EUROPEAN ENDODONTIC JOURNAL

REVIEW

Controversial Terminology In Root and Canal Anatomy: A Comprehensive Review

Hany Mohamed Aly AHMED,[1] Ali KELEŞ,[2] Thomas Gerhard WOLF,[3,4] Venkateshbabu NAGENDRABABU,[5] Henry DUNCAN,[6] Ove Andreas PETERS,[7] Paul M. H. DUMMER[8]

[1]Department of Restorative Dentistry, Faculty of Dentistry, Universiti Malaya, Kuala Lumpur, Malaysia
[2]Department of Endodontics, Faculty of Dentistry, Bolu Abant İzzet Baysal University, Bolu, Türkiye
[3]Department of Restorative, Preventive and Pediatric Dentistry, Faculty of Dental Medicine, University of Bern, Bern, Switzerland
[4]Department of Periodontology and Operative Dentistry, University Medical Center of the Johannes Gutenberg University, Mainz, Germany
[5]Department of Restorative Dentistry, College of Dental Medicine, University of Sharjah, Sharjah, UAE
[6]Department of Restorative Dentistry and Periodontology, Trinity College Dublin, Dublin Dental University Hospital, Dublin, Ireland
[7]School of Dentistry, The University of Queensland, Brisbane Qld 4006, Australia
[8]School of Dentistry, College of Biomedical and Life Sciences, Cardiff University, Cardiff, UK

ABSTRACT

Discipline-specific terminology is a central element of the vocabulary used by dentists and scientists in the context of their professional activities and plays a critical role in the understanding of dentistry. A number of controversial terms and non-standardized definitions exist in the field of endodontology. For example, in root and canal anatomy, variations are evident in the definitions of root morphology (including apical bifurcation, fusion and dilaceration), pulp chamber anatomy (including the outline of the floor, pulp horns and location of the root canal orifice), apical root canal bifurcations, canal isthmuses, accessory canals and apical foramen. This narrative review provides a critical analysis of a range of controversial terms currently used to describe root and canal anatomy. It also addresses the consequences of using such controversial terms on the accuracy and reliability of research findings and clinical practice.

Keywords: Controversial, pulp chamber, root canal anatomy, terminology

Please cite this article as:
Ahmed HMA, Keleş A, Wolf TG, Nagendrababu V, Duncan H, Peters OA, Dummer PMH. Controversial Terminology In Root and Canal Anatomy: A Comprehensive Review. Eur Endod J 2024; 9: 308-34

Address for correspondence:
Hany Mohamed Aly Ahmed
Department of Restorative Dentistry, Faculty of Dentistry, Universiti Malaya, Kuala Lumpur, Malaysia
E-mail:
hany_endodontist@hotmail.com

Received : July 26, 2024,
Accepted: September 04, 2024

Published online: November 06, 2024
DOI 10.14744/eej.2024.20981

HIGHLIGHTS

- This review provides a critical analysis of controversial terms used to describe root and canal anatomy.
- A literature shows that a wide range of terms are used to describe the same anatomical features of the roots and canals.
- A universal consensus is needed to provide accurate and consistent descriptions of key anatomical landmarks in roots and canals.

INTRODUCTION

The scientific community uses terminology as a basic tool for communication and reporting between colleagues, patients and other stakeholders (1). Unfortunately, there are occasions when the lack of consensus and universal acceptance of specific terms leads to confusion, disagreement and even controversy among stakeholders. In essence, a scientific controversy involves a sustained debate within the broader scientific community in which the arguments are based on evidence (2).

Although science is used to justify arguments within controversies, a detailed analysis of the growing body of scientific knowledge is essential (3). The study of controversies may shed light on the dynamics of science, and focus attention on different theories and assumptions evolved in a given subject (4). A resolution in most cases comes when one argument is widely accepted or the evidence in support of one side of the controversy becomes convincing compared to others (2).

In medicine, the use of consistent agreed terminology for defining diseases is essential in providing a platform for optimal understanding, communication and treatment across multiple health care providers including kidney disease (5), liver diseases (6) and urinary tract infections (7). One systematic review demonstrated that different terminologies given for the same condition influenced the patients' management preferences and psychology, concluding that modifying the terminology may be one approach to reduce patient's preference for aggressive treatment options to low-risk conditions (8). The use of misleading, confusing terminology may also lead to a lack of understanding among students and young practitioners (9).

In dentistry, the use of inconsistent terminology has been reported in several conditions such as temporomandibular joint disorders (10), developmental defects of enamel (11), dentine hypersensitivity (12) and endo-perio lesions (13). In addition, Hamilton et al. (14) concluded that inconsistent terminology within oral surgery and oral medicine is likely to lead to confusion and incorrect interpretation from patients resulting in ill-informed decision-making or unnecessary concerns.

Terminology in human anatomy provides the basis for effective communication in all medical and healthcare fields (15). The Federative International Programme for Anatomical Terminology (FIPAT) [one programme of the International Federation of Associations of Anatomists (IFAA)] develops, publishes and maintains the set of international standard terminologies of human anatomical sciences as well as promotes the correct use of terminology (16). Despite these efforts, several reports have documented deficiencies in the adoption and use of consistent terminology in several fields, for example, in the surface anatomy of dermatology (17) as well as anatomical structures in the jaw bones such as the inferior alveolar canal (18).

A detailed and comprehensive understanding of root and canal anatomy is essential before undertaking endodontic procedures (19, 20). Indeed, a lack of knowledge of tooth anatomy is likely to have a negative impact on the outcome of treatment (19). Knowledge of root and canal anatomy has increased over the years as a consequence of the large number of laboratory and clinical studies. With the ever-increasing body of knowledge on tooth anatomy and the high rate of publications in this area (21), the use of consistently accepted terminology for describing anatomical features of root and canal systems is becoming increasingly important (22).

Not only does consistent use of terms increase accuracy and understanding, but it is a key element for enhancing dental education (23). It also allows accurate comparisons between the results of research studies and ensures more accurate descriptions of a range of anatomical variations in clinical practice such as root fusions, pulp chamber anatomy, level of canal bifurcations and accessory canals (22). Despite considerable efforts, there is no universal consensus for many of the terms used to describe and define features of root and canal anatomy (24). For a dental student, researcher and clinician to interpret root canal configurations correctly and consistently, the anatomical details of the root and pulp canal space should be defined accurately using terminology that is generally accepted and can be applied universally. This paper aims to provide a critical analysis of the most controversial terms currently used to describe root and canal anatomy. It also addresses the consequences of using such controversial terms on the accuracy and reliability of different study findings and clinical practice.

Domain 1: Controversies Related to the Terminology Used to Describe Roots

Apical Root Bifurcation

The term 'bifurcation' has often been used to describe the division of a single root in the coronal region into two or more roots more apically (24–26). Defining the number of roots in a specific tooth is usually straightforward; however, it is more challenging when a division/bifurcation occurs in the apical third of the root, particularly when it is in close proximity to the root apex (24, 25, 27, 28). Unfortunately, various terms have been proposed to describe these divisions/bifurcations without a global agreement on the most appropriate term(s).

Turner (25) classified bifurcations in the apical portion of the root in two forms:

(i) a single-rooted tooth with a bifid tipped root in which the bifurcation is less than one-third to one-fourth of the total root length, and

(ii) a single-rooted tooth with a double apex that does not have a very clear bifurcation but has two distinct and identifiable small root apices that can be seen and/or felt.

Others have provided alternative definitions. For example, a micro-computed tomography (micro-CT) study on double-rooted mandibular canines considered bifurcations in the middle and apical thirds of the root as two separate roots (29). Ahmed et al. (24) categorized roots with apical bifurcations with no 'distinct double roots' as either (a) a single-rooted root with bifid tip [when the bifurcation is located in the middle portion of the apical third of the root – Bifid Root (BR)] or (b) a small double-apex root [when double root tips are present– Double Apex (DA)].

Such anatomical variations of the root can be identified when using 3D diagnostic tools [(e.g., micro-CT and cone beam computed tomography (CBCT)] (Fig. 1). With proper shifting of the X-ray beam, coronal and middle bifurcations of the root may also be identified on intraoral periapical radiographs. However, because of their inability to reveal the bucco-lingual dimension of the root apex and superimposition of anatomical struc-

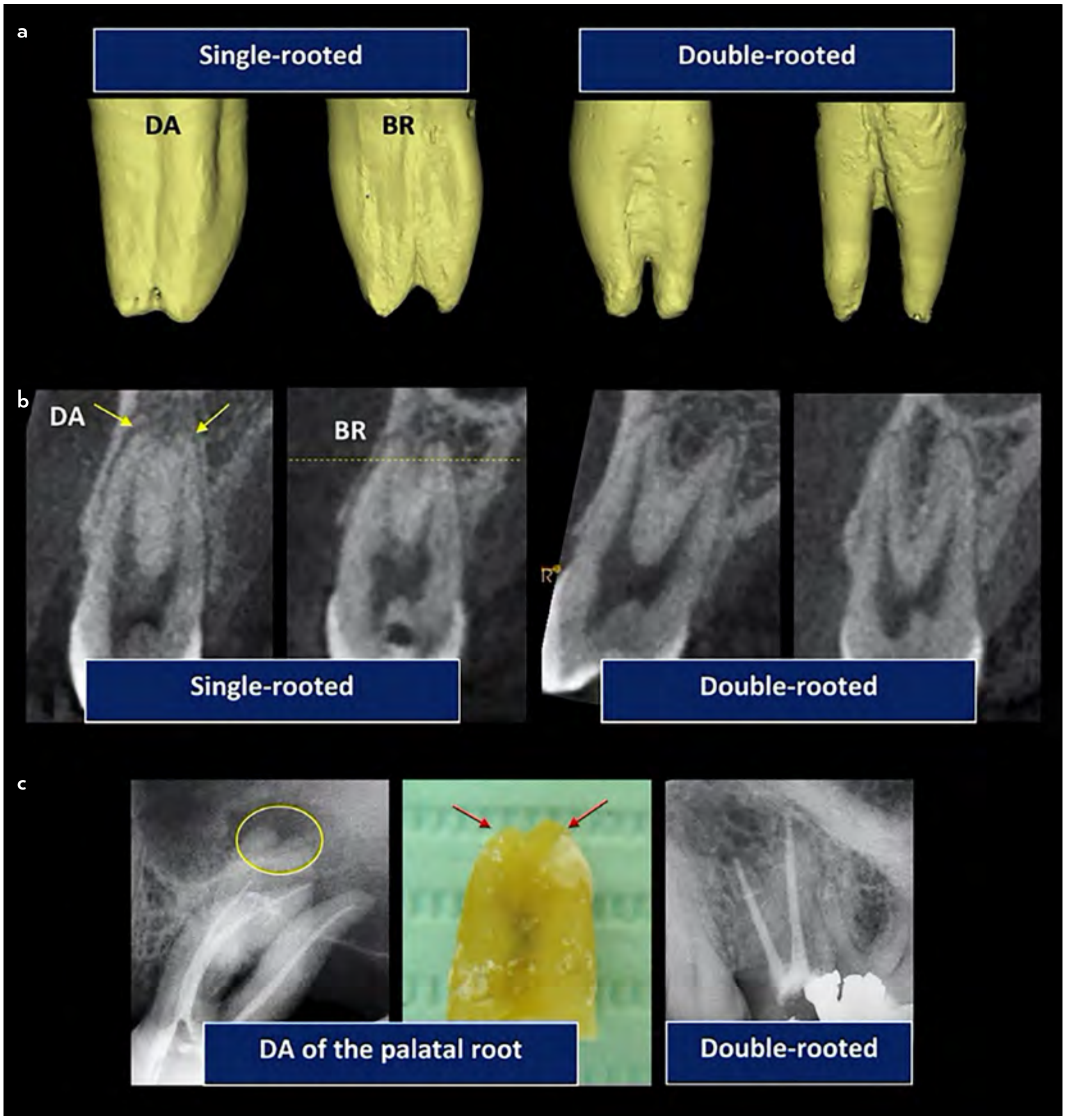

Figure 1. Interpretation of single (with double apex and bifid root) and double-rooted teeth using micro-CT, CBCT and conventional radiographic imaging. (a) micro-CT, (b) CBCT, (c) 2D radiographic image (yellow circle: identification of the double apex, red arrows: after root resection)

DA: Double apex, BR: Bifid root, CBCT: Cone beam computed tomography

tures, identifying bifid roots and double apices is challenging using conventional radiographs.

The presence of a bifid root has important clinical implications in terms of canal location and preparation during root canal treatment, retreatment and endodontic surgery. A bifurcation also indicates the increased possibility of accessory canals in the apical third (28), which will require a specific approach to canal preparation and filling.

From the discussion above, it is obvious that apical root bifurcations have important implications in research and clinical practice, the outcomes of which can be compromised by inconsistent use of terms. Reaching global agreement on the terminology used to characterize the spectrum of apical root bifurcations is essential to facilitate accurate comparisons between laboratory studies and clinical observational CBCT studies as well as enhance the understanding of techniques used in clinical practice.

Root Fusion

Anomaly or an anatomical variant

In simple terms, it is generally accepted that root fusion is the union between two or more separate roots on a tooth. For many years, the study of root fusion has been of interest to researchers and clinicians (30–34) as it has important clinical implications in several fields in dentistry such as progression of periodontal diseases and a range of treatment procedures such as root canal treatment and retreatment, root-end surgery as well as prosthodontics (35–38).

By definition, an anomaly is an anatomic phenotype that represents “a substantial deviation” from the appropriate reference population, while a variant is a mild anatomic phenotype that represents “a small deviation” from the appropriate reference population (39). It should be noted that anomalies can be classified as either a “major morphologic anomaly” that has a significant consequence on health including function

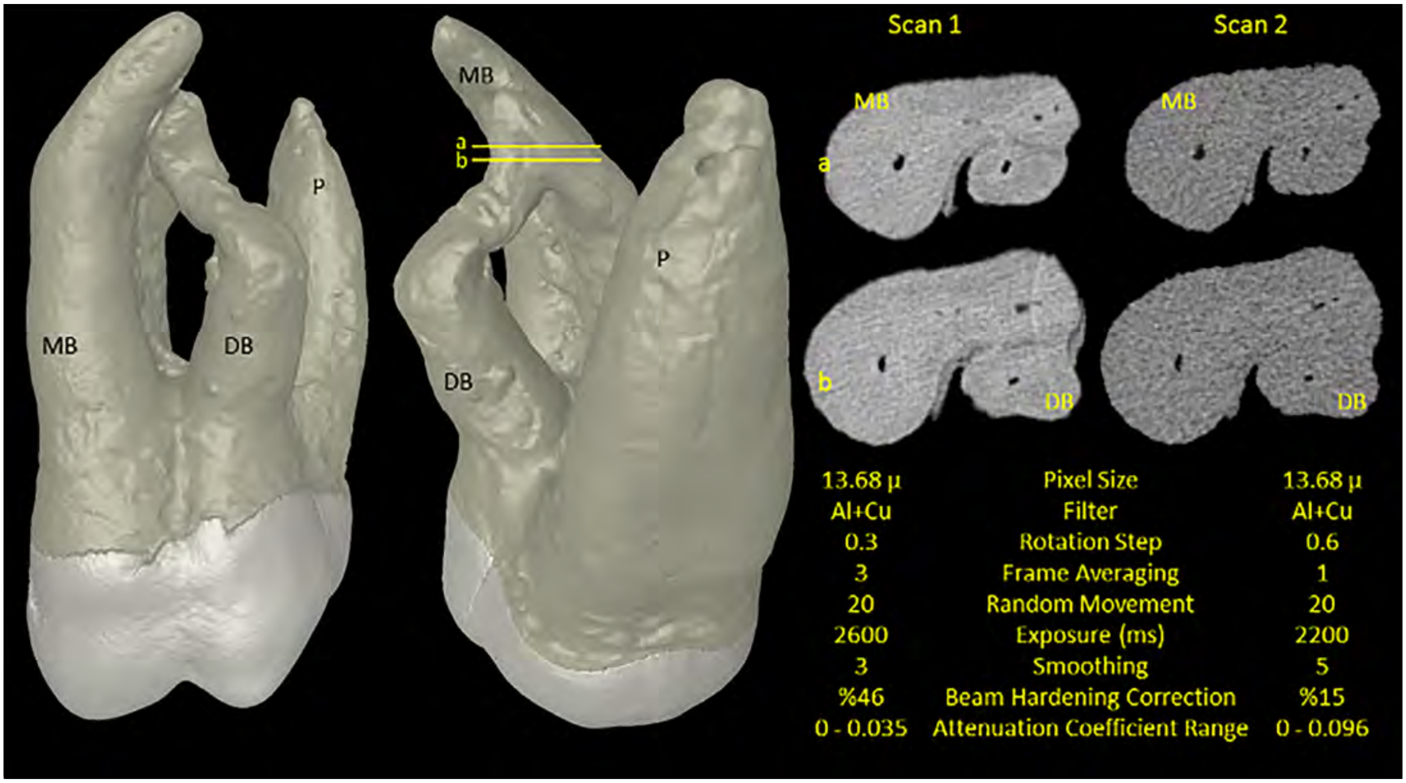

Figure 2. Cross-sectional images obtained by scanning and reconstructing micro-CT images of the same maxillary molar tooth using different parameters. Even if the images have the same pixel size (13.68 microns), their interpretation may differ

MB: Mesio-buccal, DB: Disto-buccal

and aesthetics, or a "minor morphologic anomaly" that has minimal, or no consequence on health (39). This type of categorization is also applicable to dental anomalies. For instance, Oehlers dens invaginatus type III can be considered a major morphologic anomaly when it impairs normal function and aesthetics (40–42), while Oehlers dens invaginatus type I is a minor morphologic anomaly that does not impair function or aesthetics and can be managed using preventive or less invasive treatment procedures (41).

Root fusion has been described as an "anomaly" affecting the tooth root (31, 35, 43, 44), or as an "anatomical variation" (45, 46). Apart from differences in the anatomical landmarks used to define root fusion in the literature, the use of various terms to define fusion can also be attributed to the wide range of tooth types with fused roots in the permanent dentition which can have a different prevalence (rare to common) in various populations (30, 33, 34, 47–50); this is also evident in primary molar teeth (51, 52).

It should be noted that roots may fuse as a result of either the failure of Hertwig's epithelial sheath to develop, fuse in the furcation area or be the result of coalescence owing to cementum deposition over time (53, 54). These various factors indicate that not all types of fusions are developmental. High-resolution micro-CT imaging is a useful tool for identifying the types of fusion that can occur when extracted teeth are being evaluated. On occasions, micro-CT is not able to distinguish cementum and dentine with similar radiopacities, which is a limitation of the technique (Fig. 2). However, the layer of cementum is sometimes thick enough to be segmented from the underlying root dentine (Fig. 3). Nevertheless, the majority of variations in the anatomy of root fusions (at a histological level) cannot be identified clinically on conventional radiographs or the CBCT devices that are currently available.

While there may be narrow gaps between roots united by cementum fusion on micro-CT images, these gaps are not encountered in real root fusion (Fig. 4). Indeed, the clinical application of such categorizations of the minor fusion details is virtually impossible when analysing periapical radiographs. High-resolution CBCT imaging is usually beneficial when defining fusions, but not for all types, especially those involving cementum.

Criteria to categorize a tooth with fused roots

In a tooth with fused roots, the root structure is composed of root-like divisions called "root cones or radicals", demarcated with developmental grooves (55, 56). Root fusion has been defined in several ways which vary in different teeth (30–32); however, it is currently unclear how fused roots should be identified and classified.

