

Advantages and Applications of a New System for Classifying Roots and Canal Systems in Research and Clinical Practice

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ABSTRACT

Objective: A new coding system for classifying the roots, main and accessory canals as well as developmental anomalies has been introduced recently. This paper discusses the advantages and potential application of the new system in research and clinical practice.

Methods: A comprehensive analysis was undertaken on the most common, existing classification for root canal morphology. The advantages and potential applications of a new system for classifying roots and canal systems in research and clinical practice are discussed.

Results: The analysis demonstrates deficiencies of the existing classification including lack of information on the number of roots, pulp chamber outline, lack of clarity in multi-rooted teeth, inability to define complex root canal configurations. The new coding system addresses the root and canal morphology in an accurate and systematic manner to provide detailed information of the tooth, root and canal anatomical features.

Conclusion: With current advances in endodontic research and practice and the increasing body of knowledge on root and canal morphology, the deficiencies of the existing system used for classifying root canal morphology have become more apparent. The new system for classifying root, main and accessory canal morphology as well as teeth with anomalies has the potential to be used in research, clinical practice and education to accurately reflect the real anatomy of a tooth.

Keywords: Anatomy, canal configuration, classification, morphology, root, root canal

HIGHLIGHTS

- With current advances in endodontics and increasing body of knowledge, the deficiencies of the existing system used for classifying root canal morphology have become more apparent.
- The new coding system provides detailed information on the tooth, root, main and accessory canal morphology as well as teeth with anomalies.
- The new coding system has the potential to be used in research, clinical practice and education.

INTRODUCTION

Effective root canal treatment requires thorough knowledge of root and canal morphology (1). Tooth anatomy is complex and several systems are available for classifying the variations that occur (2-4). The system proposed by Vertucci et al. (3) together with supplemental configuration types (5-8) has been the most commonly used classification.

With an increasing range of anatomical complexities being reported and the deficiencies of the existing systems becoming more apparent, new systems for classifying root, root canal and accessory

canal morphology have been proposed, which provide detailed information on tooth notation, number of roots, root canal configuration and accessory canal morphology including teeth with anomalies (9-11). The purpose of this paper is to discuss the advantages and potential applications of these new systems in research and clinical practice.

Shortcomings of the present system to categorise canal anatomy and advantages of the new system

Defining the number of roots

Maxillary premolars: Vertucci (12) categorized the root canal systems of human teeth into eight types (Figure 1). However, for maxillary premolars, whether the canals were within one,

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two or more roots was not defined (Table 1 - yellow highlight). Therefore, maxillary premolars with similar canal configuration types but involving different numbers of roots have in the past been classified under the same type (Figure 2) (12). This means that a one rooted maxillary premolar with two separate canals and a double-rooted premolar with one canal in each root are both classified as Vertucci type IV (Figure 2) (12). Similarly, this explains why, in most reports, single/double/three-rooted maxillary premolars with a total of three canals are referred to as Type VIII configurations (3, 12-14) (Figure 3). On the contrary, root canal configurations were defined separately in each of the mesiobuccal, distobuccal and palatal roots of maxillary molar teeth (12) (Table 1 - blue highlight). Clearly, in terms of endodontic management, it is critical to define the number of roots and not just

canals, as this will have clinical implications when interpreting radiographs, during access cavity preparation and when searching for the location of canal orifices (9, 15). Notably, three-rooted maxillary premolars can exist in two forms - two buccal roots and one palatal root, or one buccal root and two palatal roots (16, 17). In summary, it is unclear why buccal and palatal roots were not defined separately in maxillary premolars in the Vertucci classification, while mesiobuccal, distobuccal and palatal roots were considered separately in maxillary molars.

