

REVIEW

A new system for classifying root and root canal morphology

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Abstract

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Knowledge of root and root canal morphology is a prerequisite for effective nonsurgical and surgical endodontic treatments. The external and internal morphological features of roots are variable and complex, and several classifications have been proposed to define the various types of canal configurations that occur commonly. More recently, improvements in nondestructive digital image systems, such as cone-beam and micro-computed tomography, as well as the

use of magnification in clinical practice, have increased the number of reports on complex root canal anatomy. Importantly, using these newer techniques, it has become apparent that it is not possible to classify many root canal configurations using the existing systems. The purpose of this article is to introduce a new classification system that can be adapted to categorize root and root canal configurations in an accurate, simple and reliable manner that can be used in research, clinical practice and training.

Keywords: anatomy, canal configuration, classification, morphology, root, root canal.

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Introduction

Effective root canal treatment and endodontic surgery require a thorough knowledge of tooth anatomy and root canal morphology so that microorganisms and pulp tissue can be accessed and removed and root-ends managed properly (Cleghorn *et al.* 2008). In the human dentition, a wide range of anatomical variations in each tooth type has been reported in terms of the number and shape of roots and root canals (Vertucci 2005, Ahmed & Abbott 2012, Versiani *et al.* 2012, 2016, Ahmed 2013, Ahmed & Hashem

2016). For many decades, this topic has been the subject of numerous experimental and clinical reports, and it is clear that root and canal morphology vary greatly between populations, within populations and even within the same individual (Vertucci 2005, Ahmed & Cheung 2012, Ahmed 2015, Versiani *et al.* 2016).

Data generated from the classical work of Hess & Zurcher (1925) to the more recent studies demonstrate that the ever-expanding knowledge on this subject required the creation of a classification system for defining root canal configuration. Using sectioning and radiographic methods, Weine *et al.* (1969) were the first to categorize root canal configurations within a single root into three types depending on the pattern of division of the main root canal along its course from the pulp chamber to the root apex (Fig. 1). Later, Vertucci *et al.* (1974) developed a classification system based on the evaluation of 200

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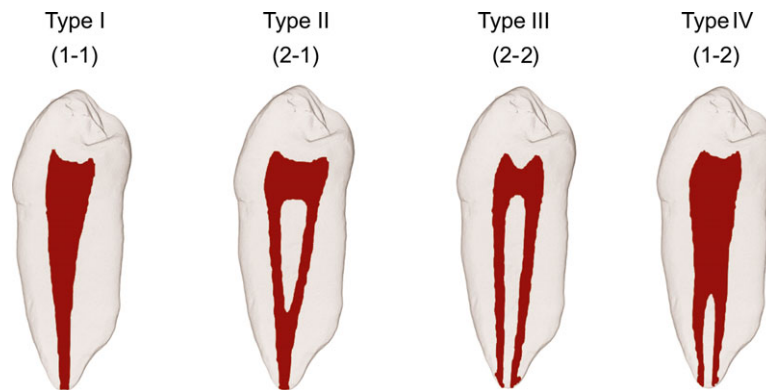


Figure 1 Diagrammatic representations of Weine's classification for root canal morphology (Weine *et al.* 1969; Weine 1982). Type I: a single canal from pulp chamber to the apex (1-1 configuration); type II: two separate canals leaving the chamber, but merging short of the canal terminus to form a single canal (2-1 configuration); type III: two distinct canals from pulp chamber to the canal terminus (2-2 configuration); type IV: a single canal leaving the chamber and dividing into two separate canals at the canal terminus (1-2 configuration).

cleared maxillary second premolars in which the pulp cavities were stained with dye; they found canal systems that were more complex than described by Weine and co-workers and identified a total of eight configurations (Fig. 2). Later, Weine (1982) added an additional type to his original system (Fig. 1).

Other classifications have also been introduced for specific tooth types, for example maxillary molars with four roots (Christie *et al.* 1991, Carlsen & Alexandersen 2000, Baratto-Filho *et al.* 2002, Versiani *et al.* 2012), maxillary premolars with three canals (Belizzi & Hartwell 1981, Ahmed & Cheung 2012), the middle mesial canal (Pomeranz *et al.* 1981) and distolingual root in mandibular molars (Song *et al.* 2010). More recently, Kottoor *et al.* (2012) and Albuquerque *et al.* (2012) suggested a new nomenclature to classify root canal anatomy in maxillary and mandibular molars, respectively.

