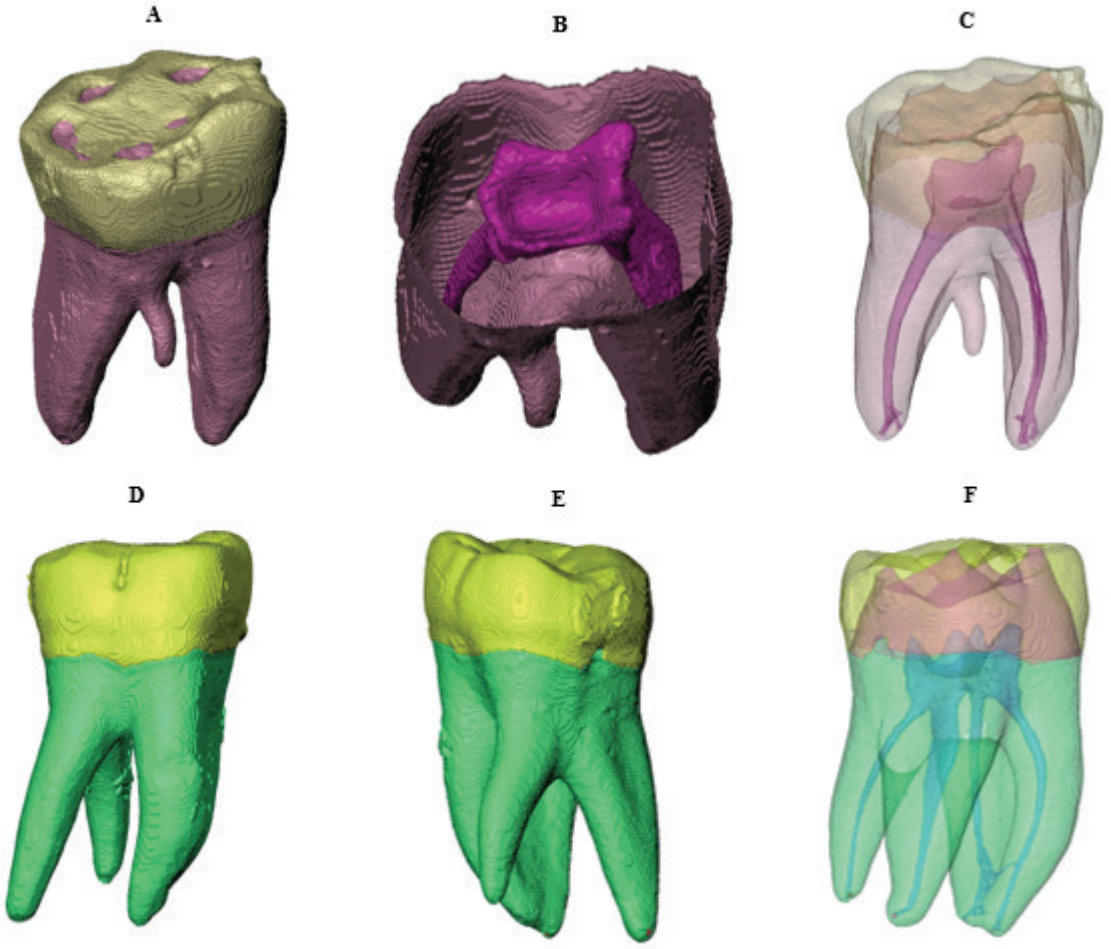

Figure 2: Micro-CT illustrations of mandibular first molars with additional DL roots and classified as RE; (A) Micro-CT view of a mandibular first molar with an additional DL root (RE); (B) No root canal system was noted in the additional DL root; (C) Adjusted transparency displaying the relationship between roots and root canals with no root canal present in the DL root; (D) Buccal view of a mandibular first molar that presents with RE; (E) DL view of the RE displaying three separate roots; (F) Transparent view allowing visualisation of the pulp-root interface.

