Root and Root Canal Morphology: Study Methods and Classifications

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ABSTRACT

Background: Morphology of the root canal system is divergent and unpredictable, and rather linked to clinical complications, which directly affect the treatment outcome. This objective necessitates a continuous informative update of the effective clinical and laboratory methods for identifying this anatomy, and classification systems suitable for communication and interpretation in different situations.

Data: Only electronic published papers were searched within this review. **Sources:** "PubMed" website was the only source used to search for data by using the following keywords "root", "canal", "morphology", "classification".

Study selection: 153 most relevant papers to the topic were selected, especially the original articles and review papers, from 1970 till the 28th of July 2021.

Conclusions: This review divided the root canal analysis methods into two approaches; clinical and in vitro techniques. The latter has shown more precise non-subjective readings, on the other hand; the clinical methods provide direct chair side diagnosis for the clinical cases. The classification systems reviewed in the present study, started with the oldest trials that simply presented the root canal systems, according to the degree of angulation, or by coded Latin numbers or English letters. Then, the most recent systems were also presented that were persisted with continuous editions up to date. These new systems could briefly describe the root and root canal's internal and external details in a small formulation, without confusion and in an easily communicated manner, highly recommended specially for students, teachers, and researchers

Keywords: root canal, root morphology, canal configuration, root canal classification, endodontic. **(Received: 20/8/2021, Accepted: 22/9/2021)**

INTRODUCTION

Tooth development is a complex biological process moderated by a series of epithelial-mesenchymal interactions (1). These biological factors can abnormalize the ultimate process of odontogenesis causing a developmental anomaly. "Anomaly is a Greek word, meaning irregular; or in other words, it is a deviation from what is regarded as normal" (1).

Depending on the stage of tooth development, various anomalies in root/canal number, size and/shape can occur (1). The most common root malformations in humans arise from either developmental disorder of the root alone, such as root dilaceration and Taurodontism or disorders of root development as a part of general tooth dysplasia, such as dentine dysplasia type 1 (2). There is a direct association of such developmental variations with pulp and peri-radicular diseases that may necessitate a multidisciplinary treatment approach (3-8).

Lack of knowledge about normal and abnormal root and root canal morphology is often associated with many failures to locate, instrument, irrigate and fill canals adequately (9, 10), therefore; identifying normal versus abnormal (aberrant) morphology of the human dentition is essential for effective root canal treatment procedures (9).

With the increased range of anatomical complexities being reported and the deficiencies of existing systems for categorizing morphological variations, a new system for classifying root and canal morphology has been proposed, which provides detailed information on tooth notation, roots number and configuration, in addition to accessory canals and tooth anomalies, in simple a practical manner which will be focused on in this review (11-14).

The presently available systems for describing the root and root canal morphology both under normal and abnormal conditions are plentiful and divergent with many interrelations in authors proposals, as they continue making their new additions depending on the preceding trials. The aim of this review is to do an electronic search and to collect most if not all of the reported methods for analyzing root canal morphology and classification systems, and summarizing them.

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METHODS

In the present literature review, a comprehensive search has been made depending on electronically published peer-reviewed resources using the "PubMed" website, from 1970 till the 28th of July 2021. The used keywords were "root", "canal", "morphology", "classification", which revealed about 153 relevant papers. After filtering, only 67 papers, all in English language, were included in this review. The filtering process included papers striving most if not all of the available root and root canal classification systems, and methodologies are applied to dental morphological identification. The selected classification systems and methodologies were ensured to have well defined and standardized guidelines and steps in their criteria of work.

3. Techniques for root canal analysis

There are different methods that have been reported for studying root canal morphology, ranging from in vitro (experimental) methods, to those which are more suitable for clinical situations (in vivo).

3.1. In vitro techniques

These are the most common techniques using extracted teeth for laboratory analysis of root morphology, serving scientists and authors in their ongoing researches.

3.1.1. Root clearing and canal staining

This technique is widely mentioned in literature and could be considered as the gold standard method for laboratory studies of root canal anatomy, and for comparison with readings from other techniques, because of its high accuracy and nondestructive approach (15).

In clean extracted teeth with fully formed roots, ink is injected through the coronal access directly into the root canals, then the access cavities of the study teeth are filled and well-sealed, leaving the apical root opening patent for ink progression. These teeth could be stored in a high-pressure chamber to enhance penetration of the dye into the fine details of the tooth structure (16). Now teeth are washed and dehydrated in an ascending concentration of ethanol up to 100%, then decalcified in a maintained active acidic solution over a day. Teeth are then placed in methyl salicylate solution for a couple of hours rendering them transparent (17). To be sure that teeth are well decalcified, some of the samples are exposed to conventional radiation, examination is done by using a magnifying lens (×3). Modified canal staining and root clearing were mentioned in this literature as it is non-destructive and more accurate than the conventional staining and clearing method (17).