Despite these efforts to systematically describe the diversity of canal configurations, additional types of root canal morphology have been reported by several authors within different populations (Gulabivala *et al.* 2001, 2002, Ng *et al.* 2001, Sert & Bayirli 2004, Versiani *et al.* 2016). Based on a review of previous reports on root canal morphology and results from recent anatomical studies using micro-CT technology, Versiani & Ordinola-Zapata (2015) described up to 37 root canal configuration types, which probably include the most common anatomical configurations that can be observed in a single root.

Notwithstanding these efforts, the creation of a simple classification system, able to be applied in all types

of root and root canal configuration in all groups of teeth, has not been achieved.

Justification for a new classification system

The systems proposed by Weine *et al.* (1969), Vertucci *et al.* (1974) and Weine (1982) have been the most commonly used classifications and have been beneficial when categorizing many, but not all, canal configurations. Recent reports on the identification of external and internal anatomical canal variations using advanced 3D imaging technology have revealed that the morphological characteristics of the root canal system are highly complex, and many canal configurations have been described as 'nonclassifiable' (Verma & Love 2011, Kim *et al.* 2013, Lee *et al.* 2014, Leoni *et al.* 2014). In fact, in one study, as many as 13% of specimens did not fit into the classification of Vertucci and co-workers (Filpo-Perez *et al.* 2015).

The literature also reveals inconsistencies regarding the classification of the internal anatomy of several tooth types, for example, maxillary premolar teeth with three canals, Vertucci *et al.* (1974) categorized this variation as type VIII and defined it as three separate, distinct root canals extending from the pulp chamber to the apex; however, no information is provided in the classification to describe whether these canals are encased in single-, double- or three-rooted teeth (Fig. 3). Therefore, in most of the studies, three-canal single-/double-/three-rooted maxillary premolars continued to be referred to as type VIII