Mandibular premolars: As with maxillary premolars, mandibular premolars with similar canal configuration types but involving different numbers of roots were classified under the same type in the Vertucci classification (Table 2 - yellow high-

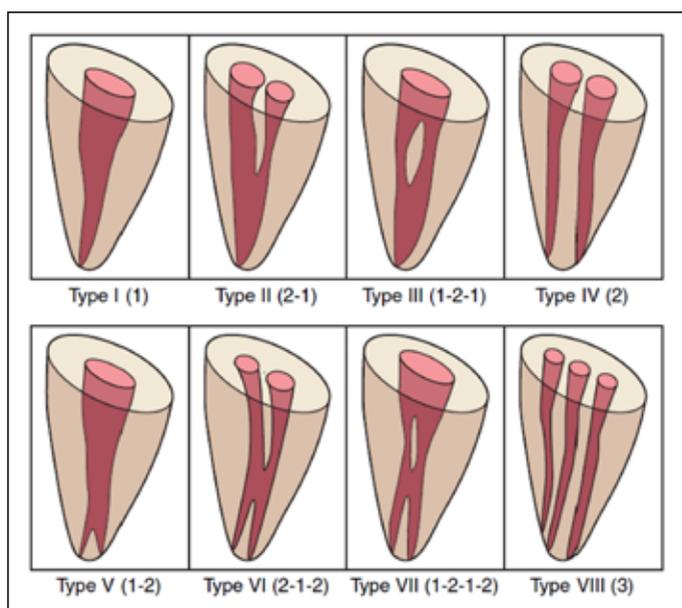


Figure 1. Diagrammatic representations of Vertucci's classification for root canal morphology. (reproduced from Cleghorn et al. (29) with permission from PMPH-USA).

TABLE 1. Application of the Vertucci classification on maxillary teeth

Teeth	Type I 1 canal	Type II 2-1 canal	Type III 1-2-1 canal	Type IV 2 canals	Type V 1-2 canal	Type VI 2-1-2 canal	Type VII 1-2-1-2 canal	Type VIII 3 canals
Maxillary central incisor								
Maxillary lateral incisor								
Maxillary canine								
Maxillary first premolar								
Maxillary second premolar								
Maxillary first molar								
Mesiobuccal								
Distobuccal								
Palatal								
Maxillary second molar								
Mesiobuccal								
Distobuccal								
Palatal								

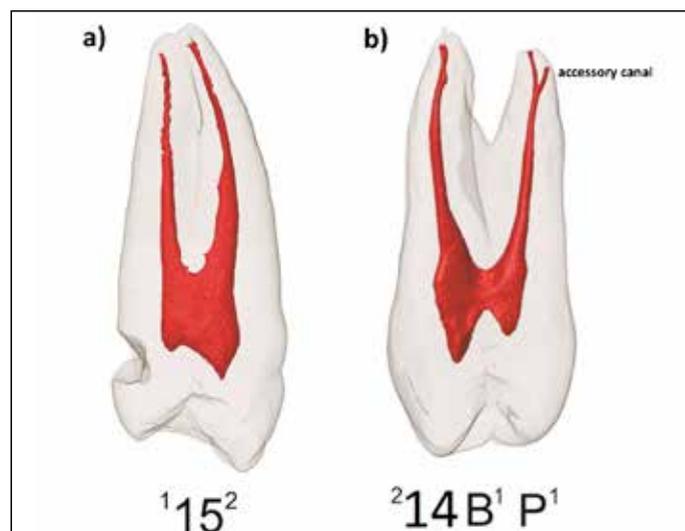


Figure 2. a, b) Both maxillary premolar teeth are classified as having a configuration type IV canal. The new system describes a) as a single rooted maxillary right second premolar having 2 separate canals with the code 15^2 , b) as a double rooted maxillary right first premolar having one canal in each of the buccal and palatal roots with the code $214B^1 P^1$ (modified from Ahmed et al. (9), reproduced with permission from Wiley).

TABLE 4. An example of a template for summarizing the root and canal morphology in right and left single, double and three-rooted maxillary first and second premolars. A similar approach can be used for other tooth types (O-C-F: Orifice-Canal-Foramen)

^R TN/O-C-F	1	1-2	2	2-1	3	B ¹ P ¹	MB ¹ DB ¹ P ¹	etc	Total (%)
¹ 14									100
² 14									100
³ 14									100
¹ 24									100
² 24									100
³ 24									100
¹ 15									100
² 15									100
³ 15									100
¹ 25									100
² 25									100
³ 25									100

TABLE 5. An example of a template for categorising canal configurations in a specific root in one type of tooth can also be categorized, e.g. the mesial roots (M) of mandibular right first molars.