Root fusion in premolars

There are wide variations in the categorization of maxillary premolars with fused roots, especially for teeth with apical root bifurcations, and roots without bifurcations but with deep developmental proximal grooves (57). Indeed, comparing the results of various studies is challenging when studies

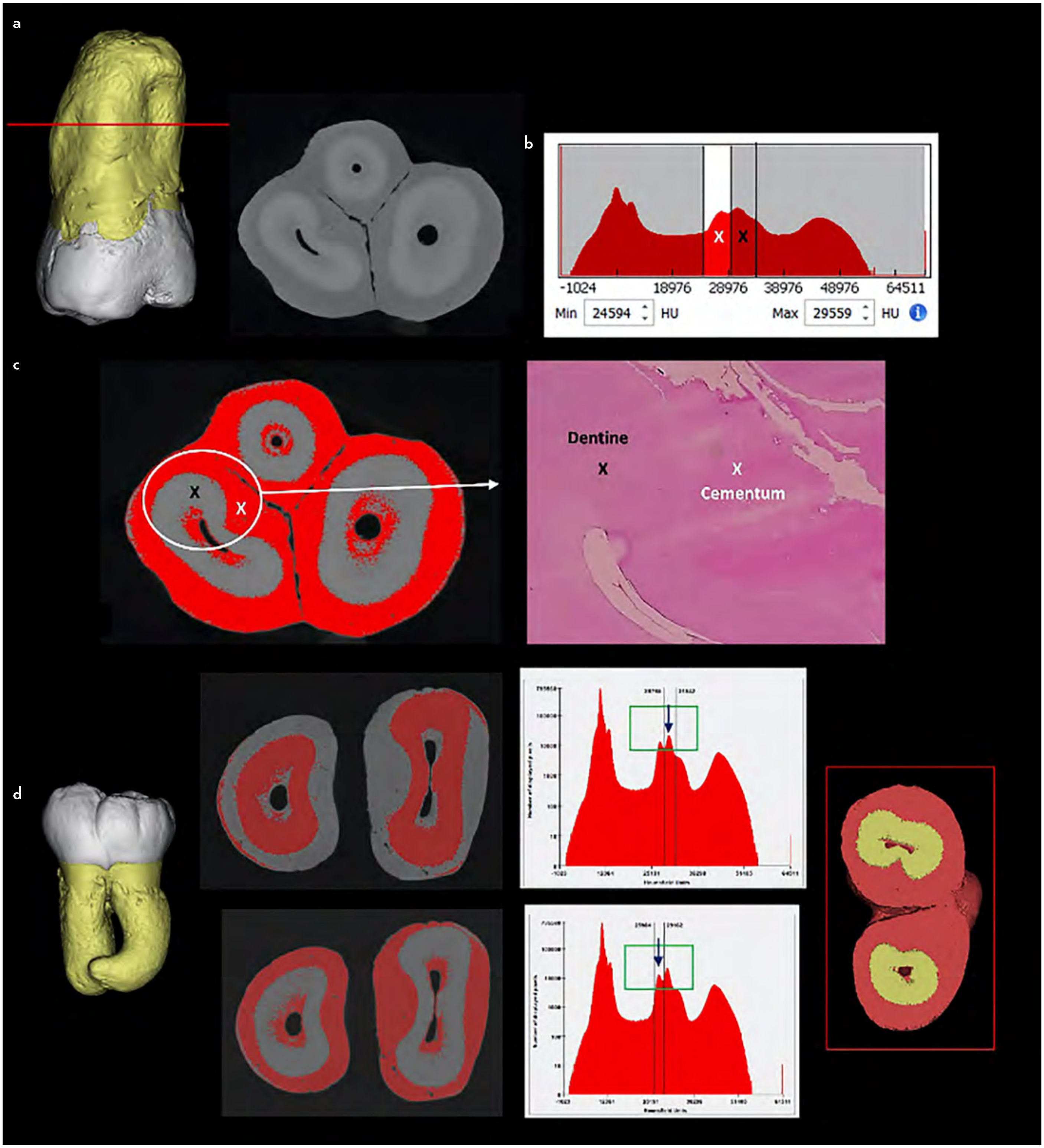

Figure 3. (a) Micro-CT images of a maxillary third molar with fused roots. (b, c) A segmentation was done for cementum (in red) (white x: cementum, black x: dentine). Histological sectioning reveals dentine and cementum corresponding to the axial slice. (d) A micro-CT image of a mandibular molar with root fusion in the apical third [dentine: black arrow (above), cementum: black arrow (below)]. 3D reconstruction (right) reveals that the fusion involves only cementum (pseudo-fusion)

have defined single-rooted and fused double-rooted maxillary premolars in different ways as follows:

- Nelson (58) explained that, in several instances, the number of roots in multi-rooted teeth is reduced by fusion. This 'fusion' of roots is because of the interposition of cementum between the roots in a way that either completely veils the separate roots or renders them partially coalescent. The former has been termed 'fused roots,' and the latter 'partially fused roots' (58).

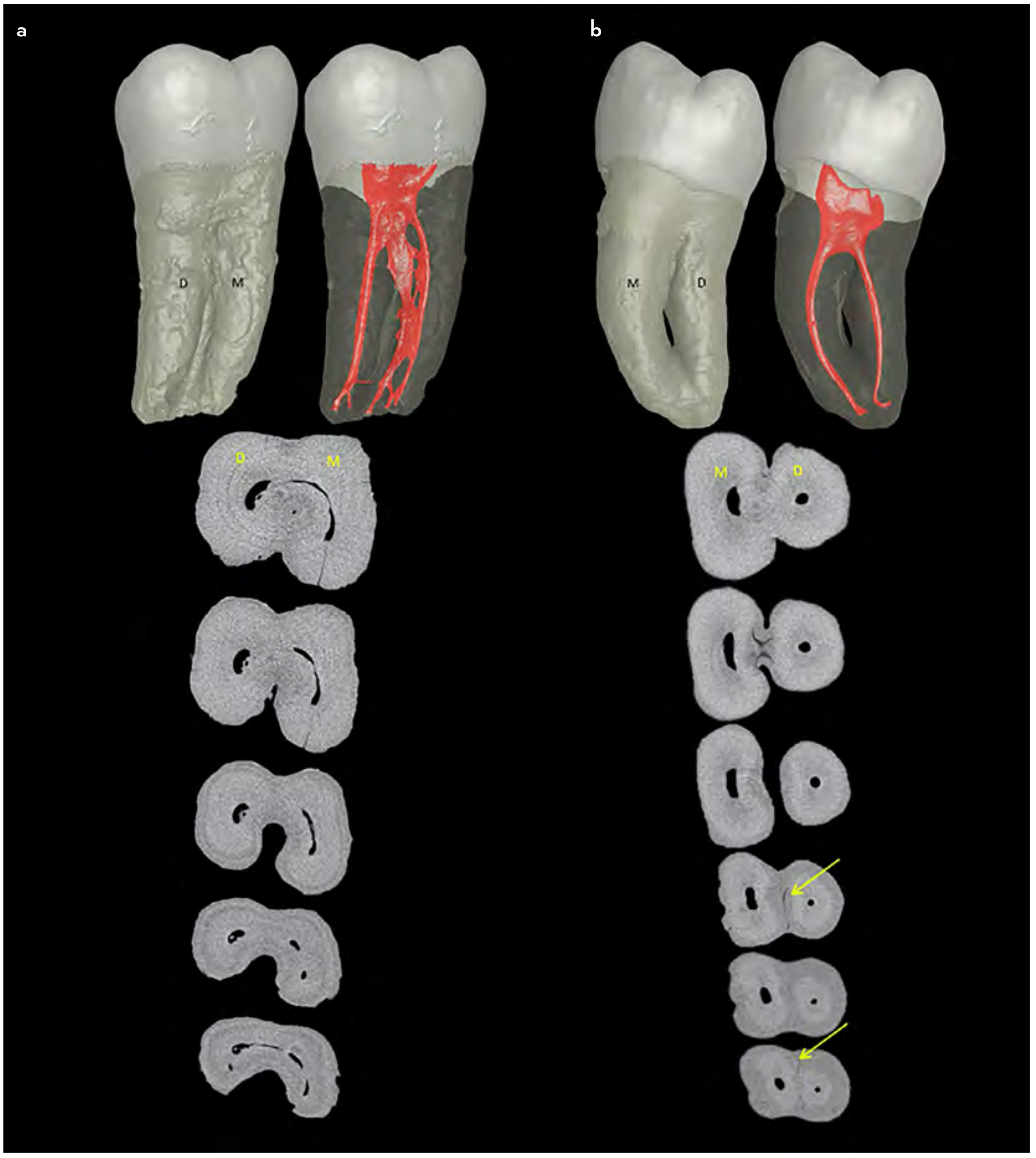

Figure 4. (a) A micro-CT image of a mandibular molar showing true fusion of the mesial and distal roots in which the root canals communicate with each other forming C-shaped canals. (b) A micro-CT image of another mandibular molar showing root fusion by cementum with separate root canals. Completely separate root parts and non-calcified narrow gaps (yellow arrows) can be seen at some root levels in cementum fusion

- Others defined fusion in maxillary premolars with root bifurcation less than half of the root length (59–61) or within the apical third of the root (62, 63).
- Loh (47) defined fused double-rooted maxillary premolars in which the roots are fused (with prominent proximal grooves) almost to the root apices having two separate root canals. The same identification was applied to single-rooted teeth (with shallow proximal grooves) with two root canal orifices and two canals exiting via one foramen or remaining as separate canals and with two foramina (47).
- Neelakantan et al. (64) defined maxillary premolar teeth with two fused roots when a clear invagination (groove) was identifiable between the roots. Bifurcation of the roots at the apical third was considered a double-rooted variant.

Figure 5 shows different forms of maxillary premolars with two canals in separate and fused double-rooted as well as single-rooted variants.

The same variation in terminology and the associated confusion also occurs in maxillary premolars with 2 canals in buccal root(s) in which the buccal component has been considered as fused MB and DB roots (65) or one buccal root with deep buccal developmental grooves (24) (Fig. 6b, c). In some instances, the buccal roots are separated in the middle and fused at the apex (Fig. 6c), or the separation is only limited to the apical third (Fig. 6d). The presence of separation along the fused section (or roots with deep grooves) may be associated with important anatomical features related to dentine thickness (Fig. 7).

Ahmed et al. (24) suggested that the categorization of fused roots should be based on the common number of roots for

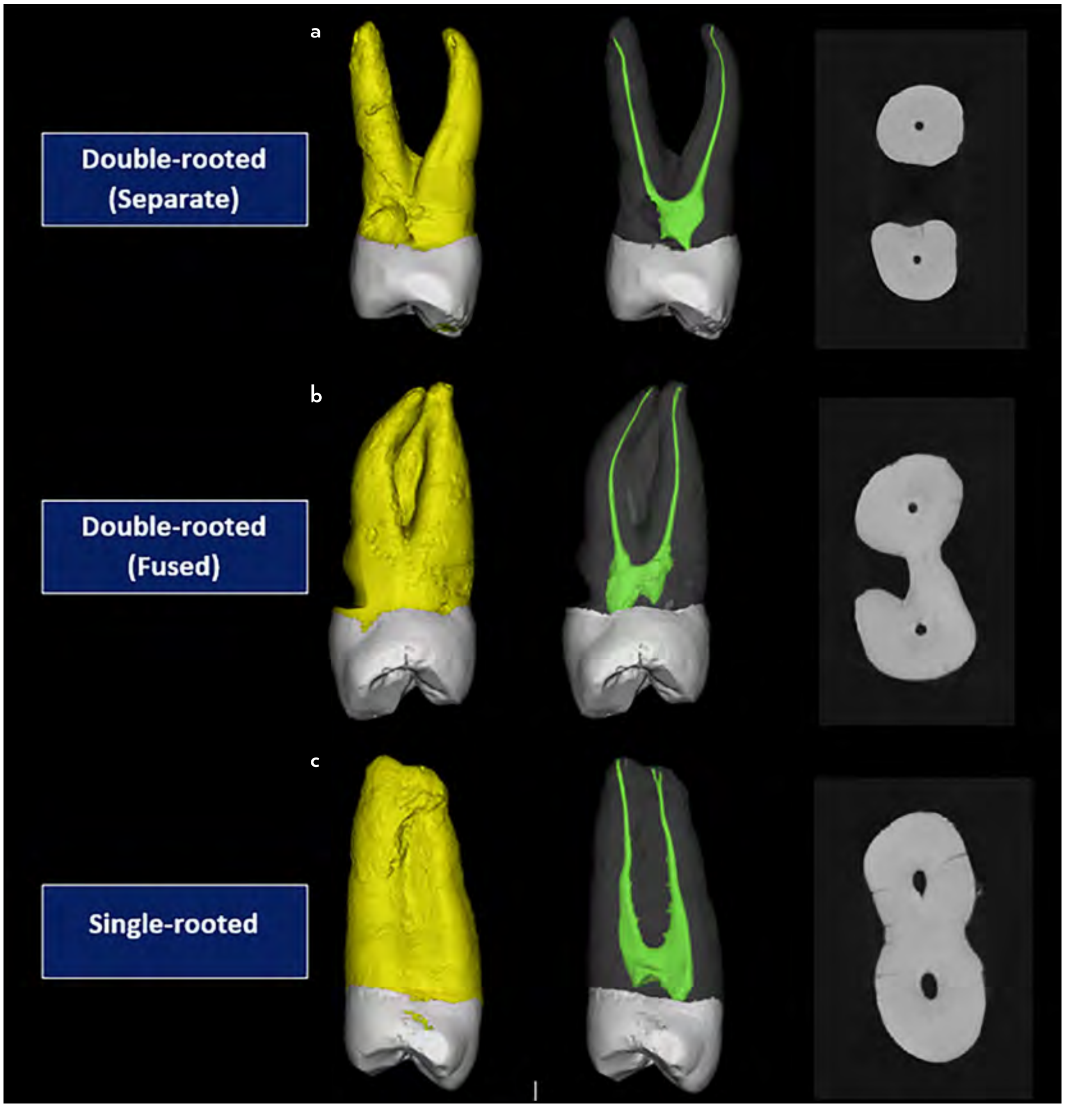

Figure 5. Micro-CT images of-maxillary premolars with two separate root canals in two roots (a) separate, (b) fused, and in (c) a single-rooted variant with two canals

that given tooth. As an example, when a double-rooted maxillary premolar has deep buccal and palatal grooves on the buccal root, then it should be considered as a buccal root with deep developmental grooves (not as two fused buccal roots) since it is well-known that maxillary first premolars are either single or double-rooted. In addition, the furcation groove on the palatal aspect of the buccal root in double-rooted maxillary first premolars is a normal anatomical landmark (66). The same applies to other teeth with deep developmental grooves (such as mandibular premolars), which are considered as single-rooted, not fused double roots (Fig. 8).

Root fusion in molars

Ross & Evanchik (30) defined maxillary or mandibular molars with one root or whose roots were fused apical to the usual furcal position as a molar with fused roots. This included molars with fusion of one-third or less of the roots, and molars with fusion along the entire root surfaces (Fig. 9a, b). Molars with roots fused only in the apical one-third and with a normal furcation were included in the category of fused roots (Fig. 7c).

Carlsen (55) defined root fusion as a phenomenon whereby two, or several, root structures are in contact apically, while the same structures, more cervically, are separate.

Hou & Tsai (31) divided root fusion in maxillary and mandibular molars into three categories (Grade I: fusion involving the cervical half of roots; Grade II: fusion involving the cervical two-thirds of roots; Grade III: complete or true fusion of roots). Root fusion by cementum in the apical region has been considered pseudo-fusion (not true fusion) (31) (Fig. 9c). Any combination of grades with 1, 2, or 3 affected surfaces in maxillary molars was recorded as one-, two-, and three-surface fusions.

Zhang et al. (32) defined root fusion in maxillary second molars when the ratio of the distance from the cementoenamel junction (CEJ) to the apical point of root furcation or where the roots fused (CEJ-RF), and from the CEJ to the apex of the root (CEJ-Apex) is not less than 70%. Defining the type of fusion (involving cementum or dentine or both) was not mentioned.

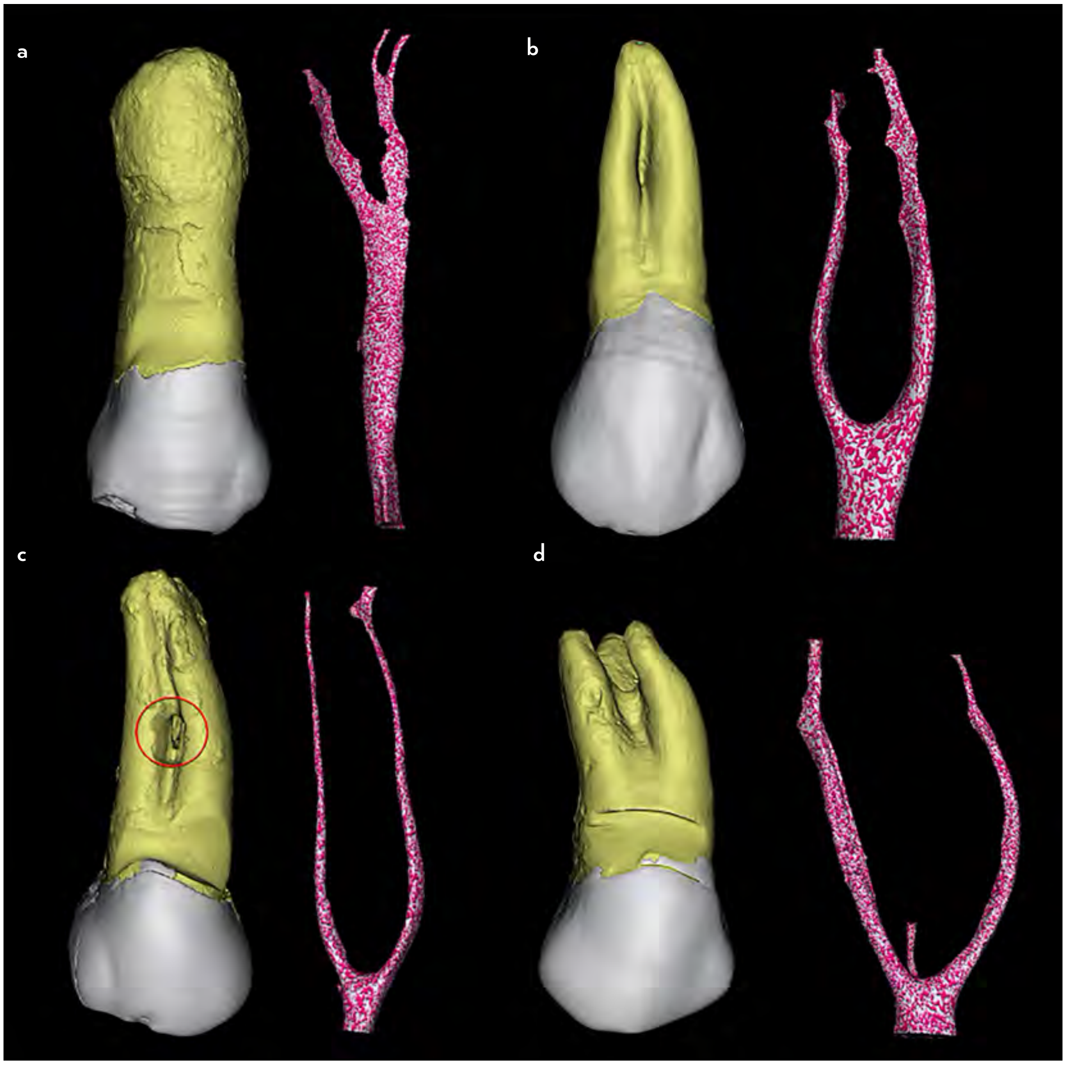

Figure 6. Reconstructed micro-CT images of maxillary premolars with different forms of the buccal root(s) and their respective root canals. (a) One buccal root with no buccal grooves. (b) Deep buccal groove on the buccal root – there is a lack of clarity whether to consider this as one buccal root with deep buccal developmental groove or fused MB and DB roots. (c) Another form in which there is an area of separation (red circle) of the MB and DB fused roots. (d) A maxillary premolar with a bifurcation in the apical third of the buccal root

