CBCT study of root-canal morphology of mandibular first molars in a Spanish population

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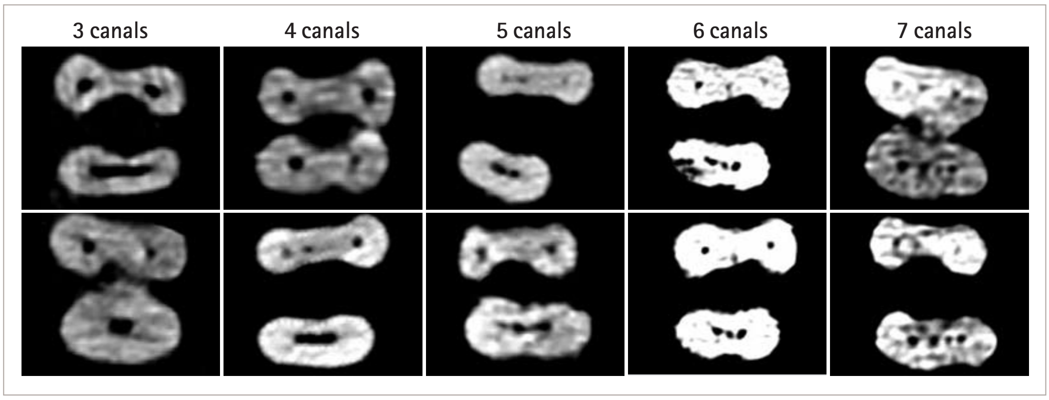
Fig. 1_Slices depending on the number of canals in the MFMs found using CBCT.



_**The objective of root-canal treatment** is the rigorous mechanical and chemical cleaning of the entire pulp cavity, its 3-D obturation with an inert material and the achievement of an appropriate hermetic coronal seal to prevent micro-organism intrusion.[1] Micro-organisms are the most important aetiological factor for pulp and peri-apical pathology. Pulp tissue not completely removed from the root-canal system is the main reason for failure of endodontic treatment in molars. The cause of failure is the infection of the remaining tissue, which is either already or subsequently infected by micro-organisms.[2] This problem seems to be aggravated by the presence of root canals unnoticed by the clinician, coinciding with anatomical variations or additional canals.[3] In fact, the lack of knowledge about root-canal anatomy has been identified as one of the most common reasons for endodontic failure.[4]

The mandibular first molar (MFM) is the most frequently endodontically treated tooth.[5,6] Furthermore, it is the tooth with the greatest rate of endodontic failure.[7,8] The relative simplicity and uniformity of the external surfaces of its roots quite often mask the internal complexity.[9] Generally, the MFM is described as having three canals, two in the mesial and another in the distal root.[10] Recent studies demonstrate the possible presence of three canals in any of the roots.[11–14]

Various methods have been employed to study the internal anatomy. The best-known and most frequently used method in the literature is achieving transparency of the roots. In recent years, 3-D imaging technology has been introduced and cone-beam computed tomography (CBCT) in particular is starting to prove very valuable in dento-maxillofacial imaging. CBCT is a useful tool in implant dentistry, for indentifying anatomic structures and for the evaluation of periodontal lesions,[15–18] as well as many other applications.

With regard to endodontics, Cotton *et al.* described a number of cases in which CBCT was the definitive diagnostic tool used.[19] In these cases, CBCT showed an MFM with an extra root that had not been diagnosed or treated initially. However, only a few studies have used this modern diagnostic technique to analyse canal configuration. Various researchers have used CBCT to evaluate maxillary molars.[20–23] CBCT has also been used to determine the number and the morphology of the roots of mandibular molars in patients.[24–27]

The following is the first *in vitro* study to use CBCT technology to determine the configuration and morphology of the canal system of the permanent MFM.

_Materials and method

In collaboration with various Spanish National Health Service centres, 53 permanent MFMs were collected. The age and gender of the patients were not known. Before extraction, the dentist confirmed that the teeth to be extracted were MFMs, relying on their position within the lower arch. Afterwards, this was corroborated through the coronal anatomical analysis of the samples. After extraction, all samples were cleaned and stored in 10% formaldehyde. All samples were submerged in 4% NaClO to dissolve any remaining organic tissue. Manual curettes and ultrasonic scalers were used to dissolve any calculus that remained on the root surfaces.

In order to locate and secure the samples within the bite holder of the CBCT device, they were embedded in Plasticine. The scanning was carried out by an expert radiologist, who had experience using CBCT. The device used for the purposes of this survey was the i-CAT (Imaging Sciences International) with a voxel size of 0.2 mm and a grey sale of 14 bits.

