Application of a new System for Classifying Root and Canal Anatomy in Clinical Practice – Explanation and Elaboration

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ABSTRACT

Adequate understanding and accurate characterization of normal and unusual root and canal morphology are essential requirements for successful root canal treatment. A new coding system for classifying root and canal morphology, accessory canals and anomalies has been introduced. In addition to technological advances related to experimental studies involving micro-computed tomography, the continuing clinical advances in magnification, illumination, imaging and intra-operative root canal treatment procedures have allowed clinicians to identify an increasingly wide range of anatomical variations in roots and canals in an attempt to achieve more predictable clinical outcomes. This review aims to provide a step-by-step explanation for the clinical application of the new coding system in dental practice, and to describe the anatomical variations in roots and canals for teeth scheduled for root canal treatment.

Keywords: Accessory canals, anatomy, anomalies, canal configuration, clinical practice, endodontics, new coding system, root, root canal morphology

INTRODUCTION

Effective root canal treatment requires a thorough knowledge and understanding of root canal anatomy (1). For decades, this topic has been the subject of numerous reports involving extracted teeth evaluated by various experimental methods from simple staining and clearing to the more advanced cone beam computed tomography (CBCT) and micro-computed tomography (microCT) techniques (2-5). This is in addition to the clinical studies involving 2D radiographic imaging as well as case reports that often describe anatomical variations and their methods of detection using various imaging techniques, magnification, and other technical intra-operative procedures (5-8).

A new classification system has been introduced that allows precise and accurate descriptions of root and canal morphology. It overcomes the inherent deficiencies of previous classification systems that do not provide an accurate categorisation of many canal systems (Fig. 1), especially those that are complex. The new system is also able to classify accessory canals and anomalies (9-12). Such complex anatomical variations become more evident with enhanced magnification and imaging facilities together with contemporary intra-operative root canal instrumentation and filling techniques (13).

A recent review has provided a detailed description for the application of the new coding system when undertaking laboratory-based microCT studies and in vivo studies using CBCT with an emphasis on the basic concepts to be followed (14). Owing to the differences in methods of identification and interpretation of the root canals in research studies compared to clinical practice, and
The Vertucci classification did not consider the number of roots in maxillary premolar teeth. (a, b) Single and double rooted maxillary premolar teeth with 2 separate canals are classified as Vertucci type IV. (c, d) Double and three rooted maxillary premolars with 3 separate canals are classified as Vertucci type VIII (Fig. 1c, d: reproduced from Ahmed and Cheung (15) with permission from Quintessence publishing).

Figure 1. The Vertucci classification did not consider the number of roots in maxillary premolar teeth. (a, b) Single and double rooted maxillary premolar teeth with 2 separate canals are classified as Vertucci type IV. (c, d) Double and three rooted maxillary premolars with 3 separate canals are classified as Vertucci type VIII (Fig. 1c, d: reproduced from Ahmed and Cheung (15) with permission from Quintessence publishing).

B: Buccal, P: Palatal, MB: Mesio-buccal, DB: Disto-buccal, P: Palatal

Figure 2. Basic concepts for the application of the new system in case reports. Tooth number with a superscript on the left for the number of roots, and superscript on the right of the tooth number for the canal configuration, or on the right of the respective root if double/multi-rooted. B: Buccal, P: Palatal, MB: Mesio-buccal, DB: Disto-buccal, P: Palatal.

the importance of proper identification of root canals during different phases of root canal treatment procedures in addition to record keeping and legal concerns (16-18), this review aims to provide a detailed description for the use of the new coding system during the various phases of clinical management from pre-operative radiographic interpretation to root canal filling and follow-up.

Application of the new coding system in clinical practice

The basic concepts of the new coding system have been described previously (9-12), and a recent review has explained and elaborated the application of the new system in research studies involving microCT and CBCT (14). In general, the basic principles of the new coding system can be applied in a similar manner (such as the tooth number when using any of the numbering systems), number of roots and canal configuration) regardless of the diagnostic assessment method or setting (experimental or clinical) (Fig. 2); however, it is important to highlight that the application of the new classification system in clinical practice differs from its use in microCT and CBCT observational studies in several ways:

1) Before inclusion of teeth in microCT or CBCT studies, the collection of teeth should fulfill specific inclusion/exclusion criteria (such as teeth with complete root formation, teeth with no resorptive defects, no fractures, no root canal fillings, etc.). This is not followed in the majority of reports related to clinical practice where teeth scheduled for root canal treatment can have mature or immature roots, resorption defects or other pathological or iatrogenic changes in the root and/or canal evident on the peri-operative radiographic view(s).