Code	M ²	M ²⁻¹	M ³	M ³⁻¹	etc
Percentage					

any tooth, regardless of its complexity (Table 3-5). This has an important clinical impact since operators must treat all canals in all roots, and not only canals in certain roots, within a tooth. In addition, it could help to compare and contrast the complexity of a canal system in one root with other roots within the same tooth. As an example, it is more relevant to report that complex canal morphology in the distobuccal root of a maxillary first molar corresponds to complex canal morphology in the mesiobuccal root than reporting the complexity of both in a separate code as with the Vertucci classification.

Those reporting the results of research projects are able to present their data using the new system in several ways based on the unique study objectives. The root and canal morphology of a single tooth type or two or even more tooth types could be reported in a single table (Table 3). Alternatively, abbreviations (such as Max for Maxillary, Man for Mandibular) can be used if teeth from both right and left sides of the arch are pooled in a given study. If the pooled data shows a wide range of root numbers and root canal configuration types or teeth from right and left sides need to be included, then the data can be presented in more than one table (Table 4). The new system can also be applied if researchers would like to present the canal morphology of a single root of a given tooth type (Table 5).

Complexity of canal systems

Transverse canal anastomosis: Vertucci (12) presented the percentage and location of a transverse canal anastomosis (a

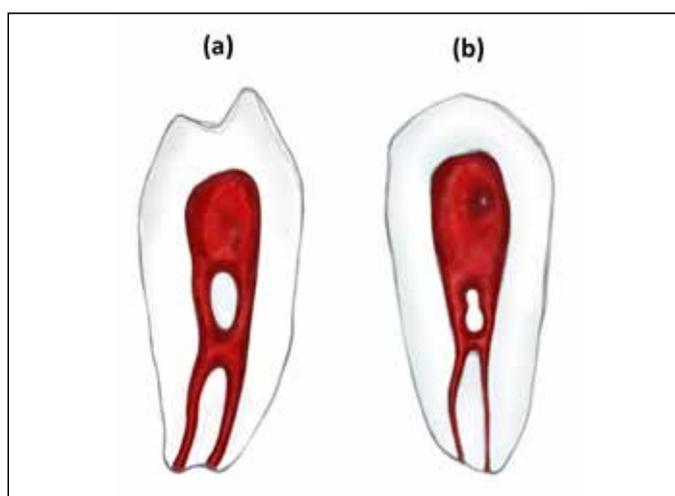


Figure 6. Drawings of samples presented in Vertucci (12). These mandibular first premolar samples were classified as Vertucci type IV. The criteria for defining transverse anastomosis were not clear, and this anatomical feature was not included in the canal classification system. The specimen can also be classified as Vertucci type.VI (2-1-2).

thin communication between two or more canals in the same root) between canals as a separate entity from root canal configurations; however, the criteria of defining such anatomy was not mentioned, and the landmarks for differentiating it from a common canal configuration were unclear (Figure 6).

The identification of a transverse canal anastomosis separately from the canal configuration is a concern since they are an integral part of the root canal configuration and because they have clinical implications during chemo-mechanical instrumentation, canal filling and root-end cavity preparation and filling (18-20). Therefore, the new system does not define a transverse canal anastomosis as a separate entity as it considers such anatomy as an integral part of the root canal configuration. However, if individuals would like to define transverse canals as a separate entity based on certain criteria, then the new system can still be used alongside.