Owing to the characteristics of the CBCT, the position of the samples during scanning did not matter. The entire volume was registered, not only the volume that falls within a determined area as would be the case using conventional techniques. Therefore, we were able to study the results in any of the spatial planes. All the samples were positioned starting with the mesial root followed by the distal.

Once the 3-D images of every sample had been processed, the data was analysed with i-CAT Vision software (Imaging Sciences International), which offers various views of the data. We used the multiplanar reconstruction screen, as it allowed us to analyse the images in slices for the three different spatial axes. In addition, the screen showed a simultaneous interaction amongst the axes, allowing the operator to rotate the inclination of the sample in a way that allowed the observation of the curvature of each root through independent axial slices.

The canal configurations observed in the samples were grouped based on Vertucci's classification.[28] (Since 1984, different configurations to the ones described by Vertucci have been proposed.) Table I shows a schematic representation of the different types of canal systems that are present in the roots of the permanent MFMs as given in the literature.[29]

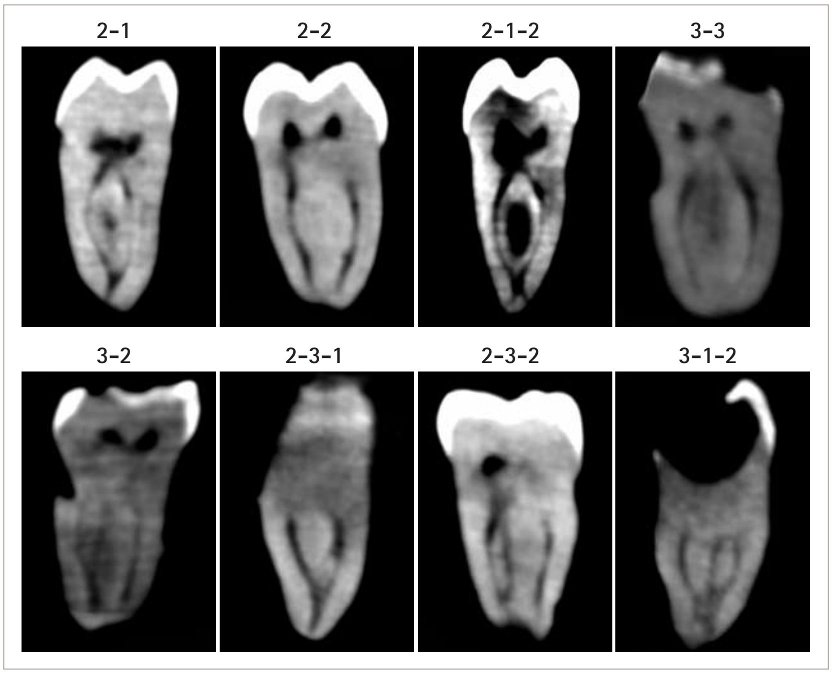


Fig. 2_Examples of different canal configurations found in the mesial root using CBCT.