MB: Mesio-buccal, DB: Disto-buccal

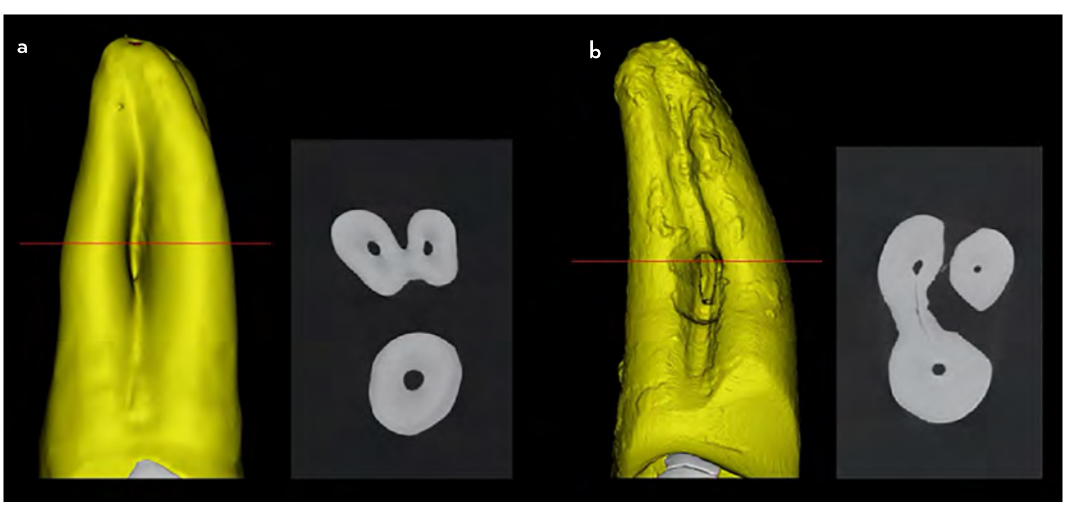

Figure 7. Anatomical features of roots with (a) deep buccal grooves (fused roots), and (b) buccal roots with partial/limited root separation in the middle third of the root

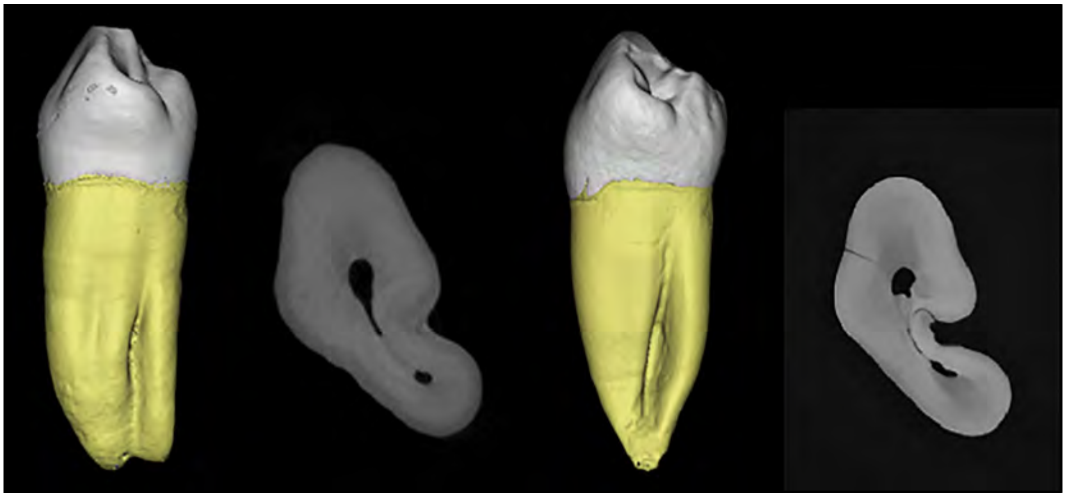

Figure 8. Micro-CT images of single-rooted mandibular first premolars with deep proximal grooves

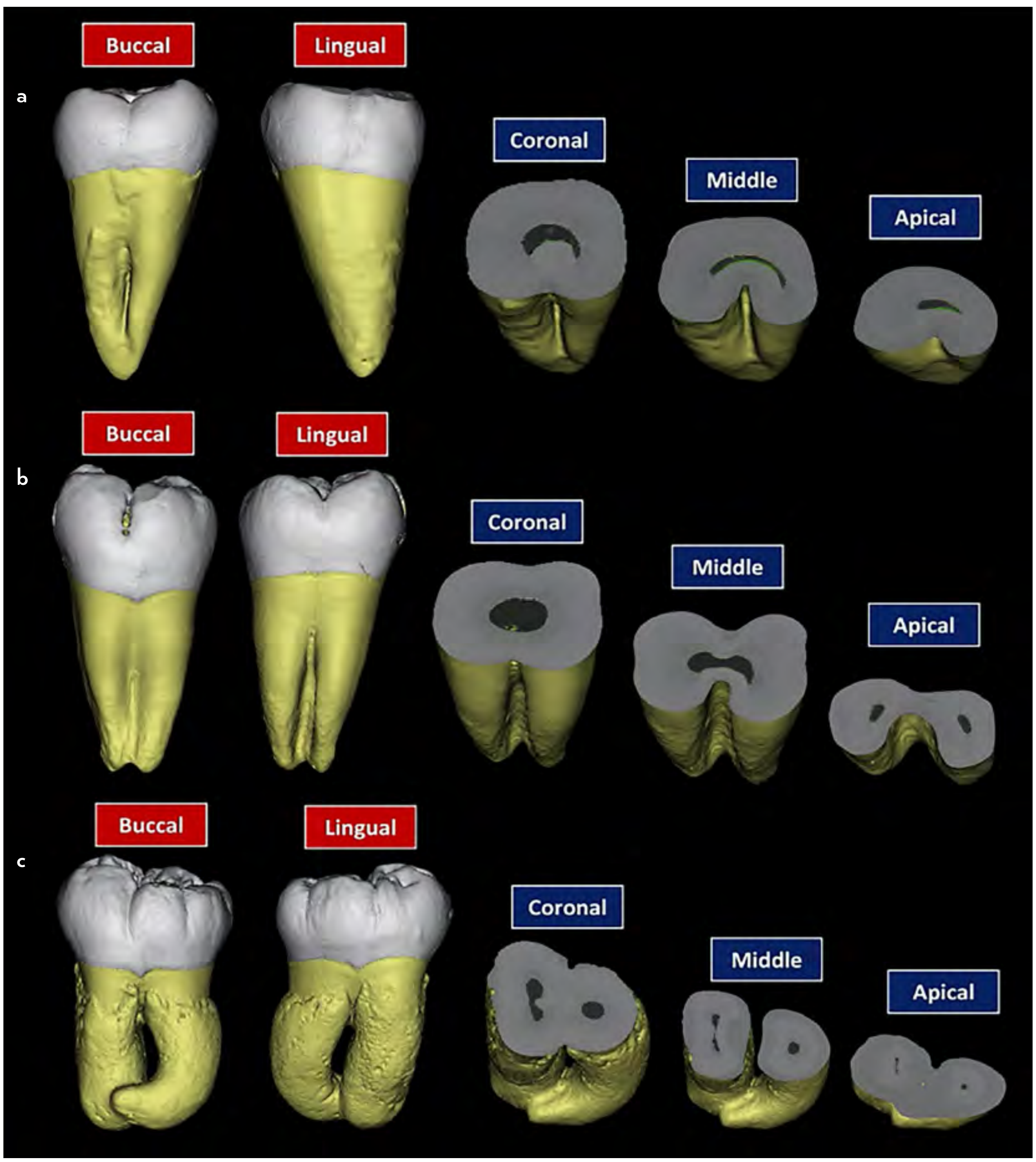

Figure 9. Various forms of root fusion in mandibular molars. (a) Fusion along the root length with a buccal groove. (b) Fusion along the root length with both buccal and lingual grooves. (c) Fusion at the apical third of the root (pseudo-fusion). Reproduced with permission from Ahmed (21)

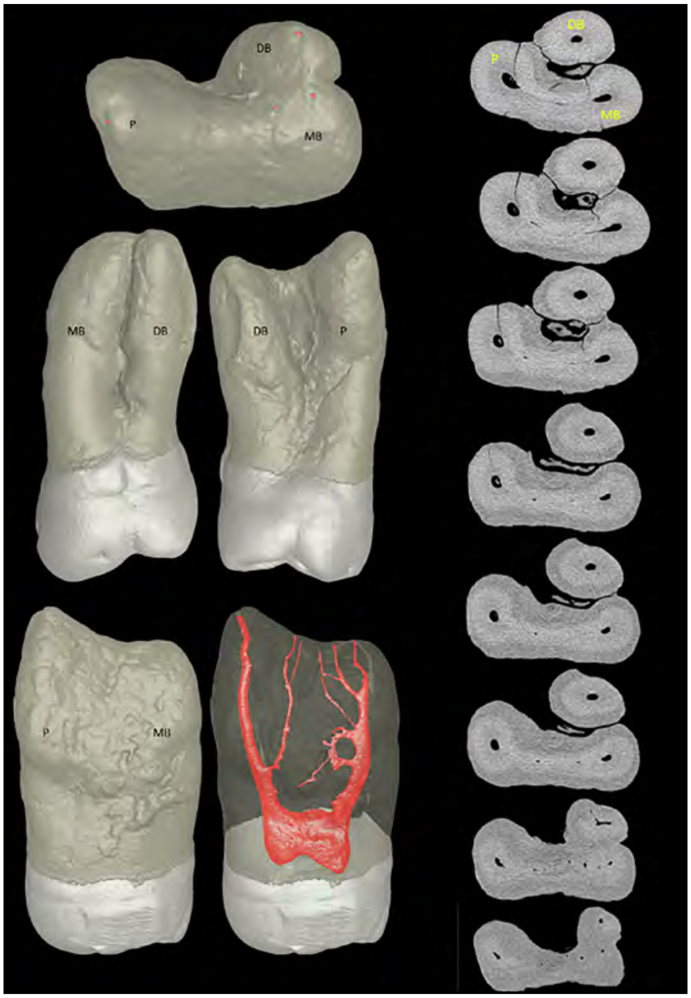

Figure 10. Micro-CT images of a maxillary second molar with fusion of the palatal and mesiobuccal roots. A cementum fusion has formed in the buccal roots of the tooth because they are close to each other; however, they are separated at some points along the root

The range of terms and definitions used to describe root fusions creates confusion. Indeed, the controversy over the definition of root fusions leads to incorrect conclusions in research studies, especially given that cementum fusion may occur along the entire root length, not only the apical third. In addition, it is also possible to have true-fused and cementum-fused roots in the same tooth (Fig. 10).

It is important to recognize that root fusion affects the internal root canal anatomy. For example, fused roots with complex internal anatomy with a higher frequency of merging canals, isthmuses, C-shaped root canals, and extra canals have been reported (34) (Fig. 11).

There is also a lack of clarity when attempting to identify whether molar teeth have fused roots or are single-rooted. A number of studies classified mandibular teeth with fusions as single-rooted teeth but with certain features categorized using various types (types 8, 9 and 10 for teeth with one, two and three canals, respectively) (67, 68). A similar concept was followed to classify maxillary molars (69). Carlsen et al. (70) classified maxillary second molars as single-rooted based on the degree of separation of the roots (if the degree of separation is equal or more than 0 and less than one-third for all roots in maxillary second molars or the degree of separation in two of the three roots are less than one third and one is more than one third). In clinical practice, single-rooted maxillary molars usually encase only one canal (71) (Fig. 12).

Root Dilaceration

Several terms have been used to describe root dilacerations, that is usually thought of as abnormal curvatures (72) (Fig. 13). Some have defined a dilaceration as a 90-degree angle or greater along the axis of the tooth or root (73), whereas others defined it as a deviation from the normal axis of the tooth of 20 degrees or more in the apical part of the root (74). One study classified root dilacerations into mild (20–40°), moderate (41–60°), and severe (>61°) (75). This strategy was followed in other studies that used periapical and panoramic radiographic views (76), as well as CBCT scans (77), which also allowed the detection of bucco-lingual root dilacerations.

In an Oral Biology textbook, dilaceration was defined as a severe bend or angular distortion of a tooth root without referring to a specific angle (78). The American Association of Endodontists (79) defines dilaceration as a deformity characterized by displacement of the root of a tooth from its normal alignment with the crown, but common usage has extended the term to include sharply angular or deformed roots. Recently, one study applied deep learning models to develop an artificial intelligence-based computer-aided detection system for root dilaceration on panoramic radiographs (80). Currently, there is no universal consensus for what constitutes "root dilaceration".

Domain 2: Controversies Related to the Terminology Used to Describe Root Canal Systems

Pulp Chamber Anatomy

Components of the pulp chamber

The pulp chamber contains the coronal pulp tissue and its shape generally reflects the anatomy of the crown (81, 82). It is subject to morphological changes as a consequence of age (through the deposition of secondary dentine) or as a defensive mechanism (through tertiary reactionary and reparative dentine formation) against microbial irritation or trauma (83). The AAE, (79), and some oral biology textbooks (78, 84), define the pulp chamber as the portion of the pulp space within the anatomic crown of the tooth the lower border of which is defined by the CEJ [or more accurately the dentino-enamel junction since the cementum may not meet with the enamel (82)].

The pulp chamber is generally surrounded coronally by what is referred to as a 'roof', which varies in shape from tooth to tooth, axial walls (which varies in number for each tooth type) and a floor in posterior teeth (78, 84, 85). The term "ceiling" has also been suggested which refers to the interior coronal surface of a pulp chamber since "a roof" refers to the external outer surface (86, 87).

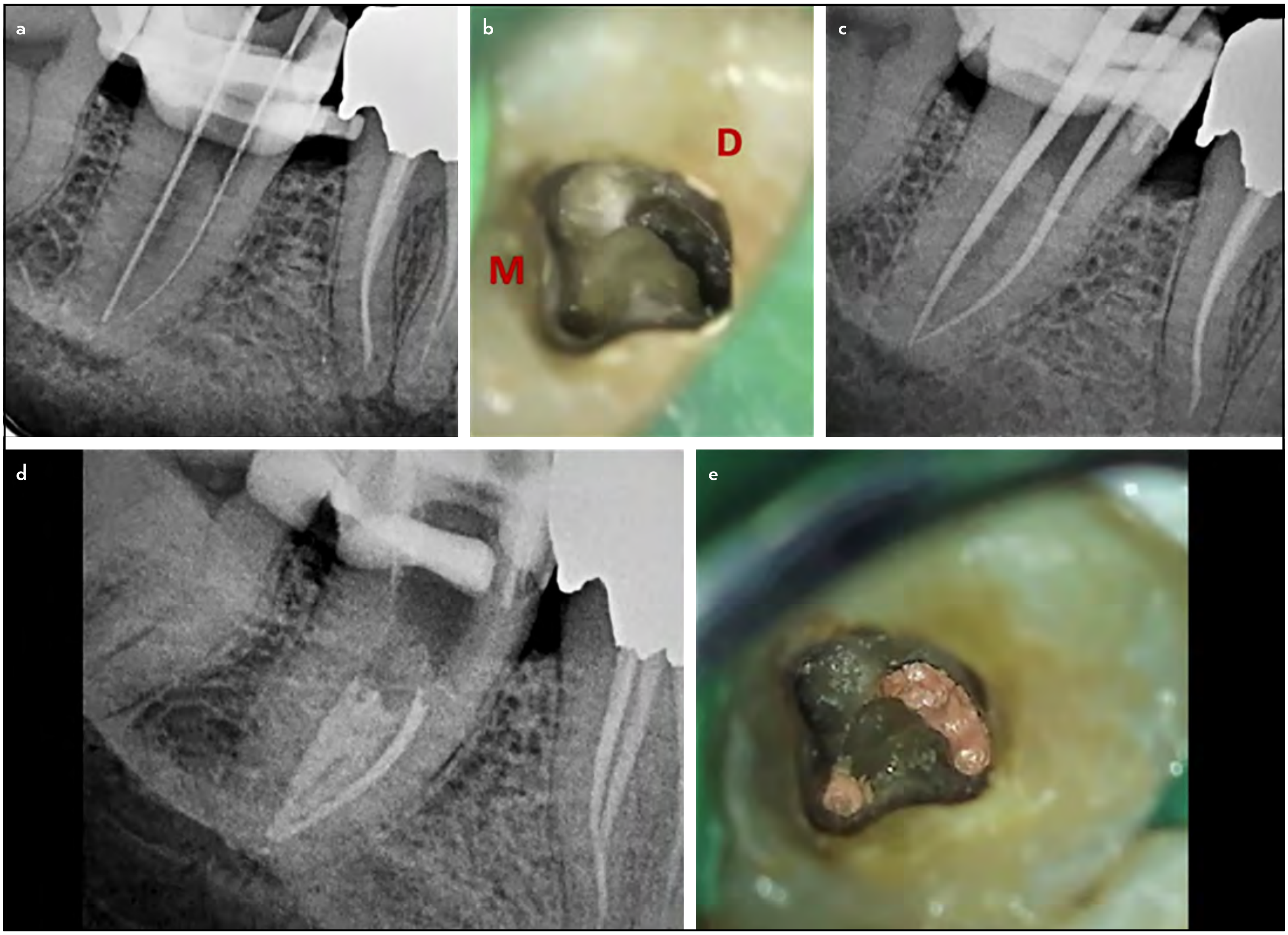

Figure 11. Management of a mandibular second molar with fused roots and complex canal anatomy. (a) Working length radiographic view. (b) C-shaped canal in the distal root. (c-e) Root canal filling using a warm gutta-percha compaction technique. Reproduced with permission from Ahmed (21)
M: Mesial, D: Distal

Pulp horn anatomy

Pulp horns are projections of pulp tissue that lie within matching protrusions within the ceiling of the pulp chamber that normally correspond to the major cusps or lobes of the crown (82). The pulp horns are usually more prominent in young compared to older individuals (82). The height and morphology of pulp horns vary in different teeth and in different cusps of the same tooth type (such as the buccal and palatal pulp horns in maxillary premolars), which could be attributed to the amount of reactionary tertiary dentine deposition in relation to the functional cusps (88), though similar histological patterns and secondary/tertiary dentine deposition have been reported in non-functioning/unerupted teeth (89–91). Cervical pulp horns have been reported in the primary dentition (92). Categorization of the pulp horns in dental anomalies such as *dens evaginatus* has been described, for example, by Oehlers et al. (93) into wide, narrow, constricted and isolated pulp horns.

Notably, pulp horns can vary in appearance when the tooth is viewed from different positions. From a proximal view in a maxillary incisor, the pulp horn appears as a pointed projection (Fig. 14a). However, from a labial view, the tooth does not appear to have a horn/projection. Figure 14b shows another maxillary incisor with a similar proximal chamber morphology, but the pulp horn can only be identified from the labial view (encircled). This demonstrates that proximal views are not the best method to define the presence or shape of pulp horns in the anterior dentition. Because of the presence of occlusal cusps, pulp horn anatomy varies in the posterior dentition, and there is no consensus for defining the apical outline of pulp horns in the posterior dentition. Considering the apical extension of the roof/ceiling of the pulp chamber as a landmark for the apical border outline of the pulp horns is inappropriate since this apical extension may extend apical to the level of the CEJ (Fig.15).