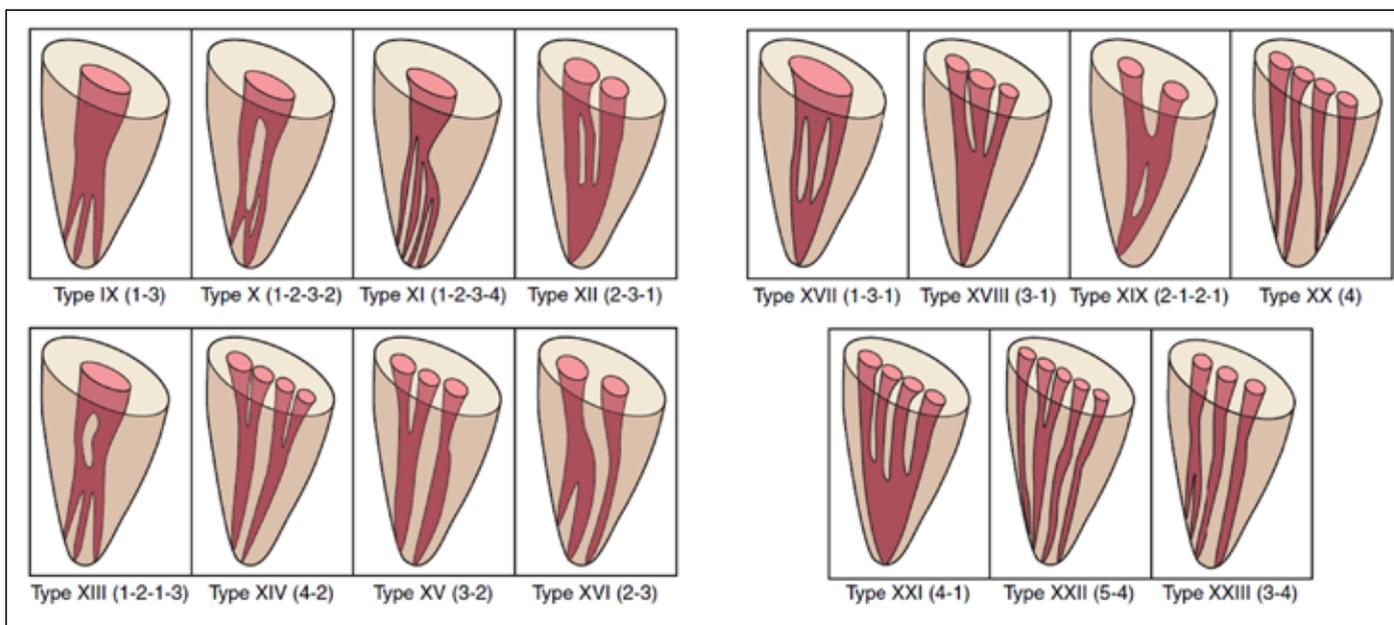


Figure 7. Illustrative diagram showing the supplemental configuration types to Vertucci's classification of root canal systems (Types IX-Type XXIII) as suggested by Sert & Bayirli (8). (reproduced from Cleghorn et al. (29) with permission from PMPH-USA).

Supplementary and non-classifiable configurations: Sert & Bayirli (8) added 14 supplementary configuration types to Vertucci's classification to categorize more complex root canals not included in the original system (Figure 7). However, categorizing root canal configuration by 'type' using simple Roman numerals becomes unworkable, inconvenient and potentially misleading. Recent reports using advanced 3D imaging technology have revealed that many canal configurations have been described as "non-classifiable" using the Vertucci system (21-24). One study reported that as many as 13% of specimens did not fit into the classification of Vertucci (25). In fact, up to 37 root canal configuration types have been identified (4).

The new coding system describes what the clinician or researcher can see in a simple yet accurate manner. It can also define previously "non-classifiable" canal configurations since only a simple code is required with no requirement to use several Latin numerals for the canals in each root of a multi-rooted tooth. Figure 8 provides examples of codes of Vertucci non-classifiable root canal configuration types.

It is worth noting that non-classifiable canal systems have also been reported within *in vivo* research studies on population groups using cone beam computed tomography (26). In addition, clinical reports have shown that the application of contemporary diagnostic modalities (including the dental operating microscope) demonstrate that some complex anatomical variations do not fit into the eight categories of the Vertucci classification, e.g. mandibular molars with various configurations in the mesial root, maxillary molars with similar anatomical variations in the mesiobuccal root, and mandibular premolars with complex canal morphology (27-29). This confirms the relevance and utility of the new system as it can help clinicians define and appreciate complex variations of the root canal system.