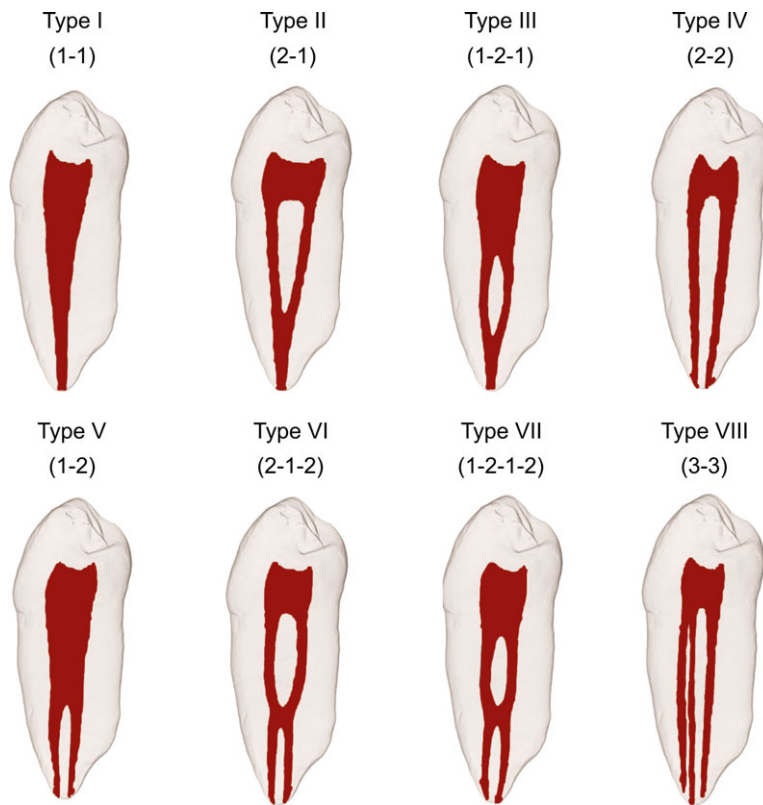


Figure 2 Diagrammatic representations of Vertucci's classification for root canal morphology (Vertucci *et al.* 1974). Type I: a single canal from pulp chamber to the canal terminus (1-1 configuration); type II: two separate canals leaving the chamber, but merging short of the canal terminus to form a single canal (2-1 configuration); type III: a single canal that divides into two and subsequently merges to exit as one (1-2-1 configuration); type IV: two distinct canals from pulp chamber to the canal terminus (2-2 configuration); type V: a single canal leaving the chamber and dividing into two separate canals at the canal terminus (1-2 configuration); type VI: two separate canals leaving the pulp chamber, merging in the body of the root, and dividing again into two distinct canals short of the canal terminus (2-1-2 configuration); type VII: a single canal that divides, merges and exits into two distinct canals short of the canal terminus (1-2-1-2 configuration); type VIII: three distinct canals from pulp chamber to the canal terminus (3-3 configuration).

configuration (Vertucci *et al.* 1974, Vertucci 1984, Velmurugan *et al.* 2005, Peiris 2008). Clearly, in terms of clinical management of teeth undergoing root canal treatment, it is critical to define the number of roots, and not just canals, as this will have implications in terms of access cavity preparation, mechanical instrumentation and root canal filling procedures (Ahmed & Cheung 2012).

Recently, Briseño-Marroquin *et al.* (2015) introduced a four-digit classification of root canal configurations, in which each root is divided into thirds (each third has a digit), with the fourth digit indicating the number of main foramina defined as the foramina that emerge from the same canal at the apical terminus and in which the measured diameter is no less than 0.2 mm. However, in this classification,

there is no information on the configuration of the root component, and there are concerns on the practicality of using these criteria in the clinical situation, that is dividing the root into thirds, and defining the main apical foramina on the basis of their diameter.

New classification system for root and root canal morphology

Categorizing root canal configuration by 'type' using simple Roman numerals has been popular for more than 50 years. However, in recent years, a considerable volume of data has been generated on the morphological variations in root canals (Versiani & Ordinola-Zapata 2015), which has resulted in the systems used today for categorizing canal configurations



Figure 3 External and internal views of three maxillary first premolars classified as Vertucci's type VIII root canal configuration, according to the literature. Top: premolar with three root canals in fused roots; middle: premolar with two root canals in a fused buccal roots and a single canal in the palatal root; bottom: three-rooted premolar with three root canals.

into certain types based on a single number being insufficient and, indeed, inaccurate and misleading. The time has now come to develop a coding system that can be used to describe root and canal configurations that will aid clinicians, researchers and be of benefit to educators and students/trainees.

The new classification system suggested in this article aims to be simple, accurate and useful as it provides information on root and root canal anatomy. It does not address the degree of root and root canal curvature, degree of root/canal separation, the exact level of bifurcation of canals/roots, type of root fusion, accessory canals (lateral and furcation canals) nor apical

deltas. Inclusion of these parameters was considered during the development of the proposed classification, but it became obvious that they added considerable complexity and the potential to lead to misunderstanding. Such additional information could be useful and in some ways provide a more accurate classification; however, the benefits of any new system must be simplicity so that it can be adopted universally.

The literature reveals many comprehensive classifications categorizing developmental anomalies related to the root or root canal such as dens invaginatus (Oehlers 1957), C-shaped canals (Melton *et al.* 1991, Fan *et al.* 2004, Kato *et al.* 2014), taurodontism (Shaw 1928,

Jafarzadeh *et al.* 2008), supernumerary roots (Christie *et al.* 1991, Carlsen & Alexandersen 2000, Song *et al.* 2010), root fusions (Zhang *et al.* 2014) and others. For simplicity, the present classification will not reclassify abnormalities already addressed in the literature.

Aim

To create a simple, accurate and practical system that allows students/trainees, clinicians and researchers to classify root and root canal configurations identified using any diagnostic method regardless of their accuracy and reliability.

Objectives

- To describe the number of roots in all tooth types;
- To describe all known and yet-undiscovered root canal configurations.

Terminology

Root canal system

It is the space within the tooth that contains pulp tissue. The root canal system is divided into two portions: the pulp chamber, which is located in the anatomic crown of the tooth, and the root canal(s), encased in the root(s).

Root canal orifice

It is the opening of the canal system at the base of the chamber where the root canal begins. Generally, it is located at or just apical to the cervical line.

Root canal configuration

It is the course of the root canal system that begins at the orifice and ends at the canal terminus (minor apical diameter).