Floor of the pulp chamber

Single-rooted teeth

The interpretation of where the pulp chamber ends (the floor) and the canal(s) begins is often challenging because the transition from the pulp chamber to the root canal is not demarcated macroscopically nor microscopically and certainly not radiographically (82, 94). The AAE, (79) and several Oral Biolo-

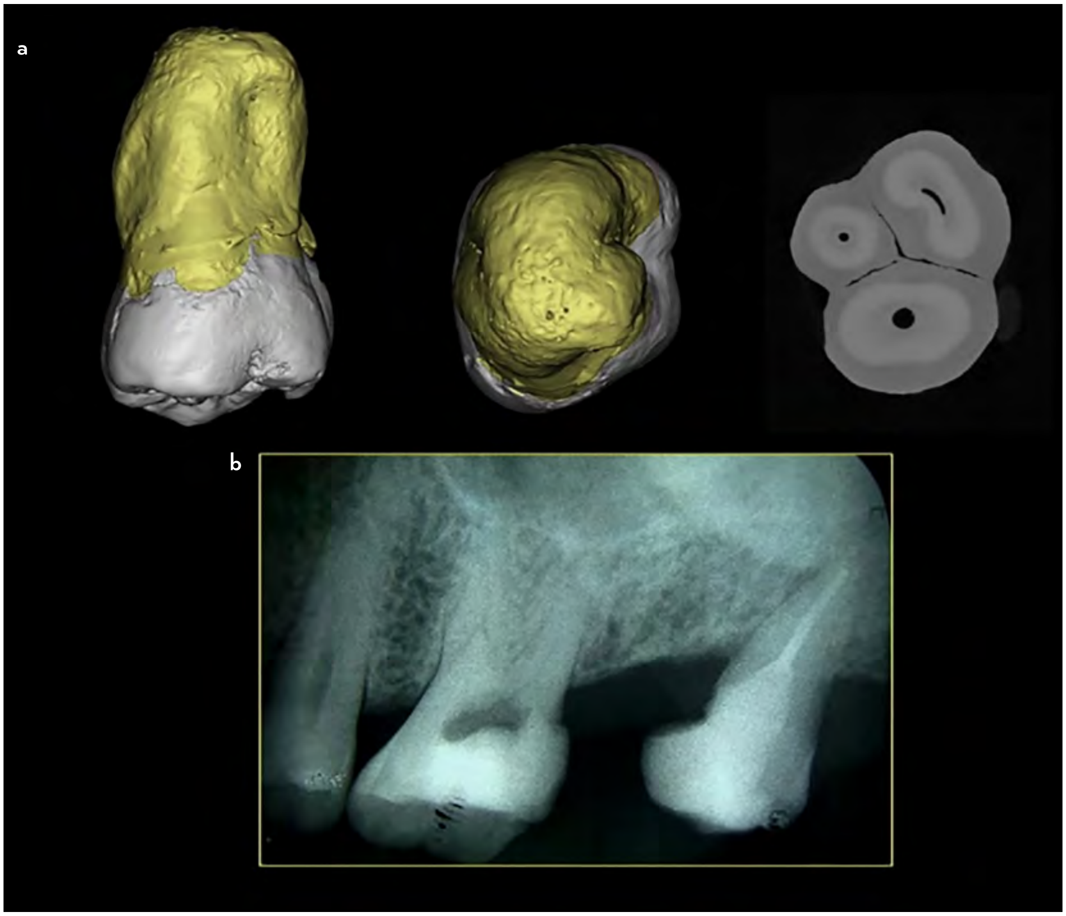

Figure 12. (a) A maxillary third molar with roots fused with cementum. (b) A periapical radiograph of a single-rooted maxillary third molar with one canal

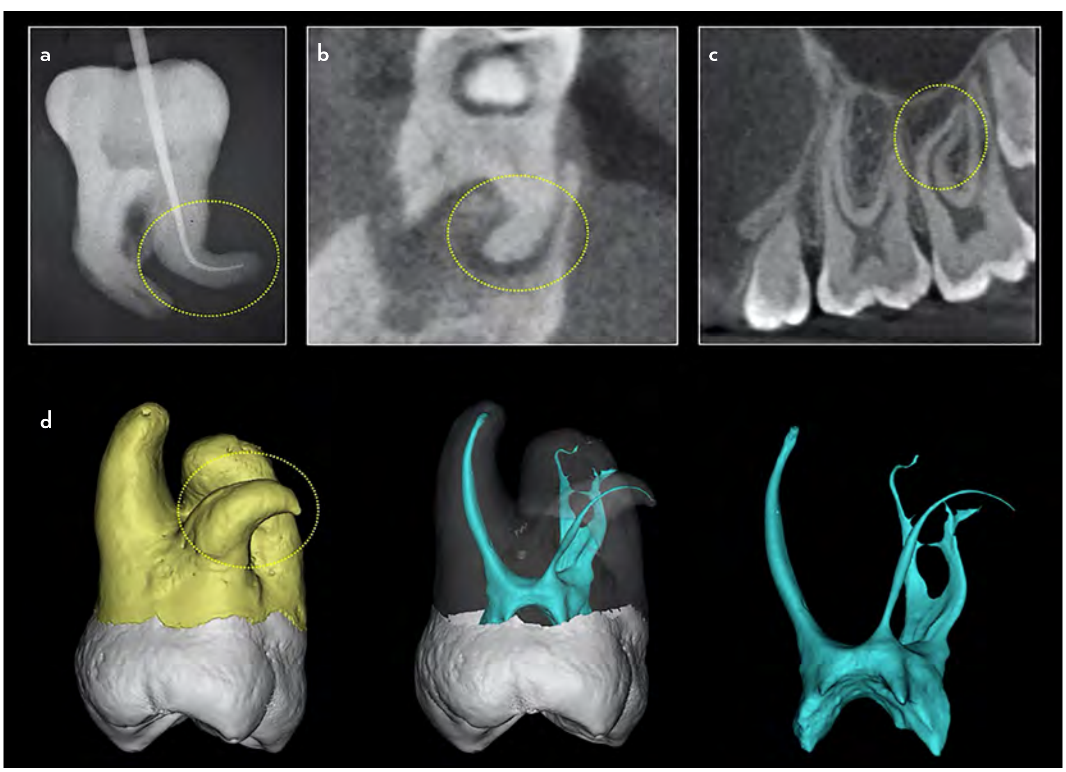

Figure 13. Different forms of root dilacerations detected in (a) periapical radiographs, (b, c) clinical CBCT images, and (d) micro-CT images

CBCT: Cone beam computed tomography

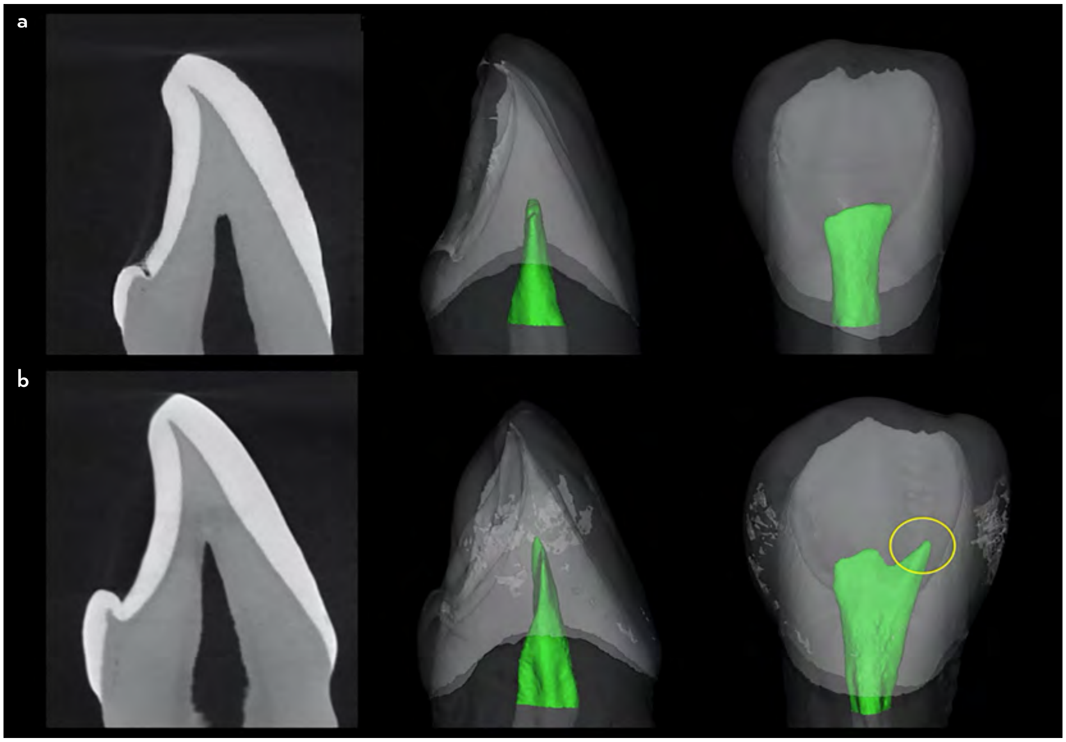

Figure 14. Micro-CT reconstructed images showing the difference between the proximal and labio-palatal views of the pulp chamber ceiling in maxillary incisors. Proximal views in (a) and (b) show similar morphology of the ceiling. Accurate detection of the pulp horn is identified in the labio-palatal view (circle)

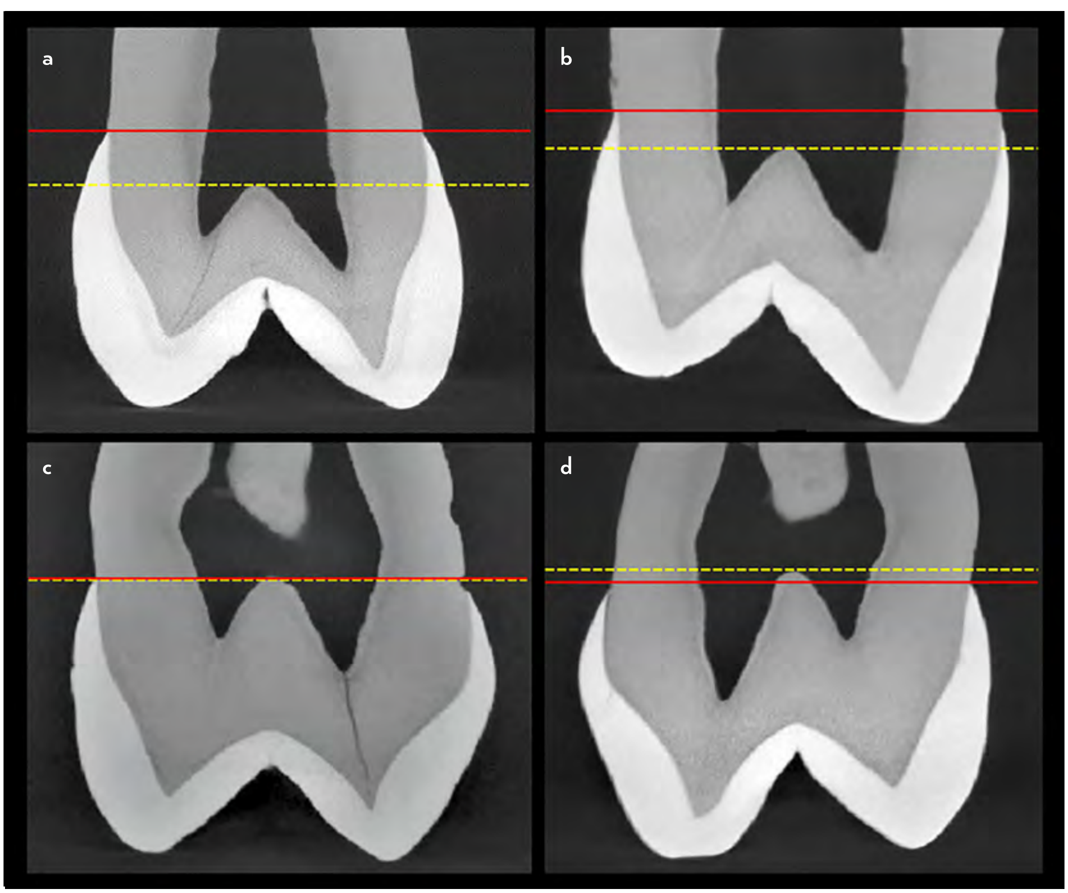

Figure 15. Micro-CT images of single-rooted maxillary premolars with mature roots (most apical point of the roof – yellow line) in relation to the most apical level of CEJ (red line). The level of the roof is: (a, b) coronal to the CEJ. (c) at the level of CEJ. (d) apical to the CEJ

CEJ: Cementoenamel junction

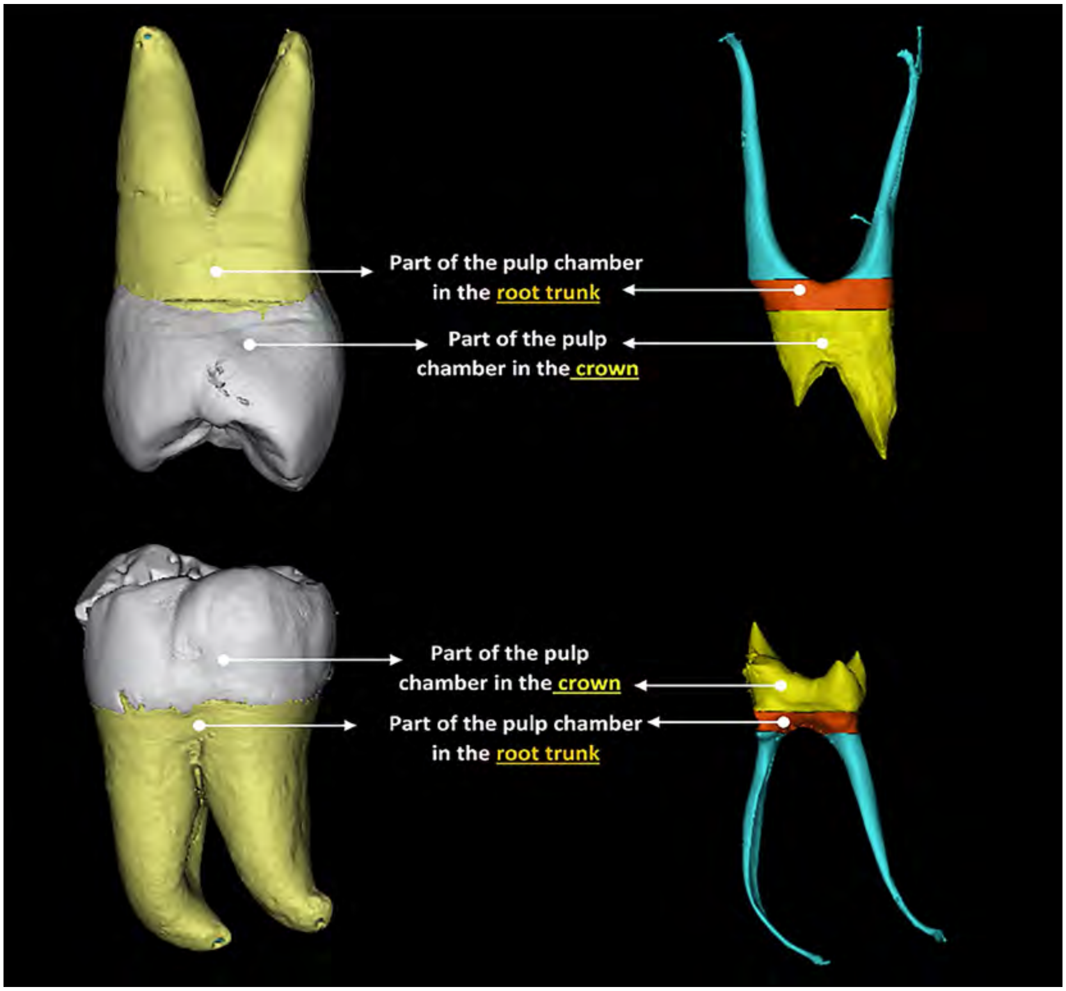

Figure 16. Micro-CT images showing the part of the pulp chamber related to the crown (at the level of CEJ), and the other related to the root trunk in double-rooted maxillary premolar (above) and mandibular molar (below). Reproduced with permission from Ahmed et al. (24)

CEJ: Cementoenamel junction

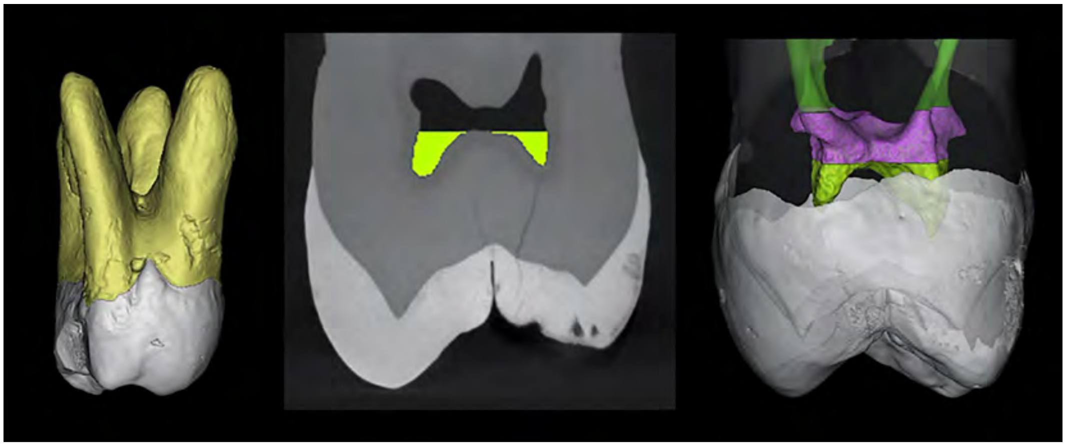

Figure 17. Micro-CT images showing the part of the pulp chamber (yellow) at the most apical level of the roof (at the level of CEJ) in a maxillary first molar. The 3D reconstructed image shows the two components of the pulp chamber (yellow – at the most apical level of the roof, purple – at the level of the pulp chamber floor)

gy textbooks (78, 84) define the pulp chamber as the portion of the pulp space within the anatomic crown of the tooth. This could be a consistent definition for single-rooted teeth but it needs further discussion and universal agreement.

Multi-rooted teeth

Defining the apical extent of the pulp chamber in multi-rooted teeth is controversial and not simple because the CEJ is not usually at the level of the floor of the pulp chamber (45, 82, 88),

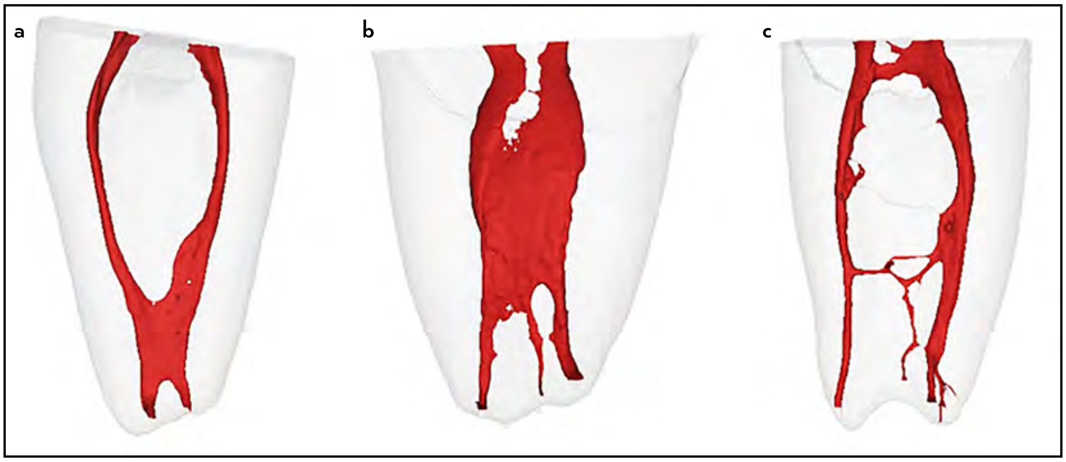

Figure 18. Different forms of inter-canal communications. (a) Isthmus in the apical third of the root. (b) Canal isthmus extending along the middle third of the canal. (c) Transverse canal anastomosis with communication to the external root surface

which is more often located some distance apical to the CEJ and thus corresponds to the root trunk (24, 82) (Fig. 16). Reports have confirmed that in the majority of molar teeth, the pulp chamber ceiling is at the level of the CEJ (86, 95) (Fig. 16, 17).