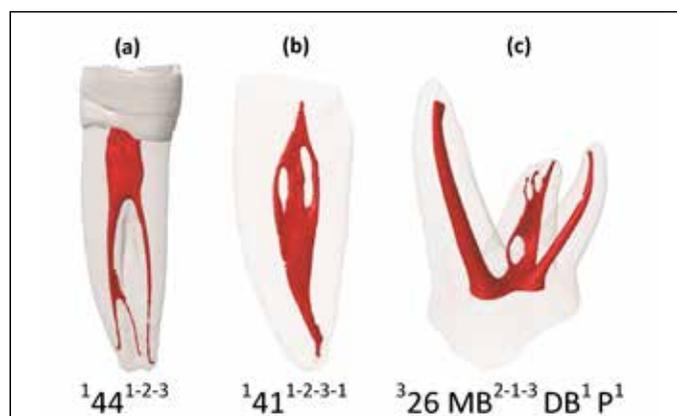


Figure 8. Examples for the application of the new coding system to present non-classifiable Vertucci root canal configuration types.

Accessory canal morphology and developmental anomalies

Vertucci (12) categorized lateral canals according to their location (coronal, middle, apical or furcation), but no information on the accessory canal configuration and type (patent, blind or loop) was provided. In addition, the percentages of lateral canals in maxillary premolars were reported without referring to the number of roots. Tooth, root and canal anomalies were not addressed in the various reports by Vertucci.

The new classification provides a coding system for accessory canals (Tables 6, 7), and developmental anomalies (Tables 8, 9). Notably, these coding systems are complementary and provide a single integrated system that adds more detailed information on the morphological features of teeth that are essential for proper diagnostic, training and research. The ability to combine codes for main root canals together with accessory canals (9, 10), and developmental anomalies has not been achieved in previous classifications (Figure 9) (11).

TABLE 6. An example of a template for summarizing the accessory canal morphology in single-rooted anterior teeth (central, lateral and canine)

^R TN	(C1)	(M1)	(A1)	(C1,M1)	(C1,A1)	(C1,M1)	(D)	etc	Total (%)
¹ Max1									100
¹ Max2									100
¹ Max3									100

C: coronal third; M: middle third; A: apical third

TABLE 7. An example of a template for summarizing the accessory canal morphology in double rooted maxillary (Max) first and second premolar teeth

^R TN	B ^(C1) P	B ^(M1) P	B ^(A1) P	B P ^(C1)	B P ^(M1)	B P ^(A1)	etc	Total (%)
² Max4								100
² Max5								100

C: coronal third; M: middle third; A: apical third

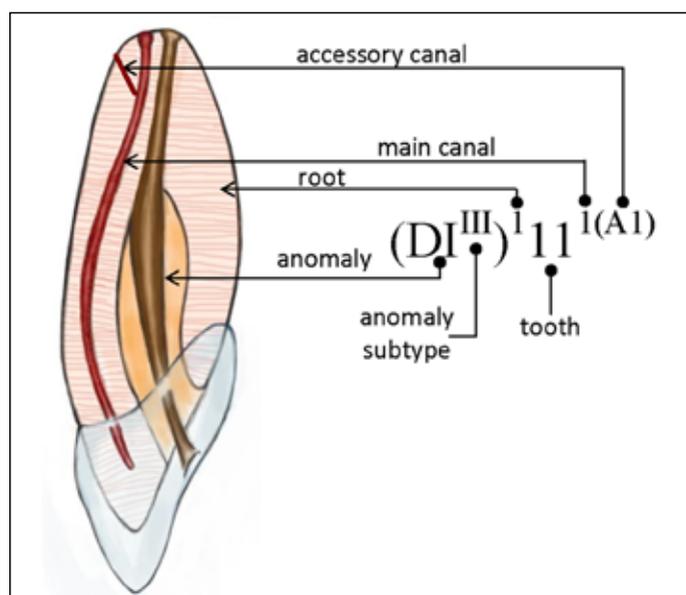


Figure 9. An illustrative drawing showing an integrated formula for the coding system for root, main canal, accessory canals and anomalies (modified from Ahmed et al. (11), reproduced with permission from Wiley). DI: Dens Invaginatus.