Major apical foramen

It is the exit of the root canal onto the external root surface, which is normally located within 3 mm of the root apex.

Minor apical foramen/apical constriction

It is the apical part of the root canal with the narrowest diameter which is generally 0.5–1.5 mm from the

major apical foramen (Vertucci 2005). It is the reference point often used as the apical termination of canal instrumentation and filling procedures.

Classification

The new classification can be adapted for root and root canal configurations. It includes codes for three separate components: the tooth number, the number of roots, and the root canal configuration.

Tooth number

The tooth number (TN) can be written using any numbering system (e.g. universal numbering system, Palmer Notation Numbering System or the FDI World Dental Federation System). If the tooth cannot be identified using one of the numbering systems (i.e. extracted teeth), then a suitable abbreviation can be used, for example maxillary (upper) central incisor (UCI).

Number of roots and their configuration

The number of roots (R) is added as a superscript before the tooth number (^RTN). For instance, ¹TN means that tooth 'TN' has one root. Any division of a root whether in the coronal, middle or apical third will be coded as two or more roots. Accordingly, a bifurcation is represented as ²TN, and trifurcation is represented as ³TN and so on. Details of roots in double- and multirooted teeth are added to the right of the tooth number (^RTN Rn) (Table 1, Appendix S1).

Root canal configuration

The type of root canal configuration in each root will be identified as a superscript number(s) after the tooth number and will define the continuous course of the root canal system starting from the orifice(s) (O), through the canal (C) to the foramen (foramina) (F) (Table 1, Appendix S1).

Inevitably, the assessment of apical canal configurations may vary depending on the method used for identification – experimental or clinical, which can be rather subjective amongst different 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 (i.e. complex ramification of branches of the root canal located near, and open on, the root apex) or a division from the main canal (type 1-2). It is obvious that a

Table 1 A summary of the codes allocated for single-, double- and multirooted teeth

Tooth type	Code
Single-rooted	${}^1\text{TN}^{\text{O-C-F}}$
Double-rooted	${}^2\text{TN R1}^{\text{O-C-F}} \text{R2}^{\text{O-C-F}}$
Multirooted	${}^n\text{TN R1}^{\text{O-C-F}} \text{R2}^{\text{O-C-F}} \text{Rn}^{\text{O-C-F}}$

TN, Tooth number; R, Root; O, Orifice; C, Canal; F, Foramen.

standard consistent view of such anatomy cannot be achieved, and therefore, the apical canal configuration type should be classified based on the method and criteria used for identification.

Single-rooted teeth

For any canal, if the numbers of O, C and F are the same, then a single code (${}^1\text{TN}^n$) is used (Fig. 4). Thus, ${}^111^1$ describes a single-rooted maxillary right central incisor having one orifice, one canal and one foramen (Fig. 4a), whilst ${}^115^2$ describes a single-rooted maxillary right second premolar having two orifices, two independent canals and two foramina (Fig. 4b).

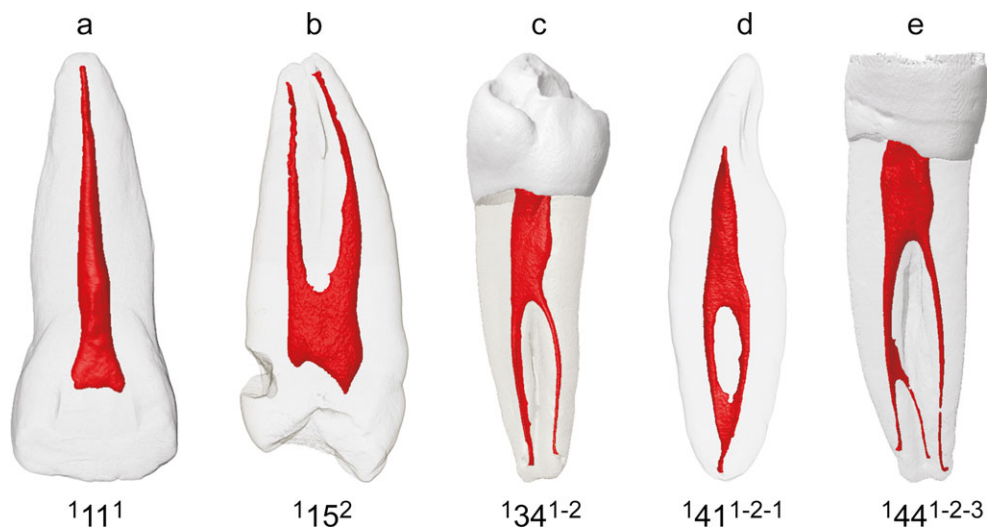
If the root has a varying number of O, C and/or F, then the configuration of the canal will be written to provide this detail (${}^1\text{TN}^{\text{O-C-F}}$) (Fig. 4c,d). For instance, ${}^134^{1-2}$ refers to a single-rooted mandibular left first premolar having one orifice and one canal initially but then bifurcating into two independent canals and having two apical foramina (Fig. 4c). ${}^141^{1-2-1}$ refers to a single-rooted mandibular right central incisor having one orifice and one canal initially but then bifurcating into two independent canals and