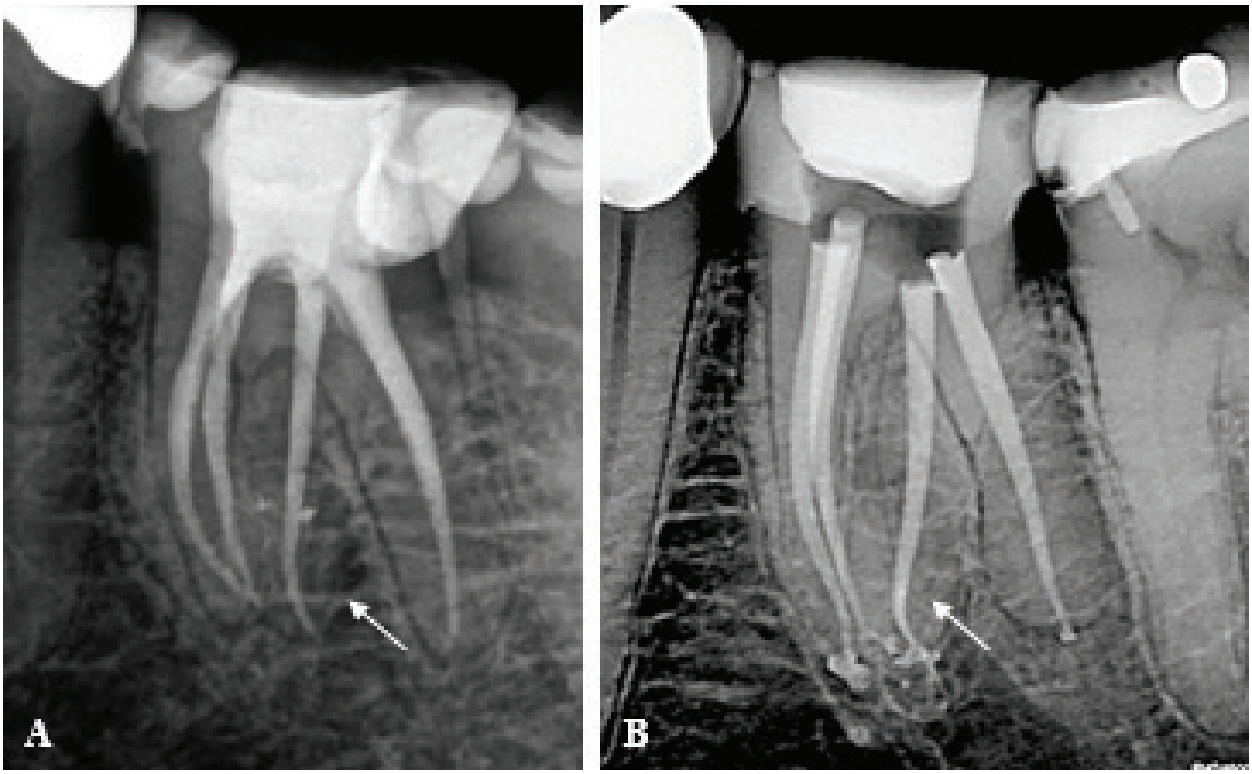

Figure 3: Completed endodontic treatment on mandibular first molars with RE; (A) Periapical radiograph of left mandibular first molar that presented with RE. Note the additional DL root and root canal system (arrow); (B) Periapical radiograph of right mandibular first molar that presented with RE. Note the additional DL root and root canal system (arrow).

https://doi.org/10.17159/sadj.v78i09.16861

population a prevalence of 3.1% was noted.[67]West Africa, revealed 15 teeth with three roots (3.12% In Egypt, a prevalence of approximately 0.7% was noted in individuals of African descent,[68] while a relatively high prevalence of 10.8% was noted in Syrian individuals.[64] In South Africa a prevalence of 1% and 5.2% respectively has been reported in mixed populations from Pretoria and Durban.[8,64]

A limited number of authors reported the presence of RE or RP when using micro-CT investigations. A prevalence of approximately

Table II: Summary of prevalence of RE or RP as reported by authors in different population groups.