The main disadvantage of this method is that it cannot be used in vivo (17). A comparable method has the accuracy of the latter technique but at the same time clinically feasible, not yet available in endodontic practice.

3.1.2. Radiographical analysis with contrast medium

In this method, water-soluble low viscosity radiopaque medium is delivered into the root canals. The low surface tension of the contrast medium and subjection of the tooth to vacuum or ultrasonic waves enable penetration of the medium into the niches of the root canal system. Then radiographs were taken in a buccolingual direction, in two horizontal angulations, 0˚and 30˚, after fixing the teeth on arch simulating models (18).

Alteration of the subject contrast is induced by variations in transmission of the radiographic beam between the tooth and the contrast medium, which definitely improves the visibility of root canal systems, in comparison with conventional radiographs (19). These altered exposures are more useful than plain radiographs in the assessment of root canal anatomy, but on the other hand, as the previous method, it cannot be used in vivo (20).

3.1.3. Histologic examination

Teeth subjected for examination in this method should be processed by demineralization in an acidic solution of formic acid, citric acid, or EDTA for several weeks to be softer and ready for sectioning. Root sections number and cutting intervals are determined depending on the study, but most commonly being sectioned at multiple intervals along the root course, then simply stained with hematoxylin-eosin for clear observation of the canals' shape at each section (21).

3.2. In vivo techniques

3.2.1. Two-dimensional imaging techniques

In this part of imaging techniques, there are three different diagnostic tools including conventional, digital, and panoramic radiography, all of which share being a two-dimensional image of three-dimensional structures, but differ in the imaging quality, resolution, and practicality (19). These diagnostic methods are still the first-line choice for before, during, and after work usage that should never be passed, taking into account the experience of the operator in manipulation and interpretation of results (19, 22).

3.2.2. Three-dimensional techniques

In this field, many attempts have been made to develop systems providing an optimum three-dimensional visualization of the tooth internal complex and unpredictable anatomy, and to be feasible aids available in each dental clinic.

- Nonionizing radiation, a high-resolution magnetic resonance spectroscopy system constitutes a powerful tool for a detailed analysis of dental soft tissues (poor detection of hard tissue changes) (23).
- Magnetic resonance tomography (MRT) with stray field imaging (STRAFI) system produces powerful proton signals in a very short time (poor differentiation between hard tissue structures) (24).
- Constant-time imaging (CTI) technique shows good resolution for both hard and soft tissue structures (195 µm), (limited description of the smallest components of the pulp chamber) (25).
- 1CT is a miniaturized conventional computerized tomography offers cross- sectional images of the roots and 3D shapes for root canal systems with resolution (36µm), which aids to detect geometrical changes after instrumentation (small field of exposure, long scanning time up to six hours) (26-28).
- High-resolution X-ray computed tomography (HRXCT): this development gives good quantitative data for dental structures (5-100µm) compared with histologic sections (non-practicality, high cost, limited availability) (29, 30).
- Flat panel-based volume computed tomography (FP-VCT): this technique shows good qualitative information about dental structures and exposes several teeth at one time (low spatial resolution (150µm), non-practicality, high cost, limited availability) (31).
- Peripheral quantitative computed tomography (p-QCT): this innovation produces a good qualitative and quantitative representation of dental structures (not fully validated technique) (32).
- Micro-computed tomography (MCT): non-invasive technique can evaluate internal and external dental anatomy non-invasively in both quantitative and qualitative values, can define even fine root canal communications and lateral canals (not suitable for clinical use) (22, 33).
- Cone-beam computed tomography (CBCT): As a more recent development has been introduced for 3D imaging of hard tissues in the maxillofacial region, these devices are now more available, with high diagnostic quality (75-450µm), short scanning time (10-70s), and less radiation dose than conventional CT (34-36).

4. Root and root canal classification systems

4.1. Old classification systems

4.1.1. Mathematical classification of root canal curvatures

First trials began with Schneider (37) when he classified root canals on angular bases, according to the degree of curvature, into straight 5° or less, moderate 10-20°, and severe 25-70°. Backman et al. (38) classified root canals on the basis of "radius quotient," which was obtained by dividing the root canal angle by its radius measurement. Dobo (39) devised a classification based on Schneider's angle and the radius of the circle that could be superimposed on the curved part of the root canal.