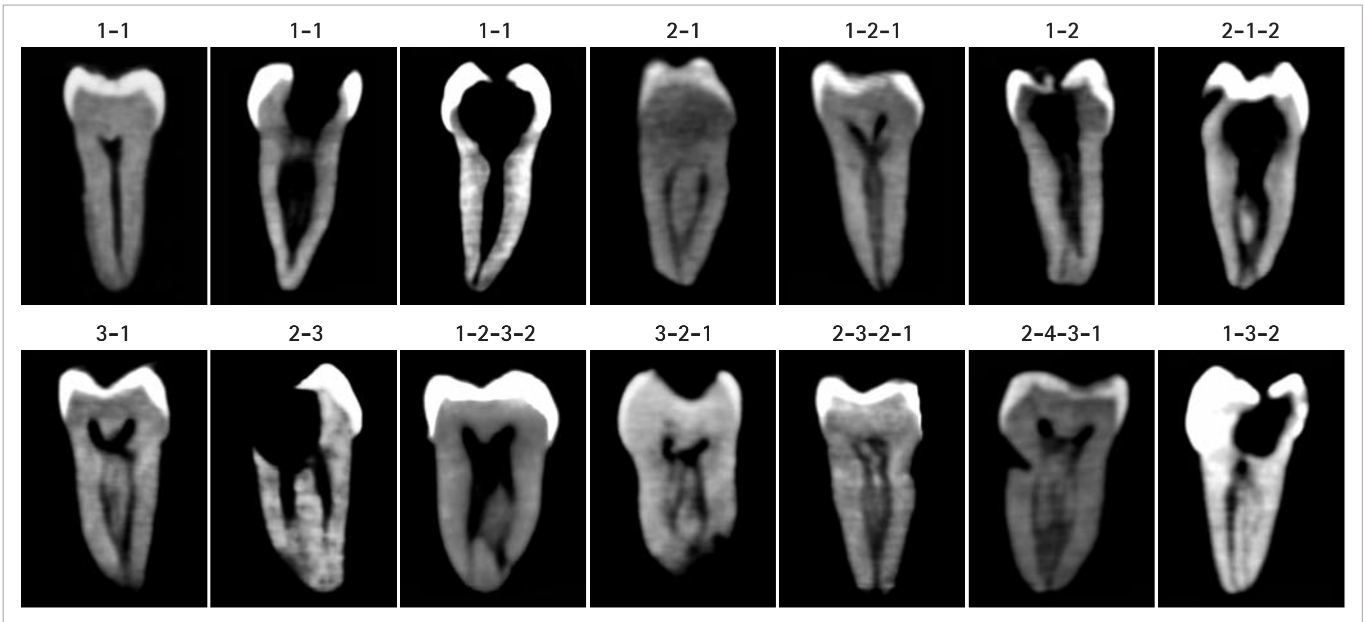


Fig. 3_Examples of different canal configurations found in the distal root using CBCT.

Vertucci 1984							
Type 1 1-1	Type 2 2-1	Type 3 1-2-1	Type 4 2-2	Type 5 1-2	Type 6 2-1-2	Type 7 1-2-1-2	Type 8 3-3

Kartal & Cimilli 1997		Gulavibala *et al.* 2001							Sert *et al.* 2004		Peiris *et al.* 2007		Al-Qudah & Awawdeh 2009			
Type 2a 2-1	Type 2b 2-1	Type 9 3-1	Type 10 2-1-2-1	Type 11 4-2	Type 12 3-2	Type 13 2-3	Type 14 4-4	Type 15 5-4	Type 16 1-3	Type 17 1-2-3-2	Type 18 1-2-3	Type 19 3-1-2	Type 20 2-3-1	Type 21 2-3-2	Type 22 3-2-1	Type 23 3-2-3

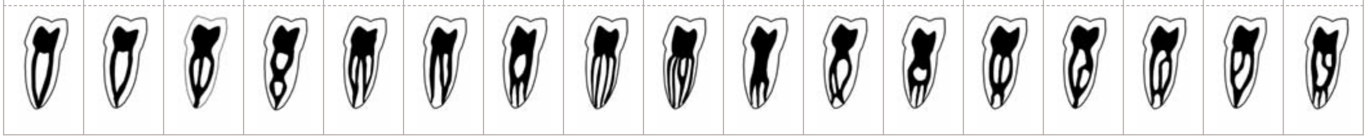


Table I_Configuration possibilities of mandibular MFM roots according to the literature.

_Results

The results of the total number of canals found, the canal configurations in the mesial root and the canal configurations in the distal roots are shown in Tables II, III and IV. Figure 1 shows examples of the slices from the molars, illustrating the number of canals. Figure 2 shows examples of the different configurations found in the mesial root, while Figure 3 shows examples for the distal root.

_Discussion

A literature review found that the number of canals in the MFM varies and that there are differences between the findings of *in vitro* and *in vivo* studies in this regard. We suggest that modifications of the access cavity and clinical effort to locate the canals may be a possible explanation for these differences.[29] The calcification of the coronal portion of the canal often does not permit adequate access to the root and canal morphology, but this does not mean that it has disappeared.

The calcification always follows a corono-apical direction. Therefore, the most complicated part for a clinician is to identify the entrance to the canal. However, once this has been achieved, instrumentation is usually simple. Thanks to CBCT, it is possible to observe axial slices of roots of any given height, allowing us to count the number of canals independently of the coronal access.

Initially, we know that both the mesial and the distal root have just one canal and the dentine apposition inside them develops a canal system.[30] On some occasions, we were able to find up to four different divisions at a given height. Clinically, it is extremely difficult not only to detect their existence, but also to access them with either manual or rotary instruments. In fact, when four canals were observed within a root, the divisions between them were so tiny that they disappeared after the instrumentation of the main canals, resulting in a simpler "prepared" anatomy. The above-mentioned facts may explain the lower number of canals found in the literature compared with the results obtained in our investigation.[29]

We obtained similar results to Forner Navarro *et al.* for the number of canals in the mesial root of the MFM using CT.[11] In two different *in vitro* studies, they found the frequency of three canals within the mesial root to be 14.8 % and 12 %. We obtained a rate of 17 % in our study, which made us question the validity of other methodologies. Further analysis of the 3-D technique is necessary. In our opinion, the main advantage of the technique is that it does not alter the structure of the samples in any way.