Most studies on root and canal anatomy did not define this anatomical landmark. The lack of a standard definition for the apical extent/floor of the pulp chamber can undermine the validity of comparisons among different studies, which define root canal configurations with unclear, confusing and subjective anatomical landmarks (24).

From the discussion above, it is obvious that a universal consensus is needed for the terminology used to define and describe pulp chamber anatomy, which also has different anatomical landmarks in teeth with anomalies (83).

Root Canal System

Transverse canal anastomosis (canal isthmus)

Transverse canal anastomosis and canal isthmus (as well as intercanal communication, intercanal connection, intercanal branch and anastomosis accessory canal) are terms that have been used interchangeably and refer to a narrow communication between two or more canals in the same root or between vascular elements in tissues (79, 96–98) (Fig. 18). However, a wide range of morphological variations for such inter-canal communications have been described, which have been categorized with/without communications with either the external root apex (24), as well as complete/incomplete (partial) based on certain morphological features (99) or measurements (100). Several definitions of canal isthmus have been used as follows:

- For the 2D classification of canal isthmus introduced by Hsu & Kim (101) (Table 1), some of the types do not have inter-canal communications (type I), which is not consistent with the definition of an isthmus.
- Gu et al. (102) introduced different types of isthmi (fin-shaped, web-shaped and ribbon-shaped isthmi) in the mesial root of mandibular first molars scanned using micro-CT (Table 2). The fin-shaped variant does not have a true connection between the canals.
- Fan et al. (103) introduced another 3D classification system based on micro-CT scanned mandibular molars. Type II (separate) refers to a narrow but incomplete connection existing between two canals from the top to bottom of the isthmus, which is also rather subjective, and does not follow the definition of an isthmus. Similar concerns are also related to the classification system introduced by Moe et al. (104).

For teeth with multiple canals and apical bifurcations, Keleş & Keskin (105) and Keleş et al. (106) defined the borders of an isthmus into a roof (or ceiling) (the most coronal level of the isthmus, where the definite connection between two root canals occurs) and floor (the most apical level of this definite connection before bifurcation) (Fig. 19). In this way, it is possible to measure and compare the volume, length, and surface areas of the isthmus. It is also possible to differentiate it from a transverse canal anastomosis, which does not have these anatomical features (boundaries) (Fig. 18c). Using the same concept, Yin et al. (107) expanded the canal isthmus into other types with/without floor and roof (Table 2).

These anatomical characteristics are consistent with a study that defined an isthmus when the two canals appeared as a single ribbon-shaped canal on the same cross-section for several consecutive cross-sections, while a transverse canal anastomosis (intercanal connection) between two canals was identified as an accessory pulp space commencing from a root canal in one cross-section that joins the other root canal in other cross-sections (108). Notably, the pulp tissues in the transverse canal anastomosis can undergo calcifications (because of age and irritation) changing the anastomosis to an incomplete connection between the canals (Fig. 20).

Lack of clarity exists over the definition of intercanal communications (isthmus or transverse canal anastomosis), which can be classified as a part of the root canals, or as a minor landmark with no impact on its classification (Fig. 21). The

TABLE 1. Summary of the classifications/categorizations used for root canal Isthmi

Hsu and Kim (1997)	
Type I	Roots with either two or three canals without visible communication.
Type II	Roots with two canals with a visible connection between the two main canals
Type III	Type III differs from type II by the presence of a canal between the two main canals – incomplete C-shaped canals with three canals are also included in this classification
Type IV	An extension from the canals to the isthmus area.
Type V	A real connection or corridor throughout the section.
Gu et al. (2009)	
Fin-shaped isthmus	A fin extending from one canal into the isthmus area.
Web-shaped isthmus	A complex and interconnected structure formed by irregular extension and fusion of canals in the isthmus area.
Ribbon-shaped isthmus	A definite ribbon-shaped connection between the two main canals
Fan et al. (2010)	
Type I	A sheet connection: narrow sheet and complete connection existing between two canals from the top to bottom of the isthmus.
Type II	Separate: narrow but incomplete connection existing between two canals from the top to bottom of the isthmus.
Type III	Mixed: incomplete isthmus existing above and/or below a complete isthmus.
Type IV	Cannular connection: narrow cannular communication between two canals.
Moe et al. (2017)	
Type I	Complete sheet structure containing a narrow sheet-like structure that connects the main MB and ML canals anywhere.
Type II	Incomplete sheet structure that contains a narrow sheet-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point.
Type III	Incomplete tubular structure that contains a tube-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point.
Type IV	Mixed complete structure that contains a narrow sheet and tube-like structure connecting the main MB and ML canals anywhere.
Type V	Mixed incomplete structure that contains a narrow sheet and tube-like structure extending from either the MB or ML canal or both but not completely connecting each other at any point.
Matsunaga et al. (2019)	
Incomplete isthmus	Each root cross-section was classified based on maximum isthmus diameter (>75 μm)
Complete isthmus	Each root cross-section was classified based on maximum isthmus diameter (50–75 μm)
Yin et al. (2021)	
Type I	Isthmus with a roof: isthmus between two canals with a coronal boundary only; the rest is connected with the main root canal or open to the apex.
Type II	Isthmus with a floor: isthmus between two canals with an apical boundary only; the rest is connected with the main root canal or open to the pulp chamber.
Type III	Band-shaped isthmus: isthmus between the two canals with both coronal and apical boundaries; it appears like a band connected to the two canals.
Type IV	Isthmus without boundaries: a complete connection between the two canals from the pulp chamber to the apex.

TABLE 2. Classification for accessory canals in the furcation area proposed by Yoshida et al. (129) 1975

Type	Definition
Type 1	Periodontium and pulpal chamber communicate through patent accessory canals.
Type 2	Accessory canals that originate from the pulp chamber and end in dentine.
Type 3	Accessory canals that originate from the periodontium and end in dentine.
Type 4	Accessory canals that originate from the pulp chamber go through dentine, and return to the pulp chamber.
Type 5	Accessory canals that originate from the periodontium, go through dentine and cementum, and return to the periodontium.
Type 6	Accessory canals found in dentine and/or cementum, but with no exit.

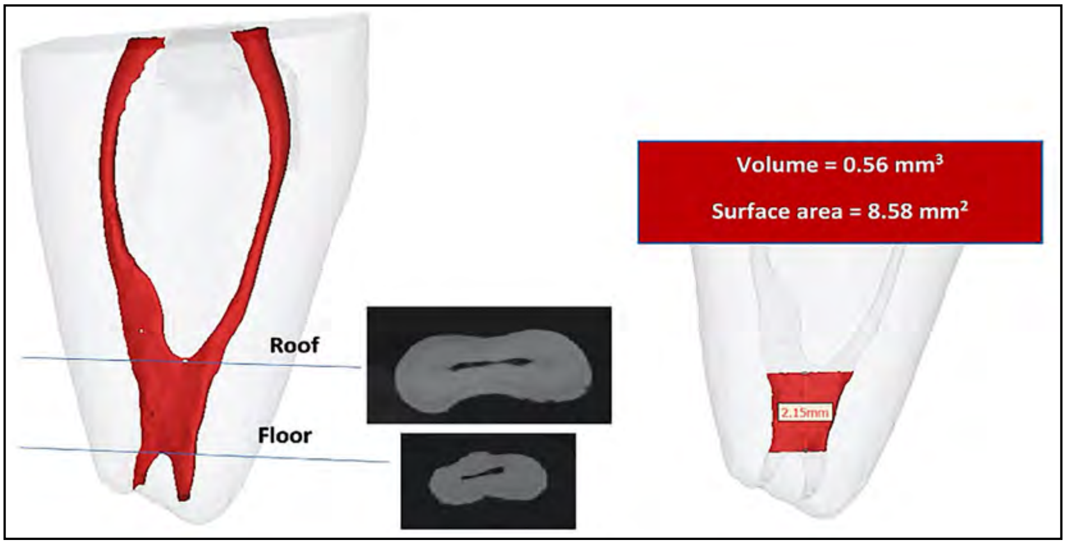

Figure 19. Defining the canal isthmus with a roof (ceiling) and floor facilitates 2D and 3D quantitative analysis

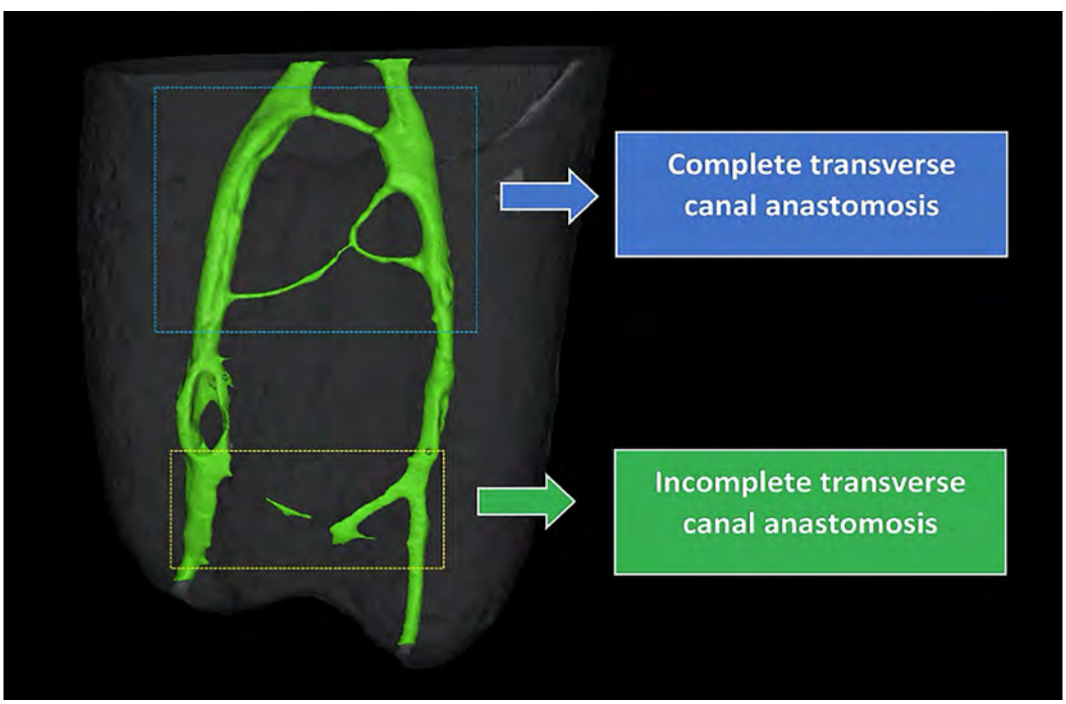

Figure 20. Complete and incomplete transverse canal anastomosis in a mesial root of a mandibular molar

use of the Vertucci system to classify the root canals could vary and become more complicated if inter-canal communications are considered as a part of the main canal configuration (109) (Fig. 21). The confusion is more obvious when micro-CT studies report canal types as 'Vertucci non-classifiable types' (24), since the criteria for defining intercanal communications were not mentioned by Vertucci (110). This may well be the case for some "complicated" canal configurations but it is misleading for other configurations because such investigations included intercanal communications as a part

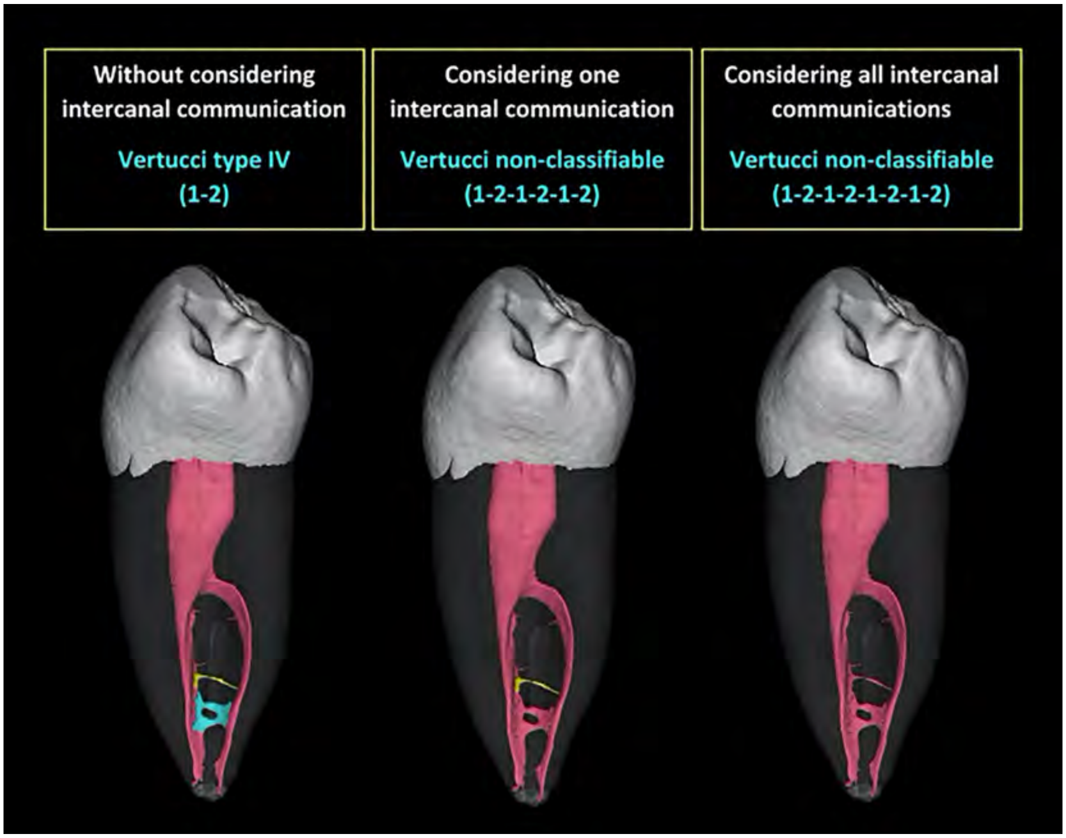

Figure 21. The use of Vertucci classification to classify a mandibular first premolar with and without considering the intercanal communication. Reproduced with permission from Ahmed et al. (24)

of the main canal (24). As a consequence, the comparison amongst studies creates conflicts not only because of the different methodology but also because the same system is being used in a different manner. The inclusion of transverse canal anastomosis as an integral part of the root canal configuration has been considered in other systems (111, 112).

Apical canal bifurcation

Divisions of the main root canal in the apical third are challenging to categorize, and their assessment varies between different observers. Some apical canal bifurcations are classified either as an accessory canal or a division of the main canal (24, 113) (Fig. 22). According to the AAE (79), an accessory canal is defined as 'any branch' of the main pulp canal or chamber that communicates with the external surface of the root. This is applicable to the main categories of accessory canals but does not differentiate accessory canals from bifurcating main canals in the apical third of the root. It is clear that a standard categorization of such anatomy has not yet been achieved (24).

From a clinical point of view, such canals can either be detected during canal exploration if they are 2–3 mm from the root apex (Fig. 23a), or can be identified on post-operative periapical radiographs (Fig. 23 b, c). During working length, apical bifurcations within 1 mm of the root apex are usually left uninstrumented since the apical stop is usually adjusted short of the radiographic apex. However, for apical bifurcations 2–3 mm from the root apex, a small size pre-curved size 8 or 10 K-file may be able to pass into one or both bifurcated canals (114) (Fig. 23d). It is also assumed that apical bifurcations (at any level from the root apex) related to teeth with single flattened and multiple canals are normally the natural continuation of wide bucco-lingual dimensions of such canals (114). Therefore, such apical bifurcations usually are considered as two separate canals during root canal preparation (Fig. 23d-f).

A recent report found that the mechanical preparation of mesial root canals containing an apical band-shaped isthmus (with apical canal bifurcations) caused transportation of the original canal position and resulted in procedural errors (Fig. 24) (115).

Accessory canal morphology

The propagation of microbial irritants occurs not only within the main root canal system but also in accessory canals that communicate with periradicular tissues, resulting in periodontitis anywhere along the root including the apex or furcation (13, 116, 117). The terminology and definitions applied to accessory canals is inconsistent, for instance, De-Deus (118) categorized accessory canal morphology into:

1) The lateral canal which extends from the main canal to the periodontal ligament (mainly in the body of the root);
2) The secondary canal which extends from the main canal to the periodontal ligament in the apical region;
3) The accessory canal which is derived from the secondary canal branching off to the periodontal ligament in the apical region.