Baumann et al., Dobo, and Southard et al. (24, 39, 40) formulated their classifications using other data besides the Schneiders angle to achieve a "semiquantitative" method for describing the shape of the curve of root canals, however, Schneider's angle which depended on as a data for classification cannot describe the course of curve of the canal along the root.

More recently published papers demonstrated the necessity of developing a more reliable classification that was presented by Nagy et al. (41). This classification is based on computer graphic analysis, with the results described in four characteristic root canal forms symbolled with alphabetical letters (straight canals (I), canals curved in their apical part (J), canals curved along their length (C), and multi curved canals (S)).

4.1.2. Diagrammatic representation of root canal configuration

Gupta and Sexana (42) presented with a new diagrammatic root canal representation, which is supposed to be simple to understand, represent, and communicate, providing a clear picture about the location, number, and length of most root canal configurations. Small details should also be included.

The proposed representation consists of five horizontal lines, which divide the tooth into four partitions in a corono-apical direction. The first line, which is a dashed line signifies the point of reference from where the length of root canal is measured "Ref". A second line, which is continuous, marked as ‘‘Orf.’’ at one end, represents the orifice level or cemento-enamel junction in the case of a single canal or Taurodont teeth. The lowermost line, which is

also continuous a one, represents the apical foramen of the root canal. Then third and fourth lines (dotted lines) divides the root canal into coronal, middle, and apical thirds; these regions are designated as C, M, and A, respectively.
The diagrammatic images of teeth (one anterior/posterior single-rooted and one posterior multi-rooted) are given for easy understanding of the orientation of an image. The whole image has a transparent background and is saved in a portable network graphics (PNG) format. The image can be rotated by 180˚ to correspond to either mandibular or maxillary teeth. It can be imported to any word processing document and a print of the image can be obtained in the reporting sheet.
Freehand vertical lines should be drawn from the top dashed line to the bottom continuous line, to represent the major root canals exist in the tooth, with each labeled at the top. The length of the individual canal from the point of reference to the apical foramen can be written in millimeters, depending on the situation, either adjacent to the origin of its corresponding line, near ''Ref.'' line, or at the end, adjacent to the fifth line representing the apical foramen.
Intercommunications and isthmuses between the canals should be drawn keeping in mind the approximate level (coronal, middle, apical) for each. Fusion between canals can be shown by one vertical line merging into another or both lines joining together at the corresponding level.
Bifurcation in the canal is represented by the division of the line at the corresponding third. The orientation of the resulting canals can be labeled in the area adjacent to the fifth line. In addition, the diameter of the canals can be represented by the relative thickness of the lines.
Lateral and accessory canals, if identified, can be shown as blind lines originating from the main vertical line and running in a horizontal direction at the corresponding locations. If the major canals, instead of appearing at the pulpal floor as separate orifice, continue as a single large canal and separate below the orifice, then the same can be represented as a thick band in the diagrammatic representation. The lines representing the divided canals, in such cases, can be labeled near the fifth line. If the major canals, instead of appearing at the apex in separate apical foramina, join and continue as single large canal, then also can be drawn as a thick band starting from the corresponding third. The above-mentioned rules can be simply summarized as ''to draw what you see'', see Figure (1).

This method still has many limitations, which are inherent in their two-dimensional representation of a three-dimensional network. It is not able to present neither the exact location of the canal orifices, nor the location and orientation of the canals. The lengths of the canals are out of proportion in order to simplify the procedure of drawing and segmenting the canals.

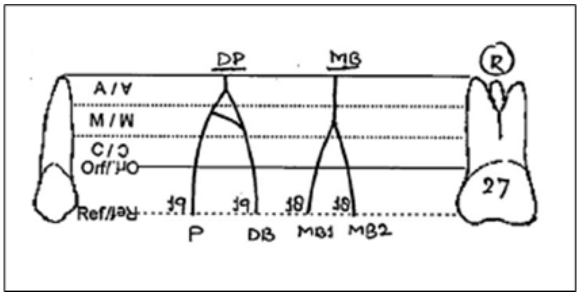

Figure (1): Representation of canal configuration of maxillary left second molar having two roots, mesio-buccal and disto-palatal. Mesio-buccal root having two canals, MB1 and MB2 with separate orifices, which merge at the middle level. Disto-palatal root with two canals, DB and P with separate orifices and merge in the apical third, having an identifiable isthmus in the middle third (42).