2) Apart from primary root canal treatment, teeth may be scheduled for root canal retreatment or other treatment options such as tooth hemi-section, root amputation, and root-end surgery. All these treatment procedures may have an impact on how the clinician defines root canal morphology, and they should be considered before the application of the new coding system.

3) In contrast to microCT and CBCT observational studies, teeth scheduled for root canal treatment/retreatment procedures will pass through two main phases of canal anatomy interpretation:

a) Observation phase:

In this phase, the operator combines the information gained from the initial clinical examination (such as probing of the external root surface, detection of palato-gingival grooves, etc), and interpretation of the pre-operative 2D radiographic images with various projections (if needed) in addition to the axial, sagittal and coronal sections obtained from 3D CBCT imaging (if indicated).

b) Intervention phase:

In this phase, following access cavity preparation, the operator gains more information on root canal morphology through exploration using DG16 probes and other exploratory methods such as ultrasonic troughing, in addition to canal negotiation before moving on to canal instrumentation and root canal filling. At each step, the interpretation of the canal morphology is likely to evolve as described in detail in the following sections.

1) Pre-operative radiographic interpretation:

2D radiographic imaging:

Currently, 2D radiographic imaging is the tool used most often for pre-operative diagnostic procedures. It is well known that 2D imaging has inherent limitations since it provides a 2D image of a 3D object. However, pre-operative images with more than one horizontal projection can provide additional information on the bucco-lingual dimension of the tooth to help the clinician define the root and canal anatomy more precisely (13). At this early stage, the new coding system can be used as an initial interpretation for the number of roots in a given tooth and the complexity of the canal system, which may evolve with different horizontal projections (Fig. 3). This initial interpretation has a significant relevance in dental schools since undergraduate students usually start their clinical practice with root canal treatment in teeth with simple canal morphological features...
compared to postgraduate students and dentists. It is important for such cases to be evaluated carefully pre-operatively to align with the level of knowledge and experience of the operator. Figure 3 is an example of a single-rooted mandibular right second premolar with an initial code of 145; however, when changing the horizontal angulation, the code becomes 1451-2 in which the canal is bifurcated in the apical third of the root. This complexity is most likely not suitable for an undergraduate student because of difficulties related to canal instrumentation and filling. Three rooted mandibular molars (Radix Entomolaris – RE) with a code of (RE)MnM M D 1 is another example of an anatomical variation that may not be suitable for undergraduate students.

Table 1 shows examples for codes that may be suitable for undergraduate and postgraduate dental students. Indeed, such codes could vary based on the criteria and guidelines followed in a given country/dental school for preclinical and clinical endodontic teaching based on regulations from related dental associations and societies. It is also important to highlight that root canal anatomy is only one component used in the assessment of case difficulty (16, 17). Other factors such as patients with complex medical history, tooth position and inclination, canal curvatures, traumatic injuries, presence of endo-perio lesions, presence of radicular or coronal obstructions such as posts and/or crowns and accessibility, have to be evaluated alongside the root and canal anatomy to identify accurately the difficulty of a given case (16, 17).