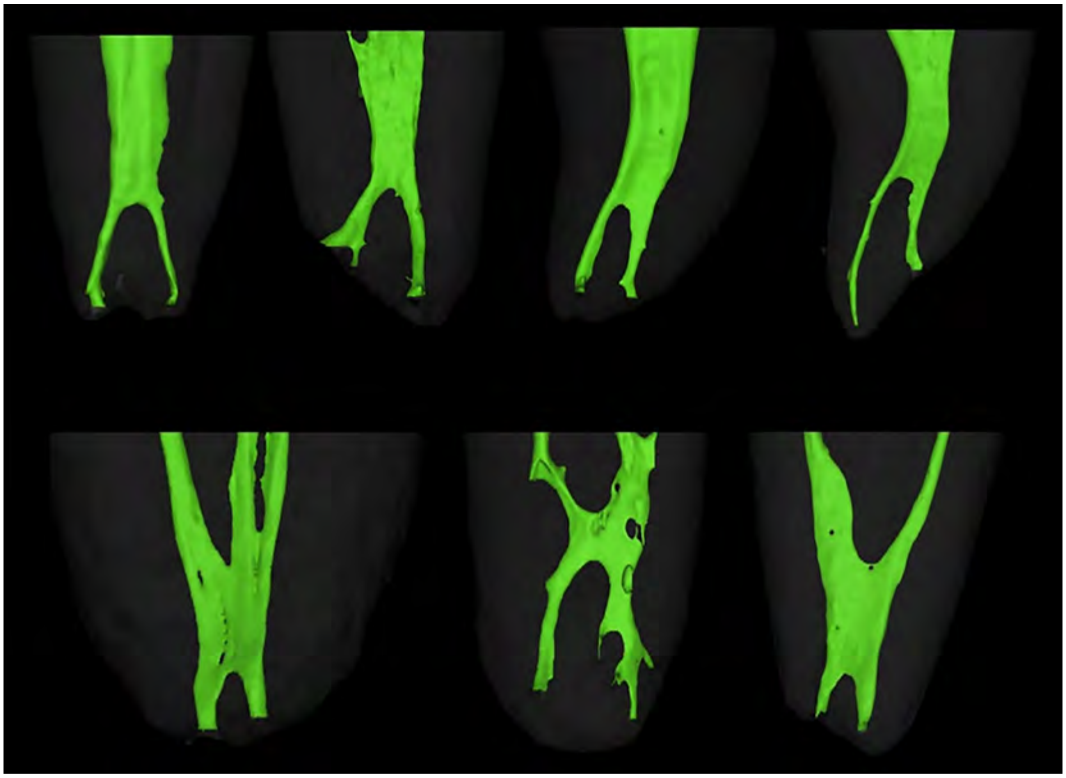

Figure 22. Micro-CT images of a range of apical canal bifurcations. Reproduced with permission from Ahmed (21)

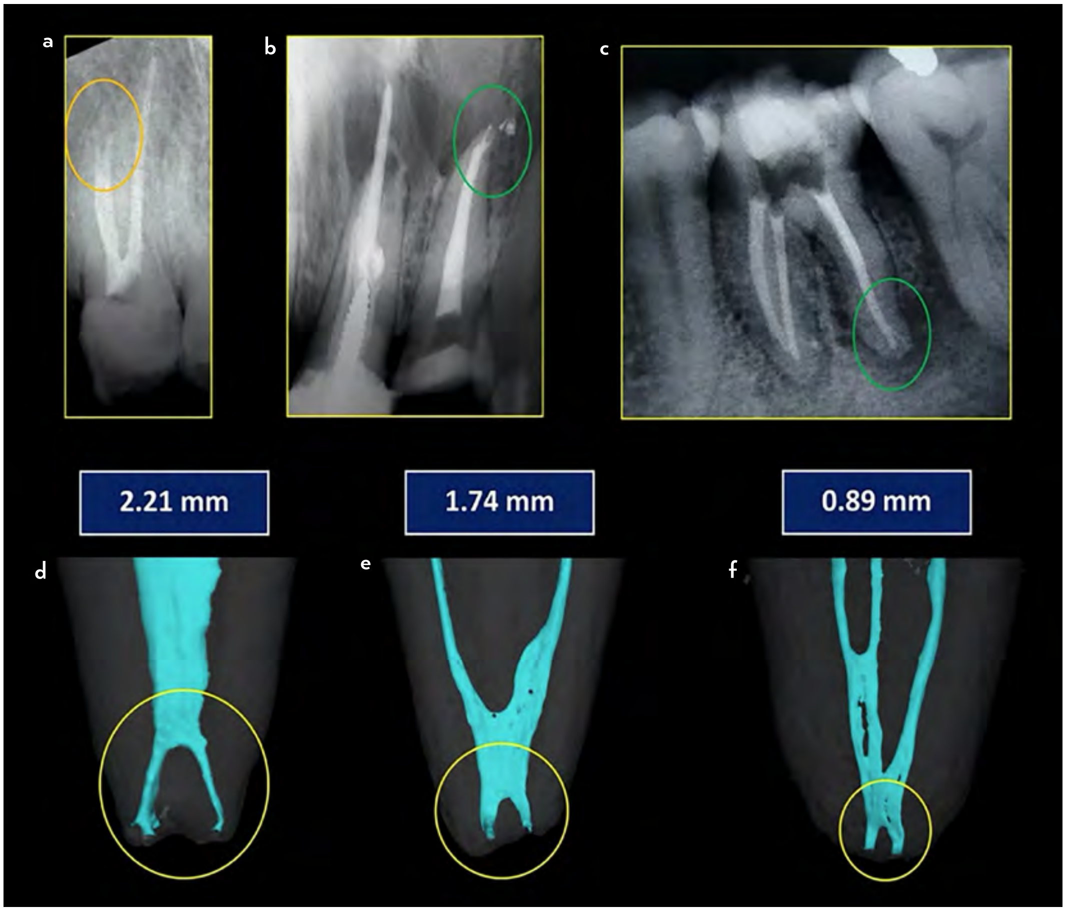

Figure 23. Periapical radiographs showing (a) apical canal bifurcation of the buccal canal in a double-rooted maxillary premolar. (b, c) Apical bifurcations (accessory canals) identified after root canal filling. (d) Micro-CT images showing different levels of apical bifurcation in a mandibular premolar, and mesial roots in mandibular molars (e, f)

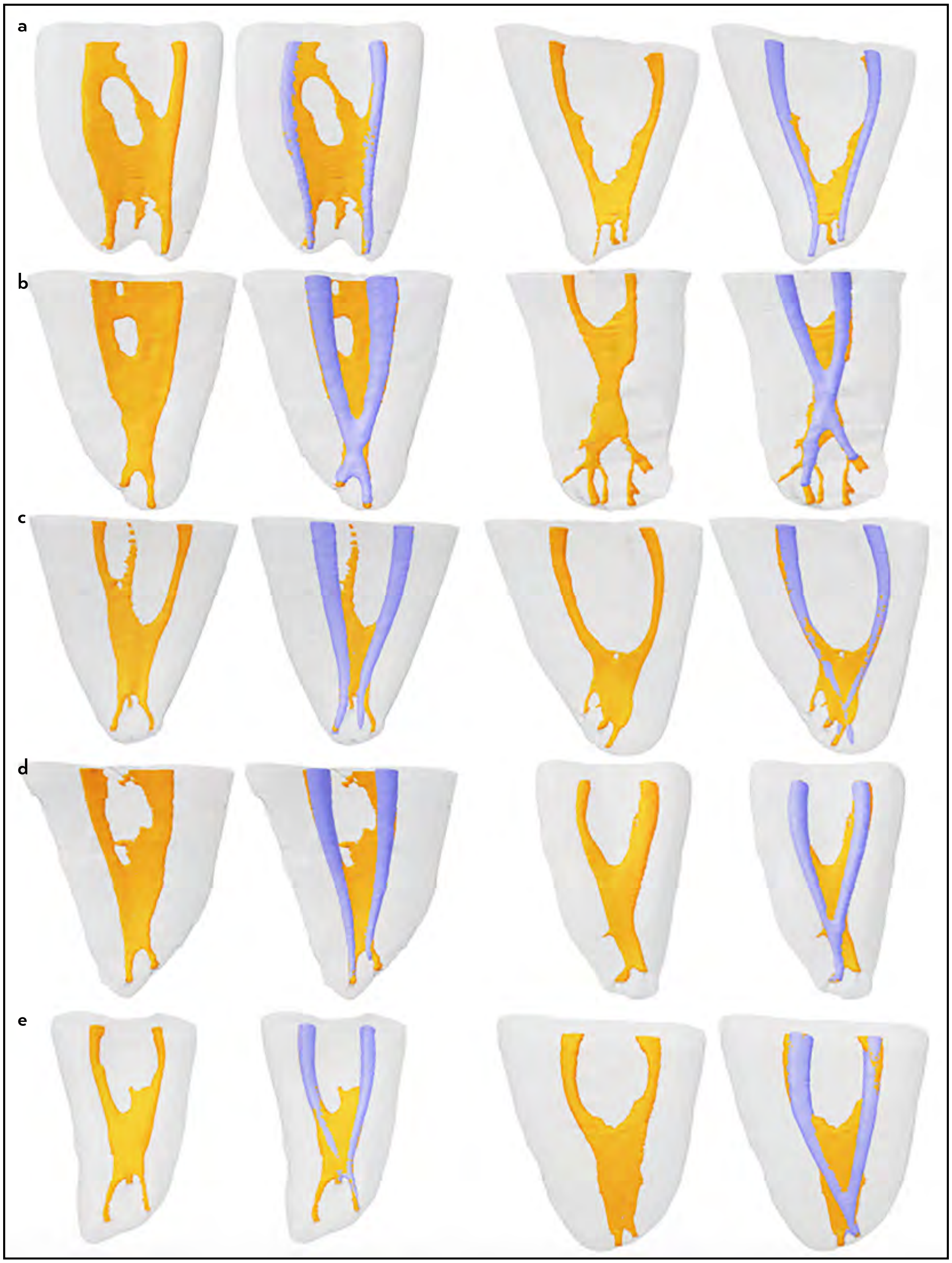

Figure 24. The procedural errors are shown by comparing the preoperative (yellow) and postoperative (purple) positions of the original canal (2). In (a), the instruments followed the main canal pathways but failed to enter a third apical canal originating from the band-shaped isthmus. (b) The instruments cross-prepared the apical canals through the isthmus (c) shows the creation of an artificial canal when the file failed to follow the apical curvature (d) and (e) one apical canal was missed during preparation. Reproduced and modified with permission from Keskin et al. (115)

Other terms, such as auxiliary, reticular and recurrent canals, have also been used (118–120). Cheung et al. (121) defined an accessory canal as "a fine branch of the pulp canal that diverged at an oblique angle from the main canal to exit into the periodontal ligament space", whilst a lateral canal was defined as "a branch diverging at almost right angles from the main canal". According to the AAE (79), 'an accessory canal is a branch of the main pulp canal or chamber that communicates with the external root surface'. By this definition, a lateral canal is also a type of accessory canal, located in the coronal or middle third of the root, usually extending horizontally from the main canal space. Others have defined lateral canals as accessory canals located in the coronal, middle as well as apical third of the root (122–124).

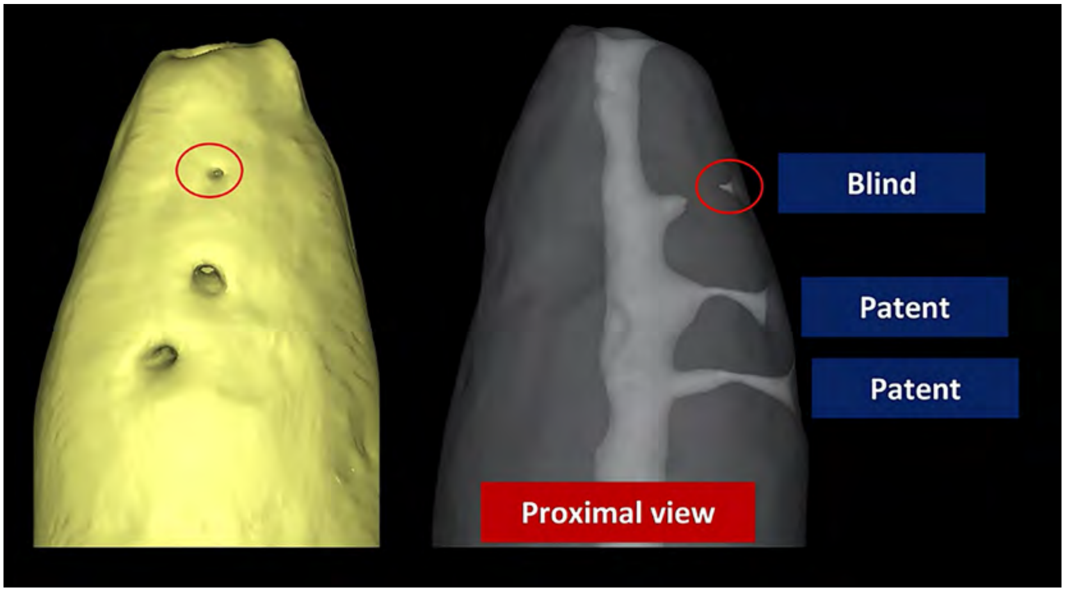

Figure 25. An example of patent and blind accessory canals in a buccal root of a maxillary premolar tooth – the opening at the external root surface (red circle) shows that the blind canal was previously patent. Reproduced with permission from Ahmed (21)

For accessory canals near the root apex, an apical delta has been defined as follows:

- A complex ramification of branches of the pulp canal located near the anatomical apex with the main canal not being discernible (121).
- A division from the main canal into three or more branches near the root apex with the main canal not being discernible (125).
- The region at or near the root apex where the main canal divides into multiple accessory canals (more than two) (126).
- A pulp canal morphology in which the main canal divides into multiple accessory canals at or near the apex (79).

Ramification is a term that defines a small gap resulting from a localized fragmentation of the epithelial root sheath that includes furcation canals, lateral canals, and apical accessory canals (79). Apical ramification is another term that refers to any branch from the main canal to the external root surface at the apex (127).

Recently, a new system for classifying accessory canals has been proposed (126), which has considered the location (apical, middle, coronal thirds and chamber canals), type (patent, blind or loop) and configuration (branching) for classifying the accessory canal morphology (Fig. 25). A similar approach has been presented in another study (128), which has categorized accessory canals into patent with/without branching and obstructed without branching.

For accessory canals in the furcation area, Yoshida et al. (129) classified accessory canals into six types according to the origin from the pulp chamber or periodontium (Table 2). Paras et al. (130) re-categorized the six types into four categories (true, blind, loop or sealed accessory canals). There is a concern, however, when using the single term 'accessory canals' to define canals originating from either the pulp chamber or periodontal tissues because the origin comes from two different tissue types (126). Other terms have been used:

- A furcation canal is an accessory canal located in the furcation (79).
- A chamber canal has also been used to define a small canal leaving the 'pulp chamber' that (usually) communicates with the external surface of the root (including the furcation). It can be of any type (patent, blind or loop) (126) (Fig. 26).
- Diverticulum is another term that defines blind accessory canals originating from either the pulp chamber or furcation (131, 132).
- Interradicular canal is a patent accessory canal (showing 2 portals of exit) connecting the pulp chamber floor with the bifurcation area (131, 132).

For accessory canals related to the apical foramen, Green (133) referred to 'accessory apical foramina' for those within 3.5 mm of the apex (more than three accessory foramina were considered as 'multiple foramina'). Foramina located beyond this limit were referred to as 'lateral canal foramina'. Cheung et al. (121) defined an auxiliary/accessory foramen as the exit of any accessory and lateral canal, or of an apical delta.

Apical constriction (minor apical foramen, minor apical diameter)

The apical extent of root canal treatment remains an important prognostic factor for successful outcomes (134). Considerable knowledge has been generated on the apical root canal anatomy since the last century (135–138). The development of non-invasive, high-resolution imaging systems has developed detailed qualitative and quantitative morphological data presentations of the apical region of the root and root canal including the apical constriction, apical foramen (major),

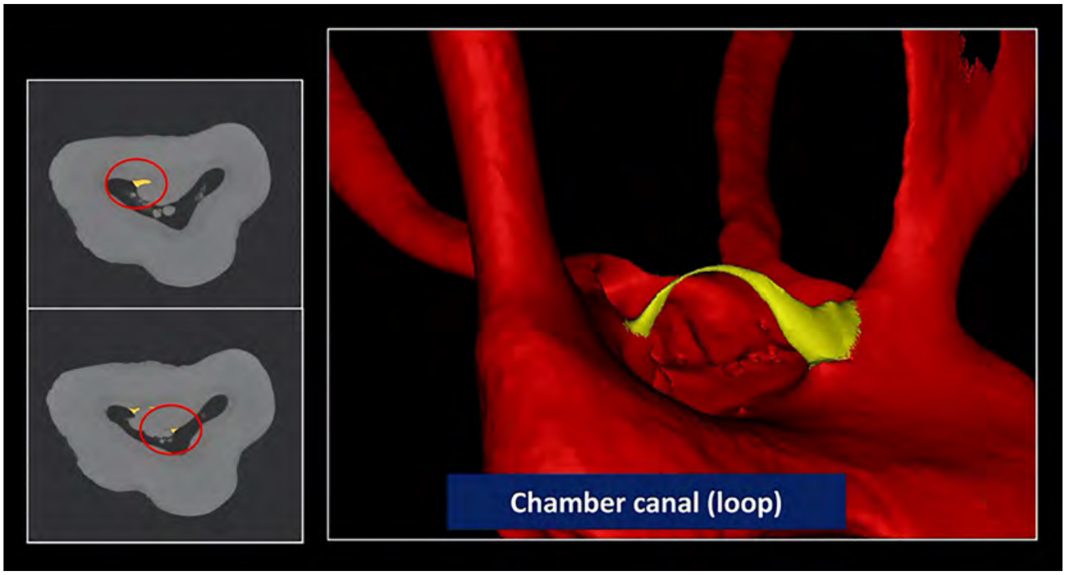

Figure 26. MicroCT images showing an example of a loop chamber canal. Reproduced with permission from Ahmed (21)

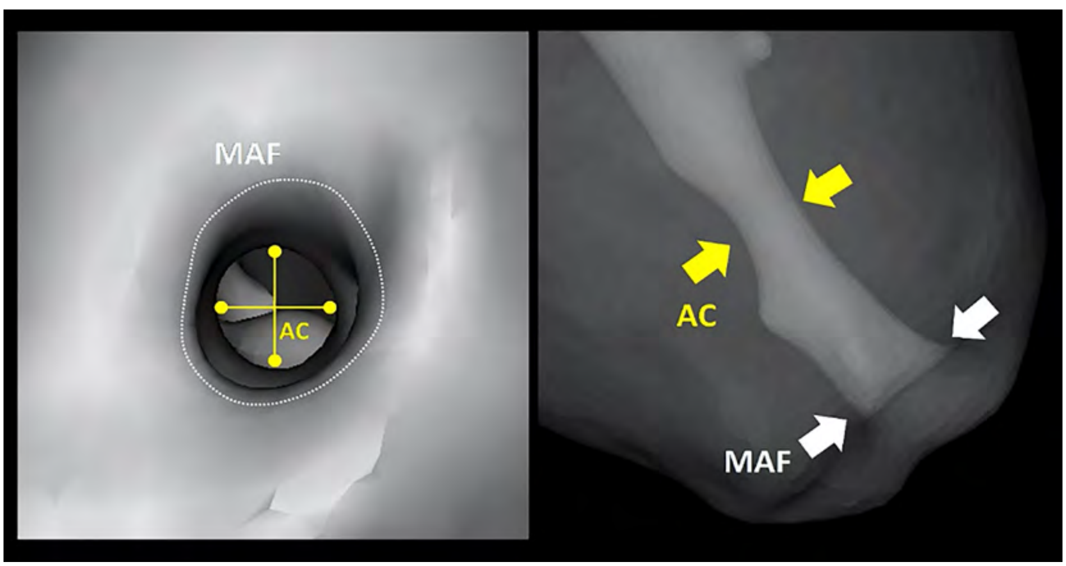

Figure 27. Micro-CT reconstructed images showing the location of the apical constriction (AC – yellow) in relation to the major apical foramen (MAF – white)

MAF: Major apical foramen, AC: Apical constriction

and anatomical root apex (139–142). Understanding the morphological features of the root apex anatomy using accurate, consistent terminology is important since such anatomy is involved in (or in close relation to) every step of the root canal treatment procedure starting from working length determination passing through root canal preparation steps (including negotiation, glide path preparation, patency, and mechanical instrumentation) ending with canal filling (143, 144).

Over the years, several terms have been used interchangeably to define the narrowest apical canal opening which represents the apical limit of root canal treatment procedures; this includes apical constriction (135–138, 145), minor (apical) foramen (138, 146), minor (apical) diameter (147) and physiological foramen (138–141, 148) (Fig. 27). The AAE (79) defines the apical constriction (minor apical diameter, minor diameter) as the apical portion of the root canal having the narrowest diameter; position may vary but is usually 0.5–1.0 mm short of the center of the major apical foramen, sometimes also called as the anatomical foramen (139–141, 148).