4.1.3 Number-digits root canal classification systems

In these systems the canals configuration is coded as number digits, to represent their number in each section of a single root in an occluso-apical direction. Weine (43) was the first to start classification by producing four configurations for the root canals course in a single root, see Figure (2).

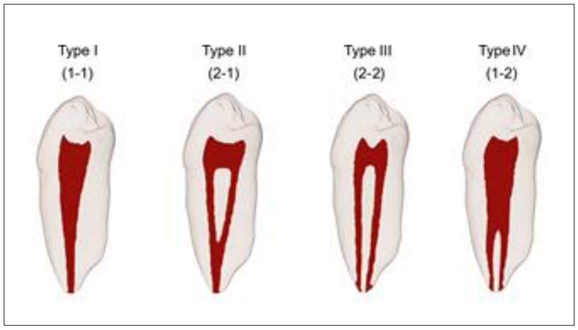

Figure (2): Root canal configurations from type I to type IV, (43).

Vertucci and Williams (44) identified more complex forms of root canal systems to add eight root canal configurations in the literature, see Figure (3).

Thereafter, Sert and Bayirli (45) described fourteen additional even more complex configurations to complement that was described by Vertucci, see Figure (4).

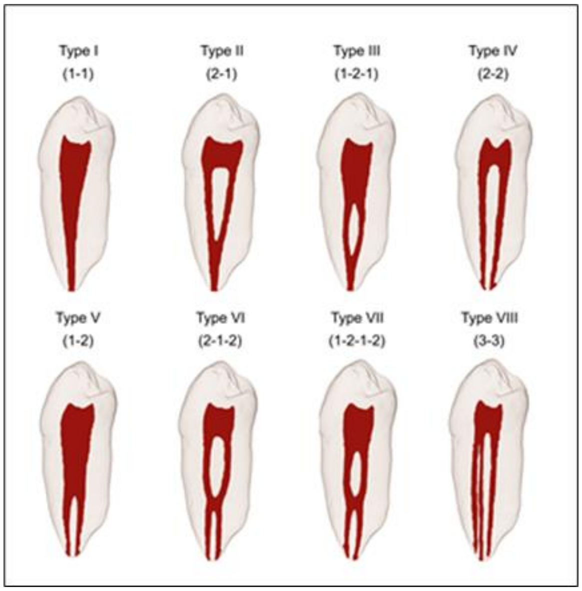

Figure (3): Root canal configurations from type I to type VIII, (44).

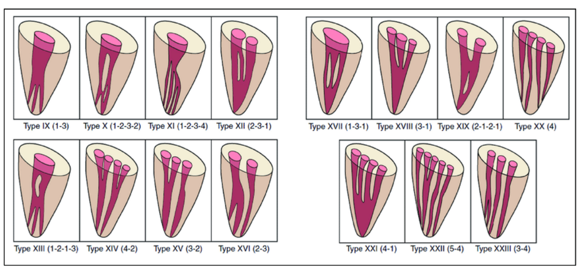

Figure (4): Root canal configurations from type IX to type XXIII, (45).

4.2. New systems for root canal classification (formulation systems)

The simple idea behind these systems is to represent the root and root canal configuration of a tooth by coded formula, including symbols and numbers, easily written and identified, these systems were developed for the first time by Ahmed et al. (11), with useful additions to this system persisted up to date.

4.2.1. New classification system for root and root canal morphology by Ahmed et al. (2017).

According to this system (11), tooth number (TN) can be written by 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, e.g., maxillary (upper) central incisor (UCI). Number of roots is added as a superscript before the tooth number (^{R}TN). Any division of a root whether in the coronal, middle or apical third will be coded as 2 or more roots. Accordingly, a bifurcation is represented as (^{2}TN), and trifurcation is represented as (^{3}TN), and so on. Details of roots (^{R}TN R1 R2 ... etc.) in double and multi-rooted teeth are added on the right of the tooth number.

When individual roots are fused, a slash ('/') should be added between the initial letters of each root. Type of root canal configuration in each root will be identified as a superscript number after the tooth number starting from the orifice (O), through the canal (C), to the foramen (foramina) (F). Considering any similar adjacent numbers for a specific root reduced into single number representing both. Number of canals before furcation, written as a subscript after tooth number, see Figure (5, 7).