Application of the new system in daily clinical practice

The new system can be applied using any diagnostic tool applied in clinical practice (periapical radiography, dental operating microscope, CBCT) (Figures 10, 11). The operator simply needs to identify the tooth type, number of roots and root canal configuration, and the presence of accessory canals and anomalies (Figure 9). Usually the tooth number and number of roots can be identified during clinical examination and from preoperative radiographs. However, in some instances, root canal treatment is performed on a tooth that has migrated from its position in the arch following extraction of neighbouring teeth or it may have been restored and the shape of the crown not visible. Thus, on some occasions, the operator is not able to identify precisely the tooth type; in such cases, a suitable abbreviation can be used (such as MCI for mandibular central incisor, etc.) in place of the normal tooth code.

The number of roots, as well as some developmental anomalies, is usually identified on periapical radiographs (perhaps using different angulations). The root canal configuration is identified usually during the treatment procedure and more easily done following root filling when the post-operative radiograph highlights the anatomy more clearly than on pre- or intra-operative films. This means that the operator will only be able to define the full code after completion of treatment. However, information on tooth number, roots and anomalies (without root canal configurations) can be used in referrals between clinicians and/or students (an example: a referral of (DI^{III})¹11 describes a single-rooted maxillary right incisor (tooth 11) with a dens invaginatus (DI) type III). This kind of detailed, consistent documentation will be of benefit for case reports in which the reader can easily follow the anatomical landmarks of a given tooth in a systematic manner. When CBCT images are used pre-operatively, it may be possible to define the canal configuration from the outset.

Consistent categorisation

As a general rule, the introduction of new systems is challenging because clinicians and researchers will find difficulty when comparing their results with previous studies that used existing classification systems. However, it is worth noting that even when using the same system a precise comparison between results of different studies is not always possible because if similar root canal configurations (such as Vertucci type IV) have been identified with similar percentages in two studies, this does not mean that both have the same number of roots as discussed above. Moreover, the Vertucci classification does not provide a clear definition of the pulp chamber outline and the location of the root canal orifice, which could lead to different identification parameters among different studies.

The assessment of canal configuration in the apical region may vary depending on the method used for identification, which can be subjective amongst observers. For example, based on certain experimental measurements of canal dimensions or clinical negotiability, some apical bifurcations could either be classified as an apical delta/ramification or a division from the main canal

TABLE 8. An example of a template for summarizing a developmental anomaly (C-shaped canals)

^R TN	(CsC ^I)	(CsC ^{II})	(CsC ^{III})	Total (%)
² Man1				100
² Man2				100
² Man3				100

CsC: C-shaped Canal

TABLE 9. An example of a template for summarizing a developmental anomaly (Root Dilaceration) in double rooted mandibular molars

^R TN	M ^(RD) D	M D ^(RD)	^(RD) M D	Total (%)
² Man1				100
² Man2				100
² Man3				100

RD: Root Dilaceration; M: Mesial; D: Distal



Figure 10. Periapical radiographs showing various root, main and accessory canal morphology as well as developmental anomalies. a) ¹11¹ - a single rooted maxillary right central incisor having a root canal configuration type 1. b) ¹42¹⁻²⁻¹ - a single rooted mandibular right lateral incisor having a root canal configuration type 1-2-1. c) ¹44² - a single rooted mandibular right first premolar having a root canal configuration type 2. d) ¹25²⁻¹ - a single rooted maxillary left second premolar having a root canal configuration type 2-1. (reproduced from Ahmed (32) with permission from Medknow). e) ²15 B¹ P¹ - a double rooted maxillary right second premolar in which the buccal and palatal roots having a root canal configuration type 1. f) ²36 M^{2-1(A1)} D^{1(A1)} - a double rooted mandibular left first molar in which the mesial root has a root canal configuration type 2-1 and the distal root has a root canal configuration type 1. Each of the mesial and distal roots has an accessory canal in the apical third configuration type 1. (reproduced from Ahmed (32) with permission from Medknow). g) (RE)²36 M² D¹ DL¹ - a three rooted mandibular left first molar in which the mesial root has a canal configuration type 2, whilst each of the distal and distolingual roots (radix entomolaris) encase a root canal configuration type 1.