It has become obvious that the longitudinal sectioning method using high-resolution micro-CT images is challenging due to the software settings that need to be adjusted in the three-dimensional range to detect the "smallest diameter" of the apical foramen (142, 149). The topography and the location of the minor diameter may vary from one longitudinal section to the other. Moreover, as root canals are not completely round, the smallest diameter displayed in the longitudinal section does not necessarily correspond to the narrow-

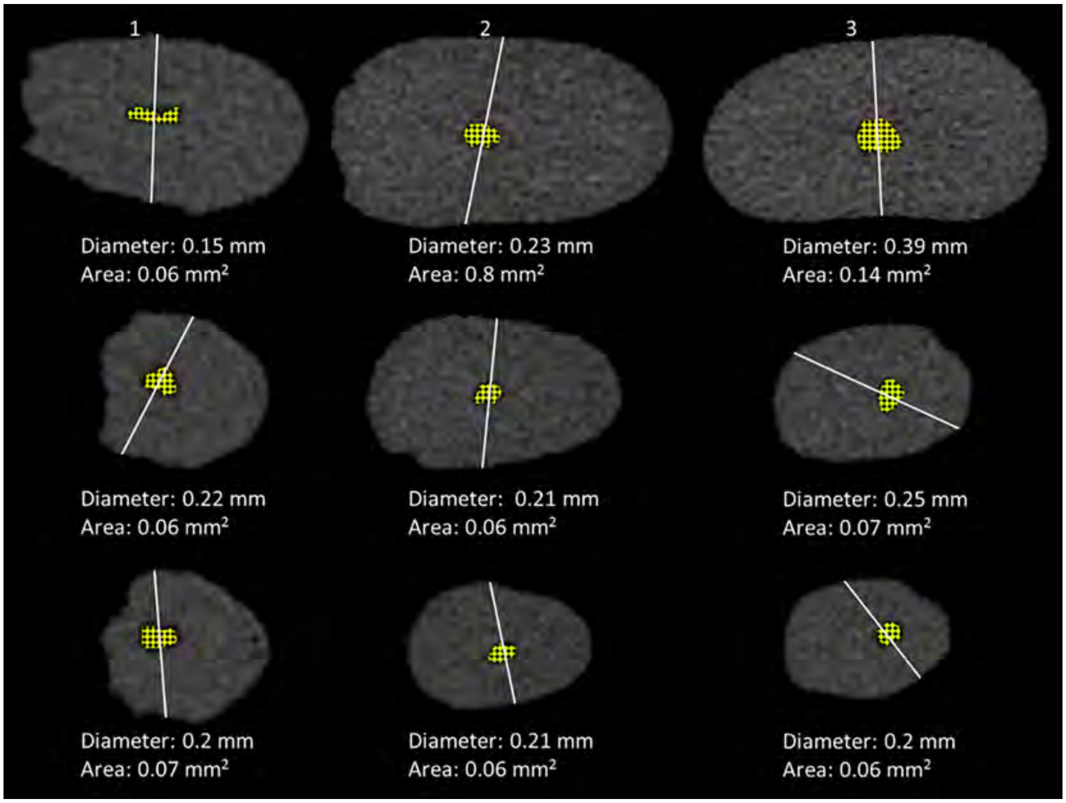

Figure 28. Axial root sections of micro-CT scanned teeth. The white lines show the proper position and direction of the plane of longitudinal section to accurately measure the smallest diameter of canal in different levels of the three roots. Yellow-black shade shows the area of the canal. The smallest diameter of the inside of the root canal (yellow-black area) does not necessarily correspond to the narrowest area of the diameter of the tooth root (white line). Reproduced with permission from Ahmed et al. (142)

est area of the root canal (Fig. 28). The smallest cross-sectional area of root canals can be measured easier in axial sections as demonstrated in micro-CT studies (149, 150).

Anatomical foramen (major apical foramen, major apical diameter)

The external opening of the root canal at the root surface has also been defined in different terms such as the apical foramen (137), major (apical) foramen (151), major (greater) apical diameter (147) and anatomical foramen (139–141, 148). The AAE (79) defines the apical foramen as the main apical opening of the root canal. It also defines the major apical diameter as the area of the apical foramen where the walls are farthest apart, usually located in the cementum (79). Others defined the opening of the root canal on the external root surface as the apical foramen and its outermost diameter was termed the 'major apical foramen' (152).

Directions for Resolving Controversial Terms in Root and Canal Anatomy

This review sets out a number of currently controversial terms related to the following:

- Root anatomy (apical root bifurcation, fusion and root dilaceration),
- Pulp chamber anatomy (pulp horn and floor of the pulp chamber),
- Root canal system (transverse canal anastomosis, canal isthmus, and apical canal bifurcations),
- Minor anatomical features of the root canal including accessory canals, apical constriction, and apical foramen.

A wide range of definitions has been presented from the available literature and textbooks of dental anatomy in different tooth types. It is obvious that consensus is needed for defining a range of anatomical structures in the root and canal system. The following considerations can also be helpful in achieving a universal agreement.

- As a result of the wide variations in anatomical structures, it could be sensible to define them according to the method used since some of the fine details identified in one method (such as patent accessory canals identified by micro-CT) may not be identified when using another diagnostic tool (such as CBCT and conventional radiographs). Therefore, it may be best to provide a general definition that can be applied to a specific term with further supplementary details added according to the details provided by the particular diagnostic tool used. As an example, an accessory canal can be defined as a branch of the main root canal or chamber which may or may not communicate with the external root surface. High-resolution diagnostic tools (such as micro-CT) may be able to identify the type of accessory canal (patent, blind or loop) that may not be identified on radiographic imaging and CBCT.

- Understanding root and canal anatomical features in different populations is important since some of the anatomical landmarks can be defined as an anomaly in one population (such as *radix entomolaris*), while a normal variation in another. Such information can be added in the definition of the term if relevant.

- The use of proper English in terminology deserves attention. An example, the term "ceiling" refers to the interior coronal surface of a structure, compared with a "roof" which refers to the external outer surface. The former is more accurate when defining the interior coronal surface of the pulp chamber.

CONCLUSION

There are a wide range of terms used to describe the same anatomical features of teeth, roots and root canal systems. A universal consensus amongst stakeholders (researchers, clinicians, educators and dental students) is needed for the terminology used to define root and canal anatomy to provide accurate and consistent descriptions of all key anatomical landmarks in roots and canals for use in education, research and clinical practice. Such a consensus and the use of common terminology will reduce confusion, as well as avoid misleading interpretations and inaccurate comparisons within and between laboratory and clinical studies; it will also be an invaluable development in dental education.

Disclosures

Authorship Contributions: Concept – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Design – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Supervision – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Funding – H.M.A.A.; Data analysis and/or interpretation – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Literature search – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Writing – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.; Critical review – H.M.A.A., A.K., T.G.W., V.N., H.D., O.A.P., P.M.H.D.

Conflict of Interest: All authors declared no conflict of interest.

Use of AI for Writing Assistance: No AI technologies utilized.

Financial Disclosure: This work is supported by Universiti Malaya grant number: RMF0602-2021.

Peer-review: Externally peer-reviewed.

REFERENCES

1. Kachlik D, Bozdechova I, Cech P, Musil V, Baca V. Mistakes in the usage of anatomical terminology in clinical practice. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2009; 153(2):157–61. [CrossRef]
2. McMullin E. Scientific controversy and its termination. In: Engelhardt, Jr. HT, Caplan AL, eds. Scientific controversies: Case studies in the resolution and closure of disputes in science and technology. Cambridge University Press, 1987; 49–92. [CrossRef]
3. Narasimhan MG. Controversy in science. J Biosci 2001; 26(3):299–304. [CrossRef]
4. Markle GE, and Petersen JC. Controversies in science and technology—a protocol for comparative research. Science, Technology, & Human Values 1981; 6:25-30. [CrossRef]
5. Kalantar-Zadeh K, McCullough PA, Agarwal SK, Beddhu S, Boaz M, Bruchfeld A, et al. Nomenclature in nephrology: preserving 'renal' and 'nephro' in the glossary of kidney health and disease. J Nephrol 2021; 34(3):639–48. [CrossRef]
6. Mubarak M. Changes in the terminology and diagnostic criteria of non-alcoholic fatty liver disease: Implications and opportunities. World J Gastrointest Pathophysiol 2024; 22(1);15:92864. [CrossRef]
7. Austin PF, Bauer SB, Bower W, Chase J, Franco I, Hoebeke P, et al. The standardization of terminology of lower urinary tract function in children and adolescents: Update report from the standardization committee of the International Children's Continence Society. Neurourol Urodyn 2016; 35(4):471–81. [CrossRef]
8. Nickel B, Barratt A, Copp T, Moynihan R, McCaffery K. Words do matter: a systematic review on how different terminology for the same condition influences management preferences. BMJ Open 2017; 10;7(7):e014129. [CrossRef]
9. Erueti C, Glasziou P, Mar CD, van Driel ML. Do you think it's a disease? a survey of medical students. BMC Med Educ 2012; 12:19. [CrossRef]
10. Ramer E. Controversies in temporomandibular joint disorder. Dent Clin North Am 1990; 34(1):125–133. [CrossRef]
11. Clarkson J. Review of terminology, classifications, and indices of developmental defects of enamel. Advanced Dental Research 1989; 3(2):104–9. [CrossRef]
12. Dababneh R, Khouri A, Addy M. Dentine hypersensitivity — an enigma? a review of terminology, mechanisms, aetiology and management. Br Dent J 1999; 187(11):606–11. [CrossRef]
13. Ahmed HMA. Different perspectives in understanding the pulp and periodontal intercommunications with a new proposed classification for endo-perio lesions. ENDO -Endod Pract Today 2012; 6(2):87–104.
14. Hamilton A, Lamey P, Ulhaq A, Besi E. Commonly used terminology in oral surgery and oral medicine: the patient's perspective. Br Dent J 2021; 230(12):823-30. [CrossRef]
15. Galic BS, Babovic SS, Vukadinovic S & Strkalj G. Clinical relevance of official anatomical terminology: The significance of using synonyms. Int J Morphol 2018; 36(4):1168-74. [CrossRef]
16. FIPAT (2019) Terminologia Anatomica (2nd ed.). FIPAT.library.dal.ca. Federative International Programme for Anatomical Terminology.
17. Navarrete-Dechent C, Liopyris K, Molenda MA, Braun R, Curiel-Lewandrowski C, Dusza SW, et al. Human surface anatomy terminology for dermatology: a Delphi consensus from the International Skin Imaging Collaboration. J Eur Acad Dermatol Venereol 2020; 34(11):2659–2663. [CrossRef]
18. Iwanaga J, Ibaragi S, Takeshita Y, Asaumi J, Horner K, Gest TR, Tubbs RS. Mandibular canal versus inferior alveolar canal: A Delphi study. Clin Anat 2021; 34(7):1095–1100. [CrossRef]
19. Cantatore G, Berutti E & Castellucci A. Missed anatomy: frequency and clinical impact. Endod Top 2006; 15(1):3–31. [CrossRef]
20. Vertucci FJ. Root canal morphology and its relationship to endodontic procedures. Endod Top 2005; 10(1):3–29. [CrossRef]
21. Ahmed HMA. A critical analysis of laboratory and clinical research methods to study root and canal anatomy. Int Endod J 2022; 55(Suppl 2):229-80. [CrossRef]
22. Ahmed HMA, Nagendrababu V, Duncan HF, Peters OA, Dummer PMH. Developing a consensus-based glossary of controversial terms in Endodontology. Int Endod J 2023; 56(7):788–91. [CrossRef]
23. Davies JR, Field J, Dixon J, Manzanares-Cespedes MC, Vital S, Paganelli C, et al. ARTICULATE: A European glossary of terms used in oral health professional education. Eur J Dent Educ 2023; 27(2):209–22. [CrossRef]
24. Ahmed HMA, Ibrahim N, Mohamad NS, Nambiar P, Muhammad RF, Yusoff M, Dummer PMH. Application of a new system for classifying root and canal anatomy in studies involving micro-computed tomography and cone beam computed tomography: Explanation and elaboration. Int Endod J 2021; 54(7):1056–82. [CrossRef]
25. Turner CG. Root number determination in maxillary first premolars for modern human populations. Am J Phys Anthropol 1981; 54(1);59–62. [CrossRef]
26. Bürklein, S, Heck, R & Schäfer, E. Evaluation of the root canal anatomy of maxillary and mandibular premolars in a selected German population using cone-beam computed tomographic data. J Endod 2017; 43(9):1448–52. [CrossRef]
27. Kupczik K, Hublin JJ. Mandibular molar root morphology in Neanderthals and Late Pleistocene and recent Homo sapiens. J Hum Evol 2010; 59(5): 525–41. [CrossRef]
28. Keleş A, Keskin C, Alqawasmi R, Versiani MA. Micro-computed tomographic analysis of the mesial root of mandibular first molars with bifid apex. Arch Oral Biol 2020; 117:104792. [CrossRef]
29. Versiani MA, Pécora JD, Sousa-Neto MD. The anatomy of two-rooted mandibular canines determined using micro-computed tomography. Int

Endod J 2011; 44(7):682–7. [CrossRef]
30. Ross IF, Evanchik PA. Root fusion in molars: incidence and sex linkage. J Periodontol 1981; 52(11):663–7. [CrossRef]
31. Hou GL, Tsai CC. The morphology of root fusion in Chinese adults (I). Grades, types, location and distribution. J Clin Periodontol 1994; 21(4):260–4. [CrossRef]
32. Zhang Q, Chen H, Fan B, Fan W, Gutmann JL. Root and root canal morphology in maxillary second molar with fused root from a native Chinese population. J Endod 2014; 40(6):871–5. [CrossRef]
33. Martins JN, Mata A, Marques D, Caramês J. Prevalence of root fusions and main root canal merging in human upper and lower molars: A cone-beam computed tomography *in vivo* study. J Endod 2016; 42(6):900–8. [CrossRef]
34. Marcano-Caldera M, Mejia-Cardona JL, Blanco-Uribe MDP, Chaverra-Mesa EC, Rodríguez-Lezama D, Parra-Sánchez JH. Fused roots of maxillary molars: characterization and prevalence in a Latin American sub-population: a cone beam computed tomography study. Restor Dent Endod 2019; 44(2):e16. [CrossRef]
35. Hou GL, Tsai CC, Huang JS. Relationship between molar root fusion and localized periodontitis. J Periodontol 1997; 68(4):313–9. [CrossRef]
36. Kato A, Ziegler A, Higuchi N, Nakata K, Nakamura H, Ohno N. Aetiology, incidence and morphology of the C-shaped root canal system and its impact on clinical endodontics. Int Endod J 2014; 47(11):1012–33. [CrossRef]
37. Ordinola-Zapata R, Martins JNR, Bramante CM, Villas-Boas MH, Duarte MH, Versiani MA. Morphological evaluation of maxillary second molars with fused roots: a micro-CT study. Int Endod J 2017; 50(12):1192–200. [CrossRef]
38. Qiu S, Chen Y, Tsauo C, Wu W, Huang D, Zhou X, et al. Microcomputed tomography analysis of the radicular residual dentin thickness in mandibular second molars after virtual fiber post placement: Identification of danger zones. J Prosthet Dent 2023; 130(1):109.e1–10. [CrossRef]
39. Hennekam RC, Biesecker LG, Allanson JE, Hall JG, Opitz JM, Temple IK, Carey JC; Elements of Morphology Consortium. Elements of morphology: general terms for congenital anomalies. Am J Med Genet A 2013; 161A(11):2726–33. [CrossRef]
40. de Sousa SM, Bramante CM. Dens invaginatus: treatment choices. Endod Dent Traumatol 1998; 14(4):152–8. [CrossRef]
41. Zhu J, Wang X, Fang Y, Von den Hoff JW, Meng L. An update on the diagnosis and treatment of dens invaginatus. Aust Dent J 2017; 62(3):261–75. [CrossRef]
42. Kritika S, Bhandari SS, Benyöcs G, Villa Machado PA, Bishnoi N, Restrepo Restrepo FA, Karthikeyan K, Ataide I, Mahalaxmi S. Demystifying dens invaginatus: Suggested modification of the classification based on a comprehensive case series. Eur Endod J 2022; 7(1):73–80. [CrossRef]
43. ALHumaid J, Buholayka M, Thapasum A, Alhareky M, Abdelsalam M, Bughsan A. Investigating prevalence of dental anomalies in Eastern Province of Saudi Arabia through digital orthopantomogram. Saudi J Biol Sci 2021; 28(5):2900–6. [CrossRef]
44. Keskin C, Toplu D, Keleş A. Dentine thickness in maxillary fused molars depends on the fusion type: An *ex vivo* micro-computed tomography study. Int Endod J 2023; 56(5):637–46. [CrossRef]
45. Nusstein JM. Application of root and pulp morphology related to endodontic therapy. In: RC Scheid, G Weiss, eds. Woelfel's Dental Anatomy, 8th edn. Philadelphia: Lippincott Williams & Wilkins, 2012; pp. 231–249.
46. Amoroso-Silva P, De Moraes IG, Marceliano-Alves M, Bramante CM, Zapata RO, Hungaro Duarte MA. Analysis of mandibular second molars with fused roots and shallow radicular grooves by using micro-computed tomography. J Conserv Dent 2018; 21(2):169–74. [CrossRef]
47. Loh HS. Root morphology of the maxillary first premolar in Singaporeans. Aust Dent J 1998; 43(6):399–402. [CrossRef]
48. Kim Y, Lee SJ, Woo J. Morphology of maxillary first and second molars analyzed by cone-beam computed tomography in a Korean population: variations in the number of roots and canals and the incidence of fusion. J Endod 2012; 38(8):1063–8. [CrossRef]
49. Aydin H. Analysis of root and canal morphology of fused and separate rooted maxillary molar teeth in Turkish population. Niger J Clin Pract 2021; 24(3):435–442. [CrossRef]
50. Buchanan GD, Gamieldien MY, Fabris-Rotelli I, Van Schoor A, Uys A. Root and canal morphology of maxillary second molars in a Black South African subpopulation using cone-beam computed tomography and two classifications. Aust Endod J 2023; 49(Suppl 1):217–227. [CrossRef]
51. Ahmed HMA. Anatomical challenges, electronic working length determination and current developments in root canal preparation of primary molar teeth. Int Endod J 2013; 46(11):1011–22. [CrossRef]
52. Ozcan G, Sekerci AE, Cantekin K, Aydinbelge M, Dogan S. Evaluation of root canal morphology of human primary molars by using CBCT and comprehensive review of the literature. Acta Odontol Scand 2016; 74(4):250–8. [CrossRef]
53. Manning SA. Root canal anatomy of mandibular second molars. Part II. C-shaped canals. Int Endod J 1990; 23(1):40–5. [CrossRef]
54. Gao Y, Fan B, Cheung GS, Gutmann JL, Fan M. C-shaped canal system in mandibular second molars part IV: 3-D morphological analysis and transverse measurement. J Endod 2006; 32(11):1062–5. [CrossRef]
55. Carlsen O. Root complex and root canal system: a correlation analysis using one-rooted mandibular second molars. Scand J Dent Res 1990; 98(4):273–85. [CrossRef]
56. Turner, C. G. II, Nichol, C. R. and Scott, G. R. Scoring procedures for key morphological traits of the permanent dentition: The Arizona State University dental anthropology system. In: Kelley, M.A. and Larsen, C.S., Eds., Advances in Dental Anthropology, Wiley-Liss, New York, 1991; 13-31.
57. Walker RT. The root canal anatomy of mandibular incisors in a southern Chinese population. Int Endod J 1988; 21(3):218–23. [CrossRef]
58. Nelson, CT. The teeth of the Indians of pecos pueblo. J Phys Anthr 1938; 23:261–93. [CrossRef]
59. Pedersen, PO. The East Greenland Eskimo dentition: Numerical variations and anatomy. Meddelelser om Grönland, 1949; 142:l244.
60. Wright, KE. The Use of Dental Morphology to Identify an Ontario Iroquois Ossuary Population. M.A. thesis. McMaster University, Hamilton. 1977.
61. Atieh MA. Root and canal morphology of maxillary first premolars in a Saudi population. J Contemp Dent Pract 2008: 1;9(1):46–53. [CrossRef]
62. Senan EM, Alhadainy HA, Genaid TM, Madfa AA. Root form and canal morphology of maxillary first premolars of a Yemeni population. BMC Oral Health 2018; 31;18:94. [CrossRef]
63. Faraj BM, Abdulrahman MS, Faris TM. Visual inspection of root patterns and radiographic estimation of its canal configurations by confirmation using sectioning method. An *ex vivo* study on maxillary first premolar teeth. BMC Oral Health 2022; 22:166. [CrossRef]
64. Neelakantan P, Subbarao C, Ahuja R, Subbarao CV. Root and canal morphology of Indian maxillary premolars by a modified root canal staining technique. Odontology 2011; 99(1):18–21. [CrossRef]
65. Versiani MA, Carvalho KKT, Martins JNR, Custódio ALN, Castro MAA, Akaki E, Silva-Sousa YTCS, Sousa-Neto MD. Effects of root canal enlargement on unprepared areas and coronal dentine thickness of three-rooted maxillary first premolars with different root configurations: A stepwise micro-CT study. Int Endod J 2022; 55(11):1262–73. [CrossRef]
66. Li J, Li L, Pan Y. Anatomic study of the buccal root with furcation groove and associated root canal shape in maxillary first premolars by using micro-computed tomography. J Endod 2013; 39(2):265–8. [CrossRef]
67. Zhang R, Wang H, Tian YY, Yu X, Hu T, Dummer PM. Use of cone-beam computed tomography to evaluate root and canal morphology of mandibular molars in Chinese individuals. Int Endod J 2011; 44(11):990–9. [CrossRef]
68. Silva EJ, Nejaim Y, Silva AV, Haiter-Neto F, Cohenca N. Evaluation of root canal configuration of mandibular molars in a Brazilian population by using cone-beam computed tomography: an *in vivo* study. J Endod 2013; 39(7):849–52. [CrossRef]
69. Silva EJ, Nejaim Y, Silva AI, Haiter-Neto F, Zaia AA, Cohenca N. Evaluation of root canal configuration of maxillary molars in a Brazilian population using cone-beam computed tomographic imaging: an *in vivo* study. J Endod 2014; 40(2):173–6. [CrossRef]
70. Carlsen O, Alexandersen V, Heitmann T, Jakobsen P. Root canals in one-rooted maxillary second molars. Scand J Dent Res 1992; 100(5):249–56. [CrossRef]
71. Ali A, Ahmed HMA, Zoya A, Arslan, H. Single Root with C-shaped Canal Configuration in all the Posterior Teeth of a Patient: A Rare Case Report. J Clin Diagn Res 2023; 17(5):Zd01–5. [CrossRef]
72. Jafarzadeh H, Abbott PV. Dilaceration: review of an endodontic challenge. J Endod 2007; 33(9):1025–30. [CrossRef]
73. Hamasha AA, Al-Khateeb T, Darwazeh A. Prevalence of dilaceration in Jordanian adults. Int Endod J 2002; 35(11):910–2. [CrossRef]