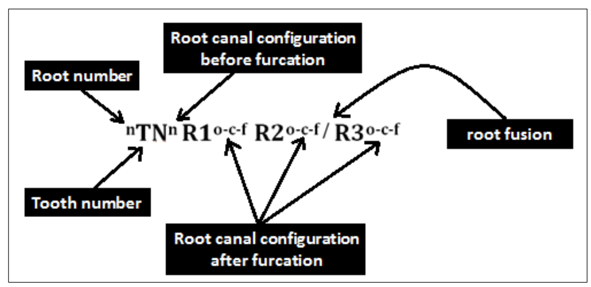

Figure (5): Diagrammatic representation of the new classification system.

4.2.2. Accessory/auxiliary root canals classification system by Ahmed et al. (2018)

Taking into account the necessity of precise interpreting, and well localizing the accessory/auxiliary root canal ramifications, we cannot go blind with the essential determining role of this characterization in attaining favorable overall final results in our routine practice of endodontic treatment. As it has been reported in many cases that apical divergent morphology is responsible for persistent apical periodontitis and incomplete healing after efficient well-sealed 3D root canal obliteration from the operator's point of view (46).

On the other hand, these ramifications may be the answer for many diagnostic questions in confusing cases, giving explanations for lateral radiolucency of unknown origin, or surprising devitalization after root planning especially with the development of new technologies for precise 3D characterization of this complex morphology with ease (46-48).

The nomenclature of accessory canals is described by several authors, with many of no clear demarcating lines for separating the many types of these canals. Some authors produced their description on angular bases, as for lateral canals meeting the main canal at a right angle, while the accessory canals being at an oblique angle. Other modalities depended on spatial location, lateral canals named for those emerging from the trunk of root in the coronal and middle thirds, accessory canals emerging in the apical third more precisely 3.5 mm from the root end, while furcation canals emerge from the floor of the pulp chamber. The term apical delta/ramifications notate divergent fine branching of the accessory canals at the apical end of the root canal with obliteration of the main canal just like a tree branch (45, 49-54).

With neglecting the old attentions to classify these canals which was with much of confusion, emphasizing on the new one that gave a nominal notation for the accessory canals in general as a new addition for the new classification system was described by Ahmed et al. (14). This system gives you a clear picture about the location of the canal along its course without additional complex information, making it suitable for trainees and researchers communication.

In this system or addition, Ahmed et al. (14) divided the root into three partitions apical, middle, and coronal (A, M, C), respectively. Moreover, they described the course of canal from the orifice opening, canal penetration within the dentinal wall, ending with its foramen on the root surface (a O-C-a F) respectively, fused into a single number when they are similar, writing it as a superscript after tooth number(TN) in single-rooted tooth or when the accessory canal located in the floor of the chamber, or after root number(RN) in double/multi-rooted teeth, apical delta notified as $(^{D})$, when these canals present in more than one-third of the root separate between root divisions by comma(,), Adding straight horizontal line among parts of canal course, one canal may have orifice in specific root third with its orifice opens in another third in such a case mention both root sections with a comma in between, see Figure (7).

4.2.3. Root canal anomaly classification by Ahmed and Dummer (2018).

Most classification systems previously added had been going very deep in describing root canal anomalies in a detailed manner with much of complexity, stands against an immediate clear interpretation of them (44, 55-58). This limitation is compensated for with the new addition of classification system described by Ahmed and Dummer (12), who allow easy simultaneous interpretation of these anomalies along with root and root canal morphology in the same notation.

The anomalies described in this system should be related directly to the root canal morphology, affecting the endodontic work. Abbreviation for the anomaly added in capital letters between brackets (A) before tooth number, with the subtype if present and identified clinically added as a superscript on the right upper corner (A^2). If the anomaly includes fusion between teeth or roots, then slash (/) is added between them, while double slash (//)is added if root canals have inter-canal communications. If the tooth has more than one of the same anomalies, write the number of repetitions on the left side to the tooth anomaly (NA), while if the same tooth has more than one different anomaly, then separate between them with comma (A1, A2), see Figures (6, 7).

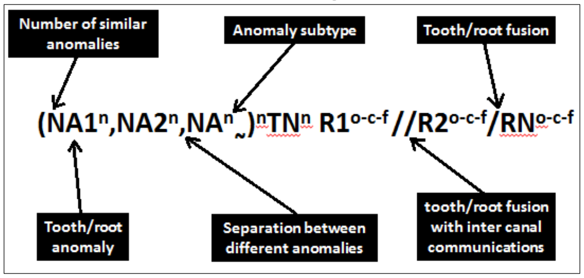

Figure (6): Diagrammatic representation of tooth/root anomalies.