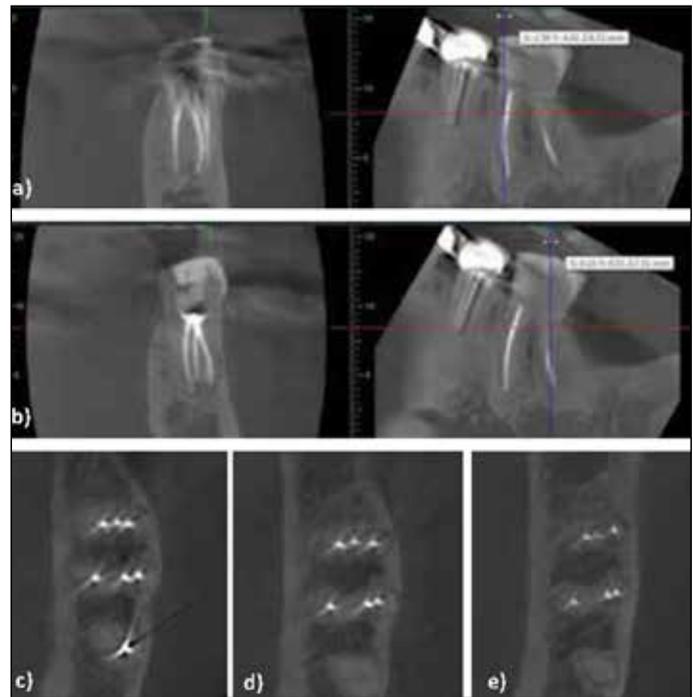


Figure 11. Postoperative CBCT image of a mandibular left first molar with 6 separate canals with the code - ²36M³D³. a) Postoperative CBCT scan (coronal and sagittal sections - mesial root) b) Postoperative CBCT scan (coronal and sagittal sections - distal root) c) Postoperative CBCT image [axial section - coronal] d) Postoperative CBCT image [axial section - middle] e) Postoperative CBCT image [axial section - apical] (reproduced from Hashem & Ahmed (33) with permission from Aves).

(type 1-2). Similar arguments do exist with regards to complex canal irregularities such as the canal isthmus, which has been classified by a number of researchers (30, 31). It is obvious that a standard consistent view of such anatomy cannot be achieved, and therefore, such anatomical landmarks should be classified based on the method and criteria used for identification (9).

The inclusion of this new system in teaching and education is another challenge. It is easier for students and trainees to present their cases using a system that defines the tooth number, root and configuration of the main and accessory canal morphology without referring to Latin numerals. Postgraduate students and specialists, who usually face more complex cases, will be able to address and correlate complex canal configuration types together with anomalies (if present) using integrated codes that accurately reflect the level of complexity of their cases, thus constructing an appropriate treatment plan and help define the risks associated with specific anatomical features.

Limitations

Despite the detailed information provided when using the new coding system, it does not provide information with regards to the shape (such as round and oval), size (narrow and wide) of the root canal system, degree of root and canal curvatures and several other sophisticated anatomical landmarks of accessory canal morphology [such as dimensions and tortuosity (34)] and developmental anomalies (such as depth/dimen-

sions of palato-gingival grooves, morphological cross sections of C-shaped canals). The inclusion of these parameters could be useful; however, they will add considerable complexity and the potential for misunderstanding. In addition, a new system must be simple so that it can be adopted universally. However, researchers and clinicians are still able to add more detailed information, if needed, using words or phrases to accompany the code to describe a particular detail related to the root or canal (such as ²14B¹P¹ with narrow buccal canal, etc.).

CONCLUSION

With current advances in endodontic research and practice and the increasing body of knowledge on root and canal morphology, the deficiencies of the existing systems used for classifying root canal morphology have become more apparent. The new system for classifying root, main and accessory canal morphology as well as teeth with anomalies has the potential to be used in research, clinical practice and education to accurately reflect the real anatomy of a tooth.

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