74. Chohayeb AA. Dilaceration of permanent upper lateral incisors: frequency, direction, and endodontic treatment implications. Oral Surg Oral Med Oral Pathol 1983; 55(5):519–20. [CrossRef]
75. Santana EJB, Consolaro A, Tavano O. Determinação da prevalência e estudo morfológico da dilaceração radicular. Revista da Faculdade de Odontologia da UFBA 1993; 12:40–52.
76. Silva BF, Costa LE, Beltrão RV, Rodrigues TL, Farias RL, Beltrão RT. Prevalence assessment of root dilaceration in permanent incisors. Dental Press J Orthod 2012; 17(6):97–102. [CrossRef]
77. Asheghi B, Sahebi S, Zangooei Booshehri M, Sheybanifard F. Evaluation of Root Dilaceration by Cone Beam Computed Tomography in Iranian South Subpopulation: Permanent Molars. J Dent (Shiraz) 2022; 23(Suppl 2):369–76.
78. Scheid R. Woelfel's Dental Anatomy. 8th ed. Lippincott Williams & Wilkins. 2012; 333.
79. American Association of Endodontists (AAE). (2020) Glossary of Terms. American Association of Endodontists. Available at: https://www.aae.org/specialty/download/glossary-of-endodontic-terms/ Accessed on Oct 18 2024.
80. Çelik, B, Çelik, ME. Root dilaceration using deep learning: A diagnostic approach. Appl Sci 2023; 13(14):8260. [CrossRef]
81. Bjørndal L, Carlsen O, Thuesen G, Darvann T, Kreiborg S. External and internal macromorphology in 3D-reconstructed maxillary molars using computerized X-ray microtomography. Int Endod J 1999; 32(1):3–9. [CrossRef]
82. Nelson SJ, Ash MM. Wheeler's Dental Anatomy, Physiology and Occlusion. St. Louis: Elsevier, 2010; pp. 111–112.
83. Ahmed HMA, Wolf TG, Rossi-Fedele G, Dummer PMH. The study and relevance of pulp chamber anatomy in Endodontics – A comprehensive review. Eur Endod J 2024; 9(1):18–34. [CrossRef]
84. Nanci A. Ten Cate's Oral Histology. St. Louis: Elsevier, 2013; pp. 165– 204.
85. Versiani MA, Basrani, B, Sousa-Neto MD. (Eds.). The root canal anatomy in permanent dentition (No. 168447). Springer, 2019. [CrossRef]
86. Deutsch AS, Musikant BL. Morphological measurements of anatomic landmarks in human maxillary and mandibular molar pulp chambers. J Endod 2004; 30(6):388–90. [CrossRef]
87. Azim AA, Azim KA, Deutsch AS, Huang GT. Acquisition of anatomic parameters concerning molar pulp chamber landmarks using cone-beam computed tomography. J Endod 2014; 40(9):1298–302. [CrossRef]
88. Oi T, Saka H, Ide Y. Three-dimensional observation of pulp cavities in the maxillary first premolar tooth using micro-CT. Int Endod J 2004; 37(1):46–51. [CrossRef]
89. Thomas, OAB. A histologic study and comparison of the pulps of embedded and erupted third molar teeth. J Am Dent Assoc 1940; 27(6):886–93. [CrossRef]
90. Nitzan DW, Michaeli Y, Weinreb M, Azaz B. The effect of aging on tooth morphology: a study on impacted teeth. Oral Surg Oral Med Oral Pathol 1986; 61(1):54–60. [CrossRef]
91. Nicklisch N, Schierz O, Enzmann F, Knipper C, Held P, Vach W, et al. Dental pulp calcifications in prehistoric and historical skeletal remains. Ann Anat 2021; 235:151675. [CrossRef]
92. Goto G, Zhang Y. Study of cervical pulp horns in human primary molars. J Clin Pediatr Dent 1995; 20(1):41–4.
93. Oehlers FA, Lee KW, Lee EC. Dens evaginatus (evaginated odontome). Its structure and responses to external stimuli. Dent Pract Dent Rec 1967; 17(7):239–44.
94. Phulari RGS. Textbook of Dental Anatomy, Physiology and Occlusion, 2nd ed. New Delhi: Jaypee Brothers Medical Publishers, 2019; p. 238–248.
95. Lokade, J, Rawlani, S, Baheti, R, Roy, S, Chandak, M, Lohe, V. Morphological Measurements of Anatomic Landmarks in Human Mandibular Molar Pulp Chambers - An *in vivo* Study. J Korean Dent Sci 2011; 4(1):1–5. [CrossRef]
96. Verma P, Love RM. A Micro CT study of the mesiobuccal root canal morphology of the maxillary first molar tooth. Int Endod J 2011; 44(3):210–7. [CrossRef]
97. Ordinola-Zapata R, Martins JNR, Niemczyk S, Bramante CM. Apical root canal anatomy in the mesiobuccal root of maxillary first molars: influence of root apical shape and prevalence of apical foramina - a micro-CT study. Int Endod J 2019; 52(8):1218–27. [CrossRef]
98. Natanasabapathy V, Arul B, Santosh SS, Vasudevan A, Mahendran SS, Namasivayam A, et al. Prevalence and morphology of root canal isthmus in human permanent teeth using micro-computed tomography: A systematic review. Saudi Endod J 2021; 11(2):142–53. [CrossRef]
99. Weller RN, Niemczyk SP, Kim S. Incidence and position of the canal isthmus. Part 1. Mesiobuccal root of the maxillary first molar. J Endod 1995; 21(7):380–3. [CrossRef]
100. Matsunaga S, Yamada M, Kasahara N, Kasahara M, Odaka K, Fujii R, et al. Tooth root cross-section variations of significance for endodontic microsurgery and predicted risk of concealed canal isthmus based on cross-sectional morphology: Three-dimensional morphological analysis of Japanese maxillary first molars using micro-CT. J Hard Tissue Biol 2019; 28(2):153–8. [CrossRef]
101. Hsu YY, Kim S. The resected root surface. The issue of canal isthmuses. Dent Clin North Am 1997; 41(3):529–40. [CrossRef]
102. Gu L, Wei X, Ling J, Huang X. A microcomputed tomographic study of canal isthmuses in the mesial root of mandibular first molars in a Chinese population. J Endod 2009; 35(3):353–6. [CrossRef]
103. Fan B, Pan Y, Gao Y, Fang F, Wu Q, Gutmann JL. Three-dimensional morphologic analysis of isthmuses in the mesial roots of mandibular molars. J Endod 2010; 36(11):1866–9. [CrossRef]
104. Moe MMK, Ha JH, Jin MU, Kim YK, Kim SK. Anatomical profile of the mesial root of the Burmese mandibular first molar with Vertucci's type IV canal configuration. J Oral Sci 2017; 59(4):469–74. [CrossRef]
105. Keleş A, Keskin C. A micro-computed tomographic study of band-shaped root canal isthmuses, having their floor in the apical third of mesial roots of mandibular first molars. Int Endod J 2018; 51(2):240–6. [CrossRef]
106. Keleş A, Keskin C, Çiftçioğlu E, Alak G. Evaluation of the band-shaped isthmuses in the mesiobuccal root canal system using micro-computed tomography. Clin Oral Investig 2022; 26(9):5909–14. [CrossRef]
107. Yin X, Chang JWW, Wang Q, Zhang C, Wang X. Three-dimensional morphologic classifications and analysis of canal isthmuses in permanent molars. Surg Radiol Anat 2021; 43(11):1793–9. [CrossRef]
108. Somma F, Leoni D, Plotino G, Grande NM, Plasschaert A. Root canal morphology of the mesiobuccal root of maxillary first molars: a micro-computed tomographic analysis. Int Endod J 2009; 42(2):165–74. [CrossRef]
109. Al-Rammahi, HM, Ahmed, HMA & Chai, WL. Microcomputed-Tomographic analysis of the root canal morphology of the mandibular first molars in a Malaysian subpopulation using two classification systems. Int J Morphol 2024; 42(1):28–34. [CrossRef]
110. Vertucci FJ. Root canal anatomy of the human permanent teeth. Oral Surg Oral Med Oral Pathol 1984; 58(5):589–99. [CrossRef]
111. Pineda F. Roentgenographic investigation of the mesiobuccal root of the maxillary first molar. Oral Surg Oral Med Oral Pathol 1973; 36(2):253–60. [CrossRef]
112. Green D. Double canals in single roots. Oral Surg Oral Med Oral Pathol 1973; 35(5):689–96. [CrossRef]
113. Ahmed HMA, Versiani MA, De-Deus G, Dummer PMH. A new system for classifying root and root canal morphology. Int Endod J 2017; 50(8):761–70. [CrossRef]
114. Xu T, Gao X, Fan W, Fan B. Micro-computed tomography evaluation of the prevalence and morphological features of apical bifurcations. J Dent Sci 2020; 15(1):22–7. [CrossRef]
115. Keskin C, Pirimoğlu B, Çiftçioğlu E, Dinger E, Kömeç O, Keleş A. Shaping outcomes of Reciproc Blue and Rotate in roots canals with band-shaped isthmuses: micro-CT study. Clin Oral Investig 2023; 27(12):7337–44. [CrossRef]
116. Dammaschke T, Witt M, Ott K, Schäfer E. Scanning electron microscopic investigation of incidence, location, and size of accessory foramina in primary and permanent molars. Quintessence Int 2004; 35(9):699–705.
117. Jang JH, Lee JM, Yi JK, Choi SB, Park SH. Surgical endodontic management of infected lateral canals of maxillary incisors. Restor Dent Endod 2015; 40(1):79–84. [CrossRef]
118. De Deus QD. Frequency, location, and direction of the lateral, secondary, and accessory canals. J Endod 1975; 1(11):361–6. [CrossRef]
119. Rubach WC, Mitchell DF. Periodontal disease, accessory canals and pulp pathosis. J Periodontol 1965; 36(1):34–8. [CrossRef]
120. Barbosa FO, Gusman H, Pimenta de Araújo MC. A comparative study on the frequency, location, and direction of accessory canals filled with the

hydraulic vertical condensation and continuous wave of condensation techniques. J Endod 2009; 35(3):397–400. [CrossRef]
121. Cheung GS, Yang J, Fan B. Morphometric study of the apical anatomy of C-shaped root canal systems in mandibular second molars. Int Endod J 2007; 40(4):239–46. [CrossRef]
122. Calişkan MK, Pehlivan Y, Sepetçioğlu F, Türkün M, Tuncer SS. Root canal morphology of human permanent teeth in a Turkish population. J Endod 1995; 21(4):200–4. [CrossRef]
123. Sert S, Bayirli GS. Evaluation of the root canal configurations of the mandibular and maxillary permanent teeth by gender in the Turkish population. J Endod 2004; 30(6):391–8. [CrossRef]
124. Al-Qudah AA, Awawdeh LA. Root canal morphology of mandibular incisors in a Jordanian population. Int Endod J 2006; 39(11):873–7. [CrossRef]
125. Gao X, Tay FR, Gutmann JL, Fan W, Xu T, Fan B. Micro-CT evaluation of apical delta morphologies in human teeth. Sci Rep 2016; 7;6:36501. [CrossRef]
126. Ahmed HMA, Neelakantan P, Dummer PMH. A new system for classifying accessory canal morphology. Int Endod J 2018; 51(2):164–76. [CrossRef]
127. Lobo NS, Wanderley VA, Nejaim Y, Gomes AF, Zaia AA. Assessment of Ramifications in the Apical Region of Root Canals: A Micro-CT Study in a Brazilian Population. Braz Dent J 2020; 31(5):505–10. [CrossRef]
128. Xu T, Fan W, Tay FR, Fan B. Micro-computed tomographic evaluation of the prevalence, distribution, and morphologic features of accessory canals in chinese permanent teeth. J Endod 2019; 45(8):994–9. [CrossRef]
129. Yoshida H, Yakushiji M, Sugihara A, Tanaka K, Taguchi M. Accessory canals at floor of the pulp chamber of primary molars (author's transl). Shikwa Gakuho 1975; 75(3):580–5.
130. Paras LG, Rapp R, Piesco NP, Zeichner SJ, Zullo TG. An investigation of accessory canals in furcation areas of human primary molars: Part 2. Latex perfusion studies of the internal and external furcation areas to demonstrate accessory canals. J Clin Pediatr Dent 1993; 17(2):71–7.
131. Wolf TG, Wentaschek S, Wierichs RJ, Briseño-Marroquín B. Interradicular root canals in mandibular first molars: A literature review and *ex vivo* study. J Endod 2019; 45(2):129–35. [CrossRef]
132. Anderegg AL, Hajdarevic D, Wolf TG. Interradicular canals in 213 mandibular and 235 maxillary molars by means of micro-computed tomographic analysis: An *ex vivo* study. J Endod 2022; 48(2):234–9. [CrossRef]
133. Green D. A stereo-binocular microscopic study of the root apices and surrounding areas of 100 mandibular molars; preliminary study. Oral Surg Oral Med Oral Pathol 1955; 8(12):1298–304. [CrossRef]
134. ElAyouti A, Connert T, Dummer P, Löst C. A critical analysis of research methods and experimental models to study working length determination and the performance of apex locators - A narrative review with recommendations for the future. Int Endod J 2022; 55(Suppl 2):281–94. [CrossRef]
135. Kuttler Y. Microscopic investigation of root apexes. J Am Dent Assoc 1955; 50(5):544–52. [CrossRef]
136. Chapman CE. A microscopic study of the apical region ofhhuman anterior teeth. J Br Endod Soc 1969; 3(4):52–8. [CrossRef]
137. Dummer PM, McGinn JH, Rees DG. The position and topography of the apical canal constriction and apical foramen. Int Endod J 1984; 17(4):192–8. [CrossRef]
138. Abarca J, Zaror C, Monardes H, Hermosilla V, Muñoz C, Cantin M. Morphology of the physiological apical foramen in maxillary and mandibular first molars. Int J Morphol 2014; 32(2):671–7. [CrossRef]
139. Wolf TG, Paqué F, Sven Patyna M, Willershausen B, Briseño-Marroquín B. Three-dimensional analysis of the physiological foramen geometry of maxillary and mandibular molars by means of micro-CT. Int J Oral Sci 2017; 9(3):151–7. [CrossRef]
140. Wolf TG, Kim P, Campus G, Stiebritz M, Siegrist M, Briseño-Marroquín B. 3-dimensional analysis and systematic review of root canal morphology and physiological foramen geometry of 109 mandibular first premolars by micro-computed tomography in a mixed swiss-german population. J Endod 2020; 46(6):801–9. [CrossRef]
141. Wolf TG, Stiebritz M, Boemke N, Elsayed I, Paqué F, Wierichs RJ, Briseño-Marroquín B. 3-dimensional analysis and literature review of the root canal morphology and physiological foramen geometry of 125 mandibular incisors by means of micro-computed tomography in a german population. J Endod 2020; 46(2):184–91. [CrossRef]
142. Ahmed, HMA, Keleş, A., Martins, JNR and Dummer, PMH. Tooth, Root, and Canal Anatomy. In Endodontic Advances and Evidence-Based Clinical Guidelines (eds H.M.A. Ahmed and P.M.H. Dummer). 2022; 1–50. [CrossRef]
143. Hülsmann M, Schäfer E. Apical patency: fact and fiction-a myth or a must? A contribution to the discussion. ENDO Endod Pract Today 2009; 3(4):285–307.
144. Plotino G, Nagendrababu V, Bukiet F, Grande NM, Veettil SK, De-Deus G, et al. Influence of negotiation, glide path, and preflaring procedures on root canal shaping-Terminology, basic concepts, and a systematic review. J Endod 2020; 46(6):707–29. [CrossRef]
145. Olson DG, Roberts S, Joyce AP, Collins DE, McPherson JC 3rd. Unevenness of the apical constriction in human maxillary central incisors. J Endod 2008; 34(2):157–9. [CrossRef]
146. Wu MK, Wesselink PR, Walton RE. Apical terminus location of root canal treatment procedures. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000; 89(1):99–103. [CrossRef]
147. Gutmann JL, Leonard JE. Problem solving in endodontic working-length determination. Compend Contin Educ Dent 1995; 16(3):288, 290, 293-4 passim; quiz 304.
148. Marroquín BB, El-Sayed MA, Willershausen-Zönnchen B. Morphology of the physiological foramen: I. Maxillary and mandibular molars. J Endod 2004; 30(5):321–8. [CrossRef]
149. Schell S, Judenhofer MS, Mannheim JG, Hülber-J M, Löst C, Pichler BJ, ElAyouti A. Validity of longitudinal sections for determining the apical constriction. Int Endod J 2017; 50(7):706–12. [CrossRef]
150. ElAyouti A, Hülber-J M, Judenhofer MS, Connert T, Mannheim JG, Löst C, Pichler BJ, von Ohle C. Apical constriction: location and dimensions in molars-a micro-computed tomography study. J Endod 2014; 40(8):1095–9. [CrossRef]
151. Green D. A stereomicroscopic study of the root apices of 400 maxillary and mandibular anterior teeth. Oral Surg Oral Med Oral Pathol 1956; 9(11):1224–32. [CrossRef]
152. Awawdeh L, Abu Fadaleh M, Al-Qudah A. Mandibular first premolar apical morphology: A stereomicroscopic study. Aust Endod J 2019; 45(2):233–40. [CrossRef]