terminating in one canal (Fig. 4d), and ${}^144^{1-2-3}$ refers to a single-rooted mandibular right first premolar having one orifice and one canal initially that bifurcates into two independent canals and terminates in three canals and three apical foramina (Fig. 4e).

Double-rooted teeth

If a tooth is double-rooted, then the code ${}^2\text{TN R1}^{\text{O-C-F}} \text{R2}^{\text{O-C-F}}$ should be used, where R1 and R2 describe the anatomy of the first and second roots, respectively (Fig. 5). As mentioned previously, only one code will be applied if the number of orifice(s), canal(s) and foramen (foramina) is the same, in the same root. For example, ${}^214 \text{ B}^1 \text{ P}^1$ refers to a double-rooted maxillary right first premolar in which each root (B: buccal; P: palatal) encases a single root canal from the orifice to the main foramen (Fig. 5a). ${}^224 \text{ B}^{1-2-1-2} \text{ P}^1$ refers to a double-rooted maxillary left first premolar in which the buccal root encases a single canal leaving the chamber and dividing into two canals and then joining into one canal before dividing again into two separate canals until the canal terminus whilst the palatal root encases a single root canal from the orifice to the main foramen (Fig. 5b).

If the root bifurcates at the middle or apical third, and the root canal configuration is different apical and coronal to the level of root bifurcation, then the code will be ${}^2\text{TN}^{\text{O-C}} \text{R1}^{\text{C-F}} \text{R2}^{\text{C-F}}$, where 'O-C' is the root canal configuration coronal to the level of bifurcation, and $\text{R1}^{\text{C-F}} \text{R2}^{\text{C-F}}$ are the continuation of the canal and number of foramina apical to the level of the bifurcation in either

**Figure 4** Micro-CT 3D models of single-rooted teeth with root and root canal morphology classified according to the new system.

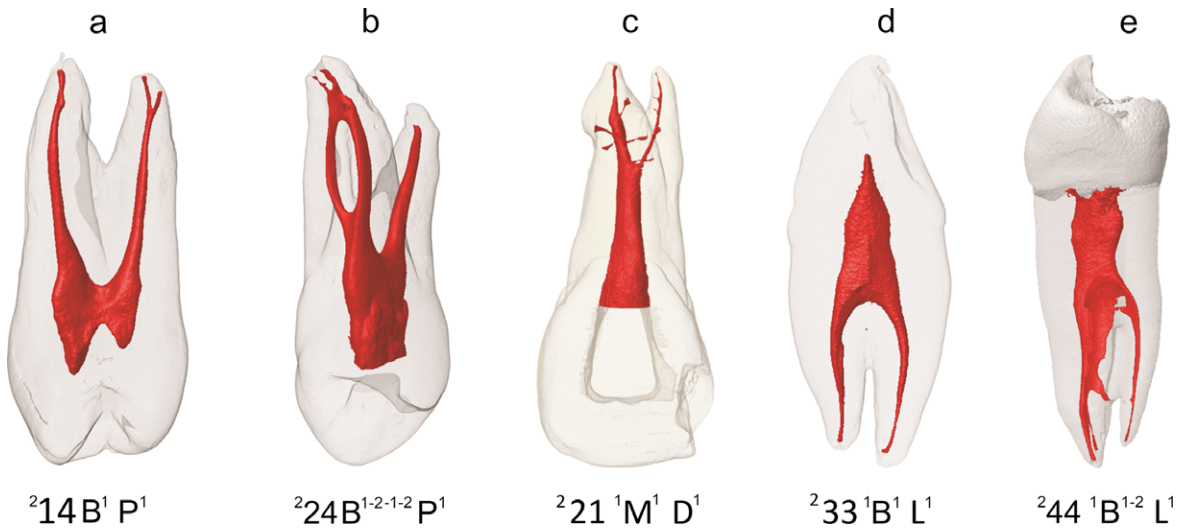


Figure 5 Micro-CT 3D models of double-rooted teeth with root and root canal morphology classified according to the new system.