Region/country	Number of teeth	Prevalence (%) RP	Prevalence (%) RE	Author and date
Africa	68	-	-	Shaw 1931[70]
Belgium	250	-	3.2	Martins et al. 2022[64]
Brazil (Africans)	106	-	2.8	Ferraz and Pecora 1992[71]
Brazil (Japanese)	105	-	11.4	Ferraz and Pecora 1992[71]
Brazil (Caucasian)	117	-	4.2	Ferraz and Pecora 1992[71]
Brazil	232	-	5.2	Da Costa Rochai et al. 1996[72]
Burma	139	-	10.1	Gulabivala et al. 2001[29]
Canada (Baffin Inuit)	69	-	21.7	Corzon 1974[73]
Canada (Keewatin Inuit)	98	-	27.0	Curzon and Curzon 1971[74]
Canada (Alberta Native American/Mongloid)	250	-	16.0	Somogyi-Csizmazia and Simons 1971[75]
China	122	-	32.0	Gu et al. 2010[26]
China	232	-	29.7	Zhang et al. 2011[76]
China	1020	-	27.1	Yang et al. 2010[77]
China	558	-	25.8	Wang et al. 2010[12]
China	910	-	22.1	Zhang et al. 2015[33]
Costa Rica	250	-	2.4	Martins et al. 2022[64]
Egypt	218	-	0.5	Sharaan and Elrawd 2017[25]
Egyptian Africans	457	-	0.7	Younes et al. 1990[68]
England (Caucasians)	390	-	3.4	Curzon 1973[78]
France	250	-	3.2	Martins et al. 2022[64]
Georgia	247	-	6.9	Beshkenadze and Chipashvili 2015[79]
Germany	1024	-	0.7	Schäfer, Breuer and Janzen 2009[80]
Greece	478	-	3.3	Kantilieraki et al. 2019[36]
Guam	400	-	13.0	Hochstetter 1975[81]
Iceland	250	-	4.0	Martins et al. 2022[64]
India	1000	-	13.3	Chandra et al. 2011[62]
India	150	-	5.3	Chourasia et al. 2012[13]
India	1100	-	1.0	Bansal and Ajwani 2010[82]
India	299	0.7	5.0	Felsypremila et al. 2015[37]
India	1054	-	4.6	Garg et al. 2010[61]
Iran	250	1.2	-	Kuzekanani and Najafipour 2018[83]
Iran	386	-	3.1	Rahimi et al. 2017[84]
Israel	1229	0.6	2.0	Shemesh et al. 2015[85]
Italy	250	-	12.4	Martins et al. 2022[64]
Japan (Caucasians)	198	-	1.0	Onda et al. 1989[86]
Japan (Chinese)	426	-	11.7	Walker 1985[87]
Japan (Chinese)	100	-	15.0	Walker 1988[88but]
Japan	38	-	31.6	Peiris et al. 2008[42]
Jordan	330	-	3.9	Al-Qudah and Awawde 2009[10]
Korea	3088	-	24.5	Song et al. 2010[69]
Korea	1304	-	33.1	Song et al. 2009[89]
Korea	1952	0.1	25.8	Kim et al. 2013[43]
Korea	727	-	22.3	Park et al. 2013[44]
Kuwait	147	-	2.7	Zaatar et al. 1997[90]

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Kuwait	110	-	3.6	Pattanshetti et al. 2008[91]
Malaysia	370	-	21.4	Pan et al. 2019[92]
Mexico	250	-	9.2	Martins et al. 2022[64]
Netherlands	1713	-	1.0	Bolk 1915[15]
New Zealand	250	-	4.4	Martins et al. 2022[64]
Palestine	322	-	3.7	Mukhaimer and Azzizi 2014[46]
Peru	250	-	5.6	Martins et al. 2022[64]
Portugal	450	-	2.2	Martins et al. 2017[48]
Saudi Arabia	251	-	6.0	Al-Nazhan et al. 1999[93]
Senegal	480	-	3.1	Sperber and Moreau 1998[67]
Singapore (Chinese)	304	-	7.9	Loh 1990[94]
South Africa (Khoisan)	23	-	-	Drennan 1929[95]
South Africa (mixed)	369	-	1.0	Tredoux et al. 2021[8]
South Africa (mixed)	250	-	5.2	Martins et al. 2022[96]
Spain	121	-	4.1	Pérez-Heredia et al. 2017[50]
Sri Lanka	100	-	3.0	Peiris et al. 2008[97]
Sri Lanka	295	-	5.6	Peiris et al. 2008[42]
Sudan	100	-	3.0	Ahmed et al. 2007[98]
Syria	250	-	10.8	Martins et al. 2022[96]
Taiwan	521	-	22.1	Huang et al. 2010[53]
Taiwan	332	-	17.8	Tu et al. 2007[99]
Taiwan	337	-	21.7	Huang et al. 2007[100]
Taiwan	832	-	21.5	Yew and Chan 1993[101]an extradistal root. (c
Taiwan	246	-	25.6	Tu et al. 2009[102]
Taiwan	183	-	19.7	Chen et al. 2009[103]
Thailand	364	-	19.2	Reichart and Metah 1981[104]
Thailand	118	-	12.7	Gulabivala et al. 2002[54]
Turkey	966	-	0.5	Nur et al. 2014[56]
Turkey	823	-	2.1	Demirbuga et al. 2013[57]
USA (Hispanics)	156	-	6.4	Steelman 1986[105]
USA (Caucasians)	45	-	2.2	Skidmore and Bjorndal 1971[106]
United Kingdom	119	-	3.4	Taylor 1899[107]
United Kingdom	250	-	3.2	Martins et al. 2022[96]
Yemen	250	-	3.2	Senan et al. 2020[60]