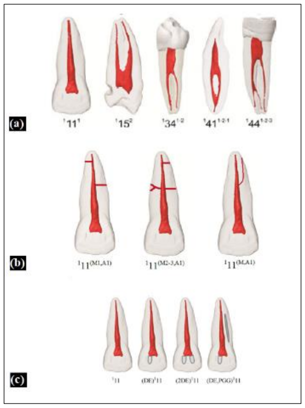

Figure (7): (a) Examples of symbolic representation of the root canal system by Ahmed et al. (11), (b) accessory root canals formulations, merged with root canal configuration details in the same formula (14), (c) examples for coding some of the common root canal anomalies (Dens Evaginatus (DE)) (12).

4.2.4. Application of the new classification system on primary teeth by Ahmed et al. (2020)

Root canal treatment or partial pulpectomy has become part of the routine treatments of primary teeth. To ensure normal physiological resorptive process and exfoliation, or if tooth retention is required for some time, and to optimize these procedures, it is necessary to realize the anatomy of these root canal miniatures, with all associated anomalies and fine communications, just like in permanent teeth (59-63).

Root canal treatment in primary teeth has challenged with many factors, signing first one which is aberrance from normal morphology specially in the posteriors, as a result of dentin islands formed continuously, in addition to physiologic resorption that may alter the working length, moreover anterior primary teeth normally show additional canals specially in upper canines. On the other hand, pathological factors such as periodontal tissue inflammatory diseases are more complicating their anatomy by altering the normal course of root resorption, which itself is uneven and not predictable (64, 65).

The present system or addition (66) sharing nearly the same formula as has been described for permanent teeth by Ahmed et al. (11), but with lightening some point differences in writing formula include (1) primary tooth number could be replaced by any simple abbreviation if the exact number could not be identified, (2) physiologic tooth resorption is not included in the formula, but the formula will be changed if the resorption altered the anatomy during the course of treatment, (3) accessory canals are usually coded as in permanent, but should be omitted from the formula in specific conditions when there is an extensive resorptive process, or tooth is about to exfoliate (67).

CONCLUSION

The root canal analysis methods, divided into two approaches; clinical and in vitro techniques, with the latter has shown more precise non-subjective readings, on the other hand; clinical methods provide direct diagnostic methods for the clinical cases on the chair-side.

The classification systems pointed to in the present literature, has been reviewed, beginning with the oldest trials to represent the root canal systems in diagrams, according to the angulation degree, or simply by Latin numbers or English letters, reaching to the most recent systems, which persist with continuous editions up to date. These new systems could briefly describe the root and root canal's internal and external details in a small formulation, without confusion and in an easily communicated manner, highly recommended specially for students, teachers, and researchers.

Conflict of interest: None.

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الخلاصة

الاهداف: تشكيل تجاويف الجذور اللبية في الاسنان مختلف على نطاق واسع وغير متوقع، وكثيرا" ما يتم ربطه بالمشاكل السريرية، مما يؤثر بالتالي بشكل مباشر على نتائج العلاجات الجذرية.

البيانات : فقط الدراسات المنشورة الكترونيا" تم البحث عنها ضمن هذا الاستعراض. المصادر: بوابة البحث الاللكترونية "PubMed" هي المصدر الوحيد الذي تم اعتماده للبحث عن مفردات الاستعراض، و ذلك باستخدام الكلمات الدلالية "root", ’’canal“, ’’morphology“, "classification".

اختيار الدراسة: تم اختيار الدراسات المكتبية والبحوث الاصيلة، التي لها علاقة مباشرة بموضوع الاستعراض، لتكون مصادرا" معتمدة في الكتابة.

الاستنتاجات: الدراسات المعنية بتحليل شكل التجاويف اللبية للجذور تقسم الى قسمين؛ سرسرية ومختبرية، الاخيرة اظهرت قراءات أكثر دقة غير متأثرة باسلوب الباحث، بينما بالمقابل، الطرق السريرية تعتبر وسيلة تشخيصية مباشرة للحالات السريرية على كرسي العلاج. الانظمة التصنيفية التي تم استعراضها في الموضوع الحالي، تبدأ مع اقدم المحاولات لتمثيل انظمة التجاويف اللبية على شكل مخططات، او بناءا" على درجة التواء الجذور، او ترمز باحرف باللغة اللاتينية او الانكليزية، انتهاءا" مع احدث الانظمة التصنيفية التي تستخدم صيغة ترميزية مفصلة، والتي لا تزال مع اضافات مستمرة الى هذا التاريخ.