The same concept can also be applied to general dental practitioners (GDPs)/dental officers, in which some cases may have complex root(s) and/or canal(s) and when it is often advisable to refer such cases to a specialist. Figure 4 is an example of a double-rooted mandibular left second premolar (tooth 45) with a complex root and canal morphology, initial code is 1451 L, in which the buccal root is suspected to have more than one canal because of the break-point appearance, which indicates the presence of canal splitting apical to the common

Table 1. An example for the application of the new coding system for defining case difficulty in teaching

| Maxillary Teeth suitable for practice using the new coding system | Maxillary Anterior | Maxillary Premolar | Maxillary Molars |
|---|---|---|---|
| Early year undergraduate students | MaxA | MaxP | MaxM |
| Final year undergraduate students | MaxA | MaxP | MaxM |
| Postgraduate dental students | MaxA | MaxP | MaxM |

| Mandibular Teeth suitable for practice using the new coding system | Mandibular Anterior | Mandibular Premolar | Mandibular Molars |
|---|---|---|---|
| Early year undergraduate students | MaxA | MaxP | MaxM |
| Final year undergraduate students | MaxA | MaxP | MaxM |
| Postgraduate dental students | MaxA | MaxP | MaxM |

| Anomalies suitable for practice using the new coding system | Accessory roots such as Radix Entomolaris: |
|---|---|
| None | 3ManM M D | 3ManM M |

MaxA: Maxillary Anterior, MaxP: Maxillary Premolar, MaxM: Maxillary Molars, ManA: Mandibular Anterior, ManP: Mandibular Premolar, ManM: Mandibular Molars
canal in the buccal and lingual roots. Figures 5 and 6 are examples of double-rooted mandibular molars with root dilacerations in one or both roots, which may require specialist treatment.

Clinical cases scheduled for root canal retreatment must also be evaluated carefully. Figure 7 shows a 2D preoperative radiographic image of a previously root canal treated single-rooted maxillary left central incisor (tooth 21) with an initial code of ‘211−2’ in which the tooth has a missed second canal bifurcating from the main canal in the apical third of the root (canal configuration 1-2). It is obvious that such a case is more suitable
Apart from its ability to classify root numbers and configuration, canal configurations, accessory canals and anomalies, the new coding system can also be used to identify the stage of root formation, which have clinical implications in treatment planning and management (Fig. 10). It can also classify pathological changes affecting the root and/or canal such as internal and external root resorption defects, perforation (either iatrogenic or pathological), canal obliteration and other variations (Fig. 10).

Cone beam computed tomography:
In some clinical situations, conventional 2D radiographic images provide limited information, and further details need to be identified (13). CBCT is an accurate and reliable diagnostic tool for the assessment of root and canal anatomy as well as a range of pathological changes in the root and canal such as resorption defects and cases scheduled for root canal retreatment procedures because of missed canals or iatrogenic errors (19).

The basic concepts and guidelines for using the new coding system in CBCT clinical studies have been described recently (14), which can also be applied for case reports. In order to provide a consistent interpretation of the root canal configuration, the observer will have to determine the most apical
position of the CEJ (cervical line) and level of the pulp floor in single and multi-rooted teeth, respectively, in order to determine the location of the canal orifice before writing the code of the tooth of interest (Figs. 11 and 12).

In cases scheduled for root canal retreatment, the new coding system can be written in a way that highlights any missed roots and canals in the tooth scheduled for retreatment if present (Fig. 13), in addition to other iatrogenic procedural errors such as root perforations (Fig. 14). Accessory canals are not usually observed in CBCT studies; however, some accessory canals can be large enough to be identified on CBCT images (14), especially when the 2D radiographic image has a lateral radiolucency indicating the possibility of its presence; this may become evident after root canal filling.

2) Intra-operative radiographic interpretation:
After access cavity preparation, the operator goes through various steps including exploration of the pulp chamber floor, orifice(s) detection, troughing (if needed), canal negotiation and exploration. Second mesio-buccal (MB) canals in maxillary molars and middle mesial (MM) canals in mandibular molars are examples of canals that are usually not identified in the pre-operative 2D radiographic images, and therefore, the initial codes given in the pre-operative phase will evolve during the intra-operative stage (Fig. 15). Indeed, this variation between pre- and intra-operative interpretation is reduced when a CBCT image is available (if indicated).

After detection of canals and defining their configurations, the operator commences canal instrumentation using various manual and/or automated systems. Based on certain anatomical features and technical factors (such as presence of thin dentine septum between canals and use of greater taper files), the configuration of the prepared canals could vary from the initial interpretation made during the early exploratory intra-operative stage. For instance, after instrumentation, one canal may merge with the other canal as shown in Figure 16. Such changes in root canal configurations may also become evident in root canal retreatment procedures. On some occasions, under assisted magnification and following the use of root canal fillings using warm compaction techniques, the operator may detect intra-canal communications, which can be detected postoperatively by the movement of filling material between canals.