first (R1) or second (R2) roots, respectively (Fig. 5c–e). Figure 5c shows a double-rooted maxillary left central incisor coded as $^{221}1M^1D^1$ in which the root bifurcates in the apical third and the root canal configuration apical and coronal the level of root bifurcation is different. Figure 5d,e shows similar anatomical variations of the root/root canal in a mandibular canine and premolar, respectively.

Multirooted teeth

If the tooth is multirooted, then the code $^{nTN}R1^{O-C-F}R2^{O-C-F}Rn^{O-C-F}$ should be used. As an example, $^{316}MB^1DB^1P^1$ means that the maxillary right first molar has

three roots (MB: mesiobuccal; DB: distobuccal; P: palatal) and a single orifice, canal and foramen in each root (Fig. 6a). $^{316}MB^{2-1}DP^1P^1$ means that the maxillary right first molar has three roots in which the MB root encases canal type 2-1, whilst the DP and P roots encase a root canal with a single orifice, canal and foramen (Fig. 6b). Similarly, $^{417}MB^{2-1}DB^1MP^1DP^1$ means that the maxillary right second molar has four roots (MB: mesiobuccal; DB: distobuccal; MP: mesiopalatal; DP: distopalatal) in which the MB root encases canal type 2-1, and the DB, MP and DP roots encase a single orifice, canal and foramen in each root (Fig. 6c). $^{347}M^2DB^1DL^1$ means that the mandibular right second molar has three roots in which the mesial root (M) encases 2 independent

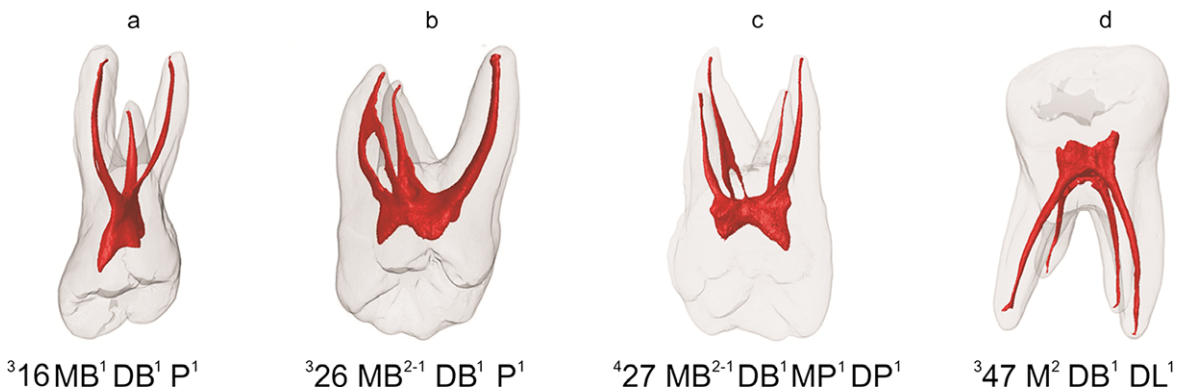


Figure 6 Micro-CT 3D models of multirooted teeth with root and root canal morphologies classified according to the new system.