Table II_Number of canals in MFMs.

Number of canals	3	4	5	6	7
Number of molars	22	14	15	1	1
Incidence in %	41.5	29.4	28.3	1.9	1.9

A recent publication confirmed the afore-mentioned data.[31] In the study, 48 access cavities were prepared *in vitro* and modified in the mesial root of MFMs. The pulp chamber was explored with a microscope and ultrasonic tips. The operator observed the presence of a middle mesial canal in nine roots (18.7 %). This confirms that the proper elimination of calcification and coronal interferences allows access to a greater number of canals in the mesial root of the MFMs.

The literature shows that Types II and IV of Vertucci's classification of the canal system configuration are the most frequent in the mesial root.[29] In our study, 39.6 % of the mesial roots—compared with 35 % in the literature—showed two canals that were linked in the apical third, a close correlation. In our study, the Type IV configuration—two independent canals—was less frequent (39.6 %) compared with the literature (52.3 %). The presence of three independent canals was only seen in one case, but other complex configurations, such as 3-2, 2-3-1, 2-3-2 and 3-1-2, were found, raising the number of mesial roots with three canals to nine.

The configuration of the canal system of the distal root offered more variety. The frequency of a single canal (47.2 % in our data compared with 62.7 % in the literature) was lower, increasing the number of cases involving more complex configurations. This is probably due to a higher rate of calcification in the canals in our samples. Most of our samples were extracted owing to large decay lesions, defective and not repairable restorations or coronal fractures, with a considerable number showing clear signs of prolonged chronic bruxism. All these factors enhance the apposition of dentine on the inside of canals, creating subdivisions of the main canal. We found three configurations not yet described in the literature:

_1-3-2: Initially, we observed a single canal, which rapidly diverged into three. Towards the middle third of the root, two canals joined to finish with two different canals in the apical third.

_2-3-2-1: One of the roots showed two canals that later divided into three. Towards the middle third, two of them joined together and all of them finished in the same common foramen.

_2-4-3-1: In another distal root, we found the most complex of all configurations in either a distal or a mesial root. Two canals divided into four, fusing afterwards into three and finally joined together to finish at the same foramen.

	2-1	2-2	2-1-2	3-3	3-2	2-3-1	2-3-2	3-1-2
								
Number of mesial roots	22	21	2	1	3	3	1	1
Incidence in %	39.6	39.6	3.8	1.9	5.7	5.7	1.9	1.9

Table III_Mesial root-canal system configuration.

Another difference between our results compared with the literature regarding the distal root was the low frequency of the Type II configuration (5.7 % compared with 14.5 %), which is in contrast with our findings for configuration Type III. The explanation seems to be simple: the results of *in vitro* studies were consistently similar to our results, while the results of *in vivo* studies were not. The problem is that when a canal divides into two towards the middle third, the only way to fill it is by instrumenting the canal to enlarge the coronal portion, allowing direct access to each of the canals. The consequence is that clinically all Type III canals (1-2-1) become Type II canals (2-1) after root-canal treatment has been completed.

Given the amount of information provided without altering the samples, CBCT technology is a great aid for the *in vitro* evaluation of the root-canal anatomy of the permanent MFM. Michetti *et al.* compared CBCT slices with histological sections to determine the appearance of the second mesiobuccal canal in maxillary molars. They found no significant differences.[32] Neelakantan *et al.* compared CBCT to four different methods for the study of the morphology of the root-canal system. Their results of CBCT were similar to those obtained using a clearing technique, which is considered the gold standard for this kind of study.[33]

The radiation a patient has to endure depends directly on the volume to be scanned, which makes *in vivo* analysis using CBCT a clinical possibility.[19] In fact, the literature review has shown, that CBCT is a very valuable and useful tool in obtaining a satisfactory treatment outcome.[34,35]

_Conclusion

It has been shown that CBCT is a useful and valid tool for *in vitro* evaluation of the morphology of the root-canal system of the permanent MFM. The most frequent configurations for the mesial root were 2-1 and 2-2, but a high percentage of roots (17 %) had three canals. Half of the distal roots had only one canal, but the other half had diverse configurations, with 1-2-1 the most frequent configuration. The CBCT results obtained in this study also demonstrated more complex configurations, such as 1-3-2, 2-3-2-1 and 2-4-3-1, which have not been previously described in the literature._

Editorial note: A complete list of references is available from the publisher.