2.6% was noted[27] in a Brazilian population, while the prevalence was approximately 32% in a Chinese study.[26] In another example of an East Asian group, using computer tomography scanning, Song et al. report a relatively high prevalence of 24.5% in a Korean population.[69]

Figure 2 depicts examples of three-rooted mandibular first molars (RE) viewed through micro-CT and Figure 3 illustrates two clinical cases of South African patients who presented with RE.
A summary of other findings in literature can be found in Table II. It is interesting to note that East Asian groups from China, Taiwan, Japan, Korea and Malaysia, as well as Inuit groups, presented with prevalence often greater than 20% and sometimes over 30%, while other populations from Europe and Africa often presented with prevalence below 10% or even below 5%. It was also noted that different populations within a country can present with variants in prevalence – for example, in China it ranged between 22.1% and 32% and in India between 1% and 13.3%.

DISCUSSION

The root morphology of the mandibular first molar is diverse and can differ greatly among populations. A number of factors can influence the incidence, including genetics and geographic distances.[108-110] The differences between individuals or populations are therefore important factors to consider in treatment. Any variations can create difficulties during the diagnostic phase and root or canal morphology that remains undiscovered greatly increases the risk of treatment failure.[2,111]

Authors have used a number of techniques to visualise the morphology of the root canal, such as radiographs,[112] scanning electron microscopy (SEM)67 and magnification.[113] Three-dimensional techniques, for example CBCT109 and micro-CT,[114] have revolutionised the study of root and canal morphology. Micro-CT has become the modality of choice for the investigation of complex root and canal morphology; it can display very fine detail that is easily missed when using other techniques.[114-116]

The typical mandibular first molar contains two roots[7] and the prevalence can range between 73.5% and 100%. The mandibular first molar can also be single-rooted, three-rooted and four-rooted (see Table I). It has also been determined that the global prevalence of two-rooted first molars is 90.2% and 8.9% for three-rooted ones.[22] An awareness of the number of roots is important for

https://doi.org/10.17159/sadj.v78i09.16861

diagnostic purposes and treatment planning. Any additional roots can create challenges for a treating clinician during endodontics and surgical difficulties once a tooth requires extraction.[2,7,96] An additional root, first described by Carabelli,[117] can be a separate morphology or partially fused with other roots.[61] As stated earlier, the additional root can be located DL (RE)[15] or mesio-buccal (RP). These roots are often small and can have a sharp apical hook.[14] They can be challenging to diagnose using traditional radiographs or two-dimensional diagnostic tools.[118]

Geographic distance between populations affects the prevalence of a third root; for example, it is greater in East Asian populations than in European and African groups. The prevalence can be as high as 33.1%, which was noted in a Korean population.[89] In most African populations only two roots were present (Tanzania, Uganda and Kenya) in individuals of African descent.[9,23,24]10% nitric acid, and 99% methyl salicylate. India ink was coronally injected into the pulp chamber and withdrawn apically by suction. The teeth were viewed under a magnifying lens and the numbers of root canals and their configurations, lateral canals, intercanal communications, and multiple apical foramina were recorded, along with the number of roots and their morphology. Student's t test for independent samples was used to assess significant differences in the root canal system. All specimens were tworooted with one mesial and one distal root. Root fusion was more frequent in the second than in the first molar: 3.2% versus 0.4%. Vertucci type IV canal configuration was most frequently recorded in the mesial root of the first (44.6% In a Senegalese population of African descent, a prevalence of 3.2% was noted for three-rooted first molars, which could be ascribed to a larger sample size than in the other African studies mentioned. Smaller sample sizes should be interpreted with care.[115] In South Africa, Tredoux and co-workers[8] found a prevalence of 1% for RE. In another mixed population group from South Africa, but in a different region (Durban, KwaZulu-Natal), a prevalence of 5.2% was noted.[96] In both these South African studies, CBCT was used. In two non-identical worldwide studies on the prevalence of RE in the same year (2022), different prevalences were reported (5.6% and 12.3%). As the prevalence is population-specific, reviews including different populations will report different prevalences. No studies could be found reporting on RE or RP in a South African population group using micro-CT.

In conclusion, the root morphology of the mandibular first molar can show variations between populations. Clinicians should be mindful of root variations or the presence of additional roots, as they can contain additional root canal systems and complicate root canal treatments. Studies focusing on African populations and specifically on South Africa are limited and no micro-CT studies were reported on in the literature researched.

Authors' declaration

The authors declare that there is no financial interest in this paper and that this paper has not been submitted elsewhere for publication. All authors agree with the content of the manuscript.

This manuscript did not receive any funding from funding agencies in the public, commercial or not-for-profit sectors.

Conflict of interest

The authors declare there is no conflict of interest.

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