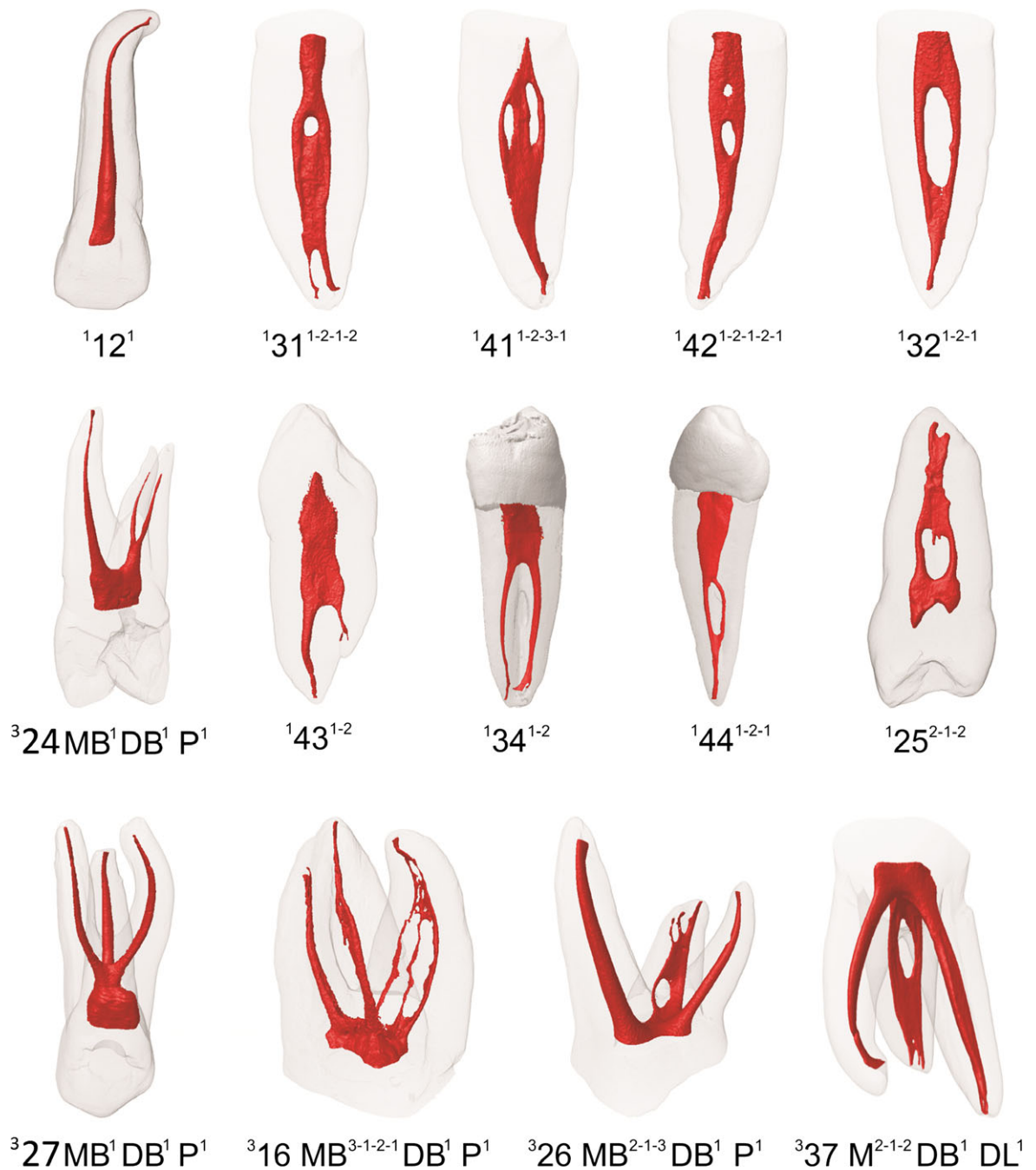


Figure 7 Micro-CT 3D models of different groups of teeth with root and root canal morphologies classified according to the new system.

canals, whilst the DB and DL (distolingual) roots encase a single root canal (Fig. 6d). Similar considerations will be applied if one of the roots bifurcates in the middle or apical third, and the root canal configuration is different apical and coronal the level of bifurcation.

Figure 7 shows the application of the new configuration system on different types of root canal systems. Appendix S1 shows several examples of codes allocated for different teeth, root and root canal configuration types.

Conclusions

The new proposed classification attempts to provide a simple, accurate and practical system that allows students, dental practitioners and researchers to classify root and root canal configurations. It provides detailed information on the tooth number, number of roots and root canal configuration types, whilst excluding developmental anomalies and minor canal anatomy to pave the way for simplicity and universal adoption.

Conflict of interest

The authors have stated explicitly that there is no conflict of interests in connection with this article.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Supplementary powerpoint presentation describing the new proposed classification for root and root canal morphology.