_contact roots

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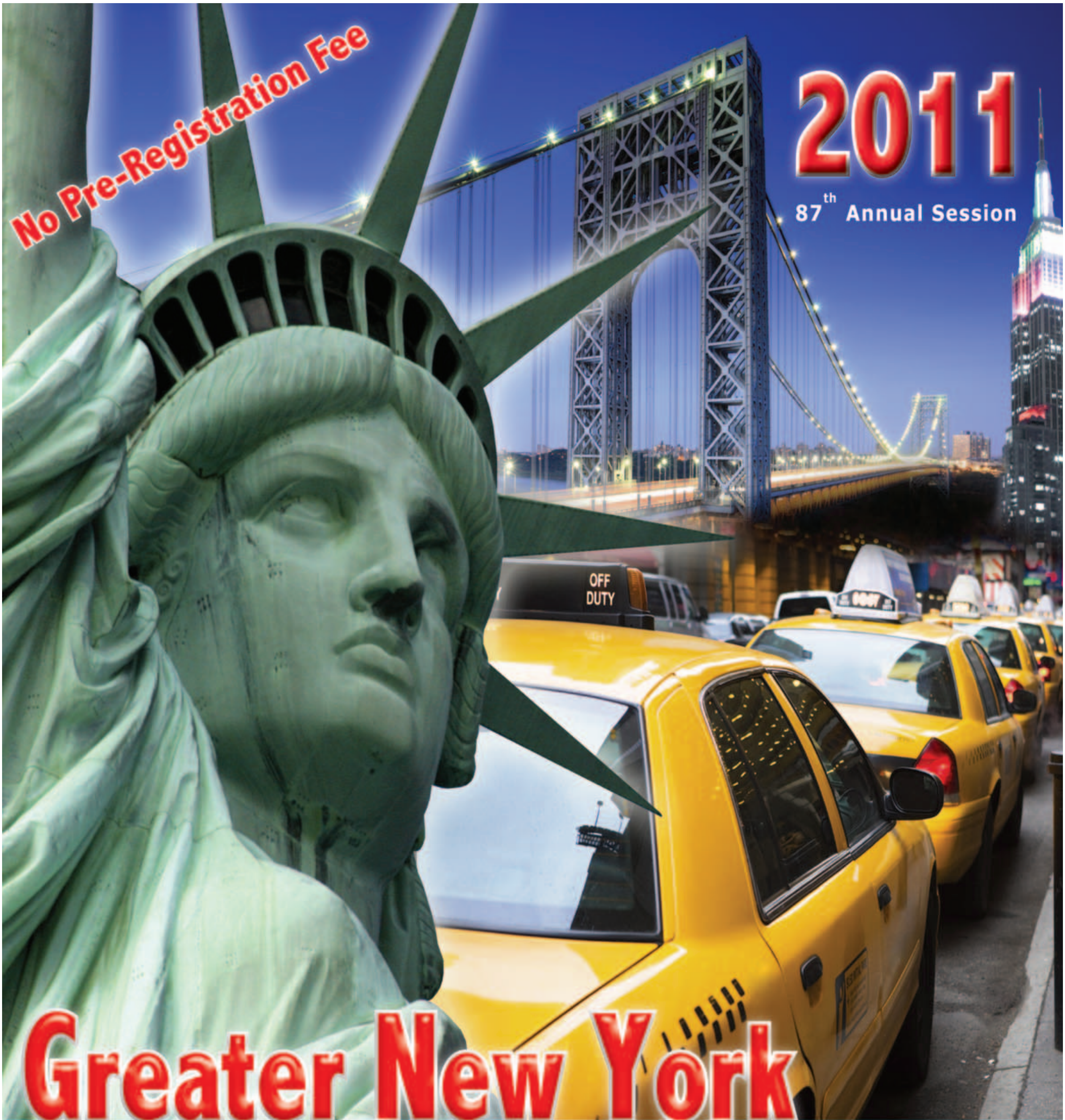
Table IV_Distal root-canal system configuration.

	1-1	2-1	1-2-1	1-2	2-1-2	3-1	2-3	1-2-3-2	3-2-1	2-3-2-1	1-3-2	2-4-3-1
												
Number of mesial roots	25	3	10	2	1	4	1	1	2	2	1	1
Incidence in %	47.2	5.7	18.9	3.8	1.9	7.5	1.9	1.9	3.8	3.8	1.9	1.9



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