During root canal treatment, the operator may create procedural errors such as a ledge, zip or apical, mid-root, coronal or strip perforations. Such iatrogenic factors can be highlighted in the codes as explained above. Other treatment options such as root amputation, tooth hemisection and root-end surgery can also change the code of a given tooth – as explained below.

3) Post-operative radiographic interpretation
Post-operative radiographic images usually provide the definitive code of a given tooth. Figure 17 shows examples of teeth with codes during both the pre-operative assessment phase and post-operative phase.

As mentioned in the intra-operative stage, a change in the root canal configuration may become evident after retreatment procedures. Figure 18 shows a CBCT image of double-rooted tooth 46 in which the mesial root has 2 separate canals and the distal root has one canal (code 246 M^2 D^1). After canal preparation and filling of the perforating resorption defect, the two mesial canals merged in the apical third, and the code becomes 246 M^3 D^1.

Figure 10. Applications of the new coding system to address other morphological and pathological changes in the root and canal position of the CEJ (cervical line) and level of the pulp floor in single and multi-rooted teeth, respectively, in order to determine the location of the canal orifice before writing the code of the tooth of interest (Figs. 11 and 12).

Figure 11. Application of the new coding system in CBCT reports (root and canal morphology). Code 13 refers to a single rooted tooth 13 having one root canal. Code 24 B^1-2-1 P^1 refers to a double rooted tooth 24 in which the buccal (B) root has canal configuration 1-2-1 and the palatal root (P) has one root canal.
In some clinical situations, the outcome of treatment results in tooth hemisection or amputation of a root. The new system can address this change in the root and canal anatomy before and after treatment as shown in Figure 19. A “strikethrough” can be given to the code of the resected root.

In some cases, the operator may identify “hidden” anatomy that was not detected in the pre- and/or intra-operative phase. Interpretation of the post-operative radiographic images is the common stage where accessory canals are identified after canal filling; however, the operator (up to that time) may not be able to define whether an accessory canal is patent or blind. Figure 20 shows cases with accessory canals identified after canal filling. Filling of inter-canal communications is another example of hidden anatomy that may not be identified at the intra-operative stage.

**Application of the new system in the primary dentition**

The new coding system can also be used to describe canal morphology in the primary dentition as explained in a pre-
In the intra-operative, the root canal configuration is dynamic in nature – which may show changes along instrumentation. In this case, the initial intra-operative stage shows that the mesiobuccal (MB) root of the three rooted tooth 16 has 4 MB canals with a configuration 4-3-2 (tooth code 316 MB4-3-2 DB1 P1). However, after instrumentation, the MB3 and MB4 merged, and the code changed to 3-2 (tooth code 316 MB3-2 DB1 P1).

Figure 14. Application of the new system for describing teeth scheduled for root canal retreatment before and after CBCT imaging. RP – Root perforation. (a) In the 2D radiographic image, the tooth is coded as 111. However, after CBCT scan (b), a root perforation was detected. Therefore, the code becomes (RP)111.

Figure 15. Application of the new coding system in the intra-operative stage. The code may change during intra-operative procedures. Based on the pre-operative radiographic image, this molar tooth was coded as 236 M2 D1. During intra-operative exploration, a middle mesial canal was identified, and the code changed after root canal treatment to code 236 M3 D2-1 (Reproduced from Ahmed and Luddin (20) with permission from Quintessence publishing).

Figure 16. In the intra-operative, the root canal configuration is dynamic in nature – which may show changes along instrumentation. In this case, the initial intra-operative stage shows that the mesiobuccal (MB) root of the three rooted tooth 16 has 4 MB canals with a configuration 4-3-2 (tooth code 316 MB4-3-2 DB1 P1). However, after instrumentation, the MB3 and MB4 merged, and the code changed to 3-2 (tooth code 316 MB3-2 DB1 P1).
ration at different phases of root canal treatment. This systematic characterization of the root canal system has a significant impact on canal anatomy difficulty assessment and teaching.

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