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Review Article

Methods of Studying Root Morphology and Canal Anatomy of Permanent Human Teeth: Scope Review

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Abstract: ***Introduction***: The objective of this review was to identify the work carried out on the means of studying the root morphology and canal anatomy of permanent human teeth. ***Methodology***: The search was carried out in the electronic databases Pub Med, Google Scholar, Scopus, using the following keywords: "Root canal anatomy and study methods", "Root canal anatomy" in "permanent dentition", "Dental root canal morphology", "Dental root canal anatomy". These terms were used separately. Duplicates were removed using the reference management software "Zotero". Titles and abstracts were manually reviewed. Original articles, published in French or English, on the means of studying root morphology and canal anatomy of permanent human teeth were included. ***Results***: A total of 21 articles were selected for this literature review. Two types of study methods are used: *in vivo* methods which are carried out in the clinic and *in vitro* methods which are carried out in the laboratory on extracted teeth. Cone beam computed tomography (*in vivo*) was used in eight studies. The in vitro methods used were Micro-tomography (six studies), Diaphanization technique (five studies), direct vision, Dental Microscope, Two-dimensional Radiography and Micro-tomography (one study), direct observation and Microscope (one study). ***Conclusion***: From this literature review, it should be noted that the means of studying the root morphology and canal anatomy of teeth are *in vivo* means (two-dimensional and three-dimensional radiographs) and *in vitro* means (direct vision, molding, operating dental microscope, two-dimensional radiography, diaphanization, anatomical sections, micro-computed tomography).
Keywords: Study Methods, Root Canal Anatomy, Permanent Human Teeth.

INTRODUCTION

Etymologically, endodontics comes from ancient Greek and means "knowledge of the contents of the tooth", this discipline is interested in the anatomy of the endodont (Bergenholtz, G. *et al*., 210). Thus, one of the objectives of endodontics is the prevention, diagnosis and treatment of diseases of the dental pulp and periapical infections (Bergenholtz, G., *et al.,* 210). A good knowledge of the root canal system and the presence of advanced diagnostic tools to evaluate the anatomy of the root canal are essential to perform correct diagnoses and treatments in order to obtain positive results (*Mashyakhy, M et al., 2019;* Mashyakhy, M. H *et al*., 2020). Root canal treatment poses a great challenge to clinicians in dental practice. It involves obstacles, variations and difficulties, especially for posterior teeth,

which negatively affect the main objective of root canal treatment and reduce the prognosis (*Mashyakhy, M et al., 2019;* Mashyakhy, M. H *et al*., 2020). Root canal treatment failure can be attributed to many factors. However, infection in missed, unfilled, or incompletely debrided canals is the main cause (Margarit, R *et al*., 2011; Mashyakhy, M., *et al*., 2021).

Since the beginning of the 20th century, the external and internal anatomy of different groups of teeth has been studied using a number of *in vivo* and *in vitro* techniques. The results of anatomical and morphological investigations may differ depending on the study technique, age, sex and population of the group of interest (Cleghorn, B.M., *et al*., 2006; Grover, C., *et al*., 2012).

The objective of this study was to identify and review available work on the means of studying root morphology and the anatomy of the canal system of permanent human teeth.

METHODOLOGY

Search Strategy:

The electronic biomedical databases Medline (via the Pub Med search engine), Google Scholar, and Scopus were searched for literature using the following keywords: "Root canal anatomy and study methods", "Root canal anatomy" in "permanent dentition", "Dental root canal morphology", "Dental root canal anatomy". These terms have been used separately. Duplicates were removed using the reference management software "Zotero". Then, titles and abstracts were manually reviewed and articles that did not meet the inclusion criteria were excluded. The remaining articles were read in their entirety and those that dealt with a topic other than that of interest for this literature review were excluded.

Selection Criteria:

Original articles, published in French or English on the means of studying root morphology and canal anatomy of permanent human teeth were included. No time range has been defined for the search. Case reports, editorials, reviews, animal studies, opinion pieces, and books or papers were excluded from this review.

RESULTS

Selected Articles:

In this search, 1870 references were identified in the consulted databases (Pub Med, Google Scholar and Scopus). After applying the inclusion criteria, 1518 references were excluded. And after reading the titles and abstracts, 251 articles were excluded as well as 52 duplicate articles. In total, 49 articles were read in full text and 28 articles were excluded for their compliance with the exclusion criteria. Finally, 21 articles were retained for this review.

Identification of Studies on the Pub Med, Google Scholar, Scopus Databases
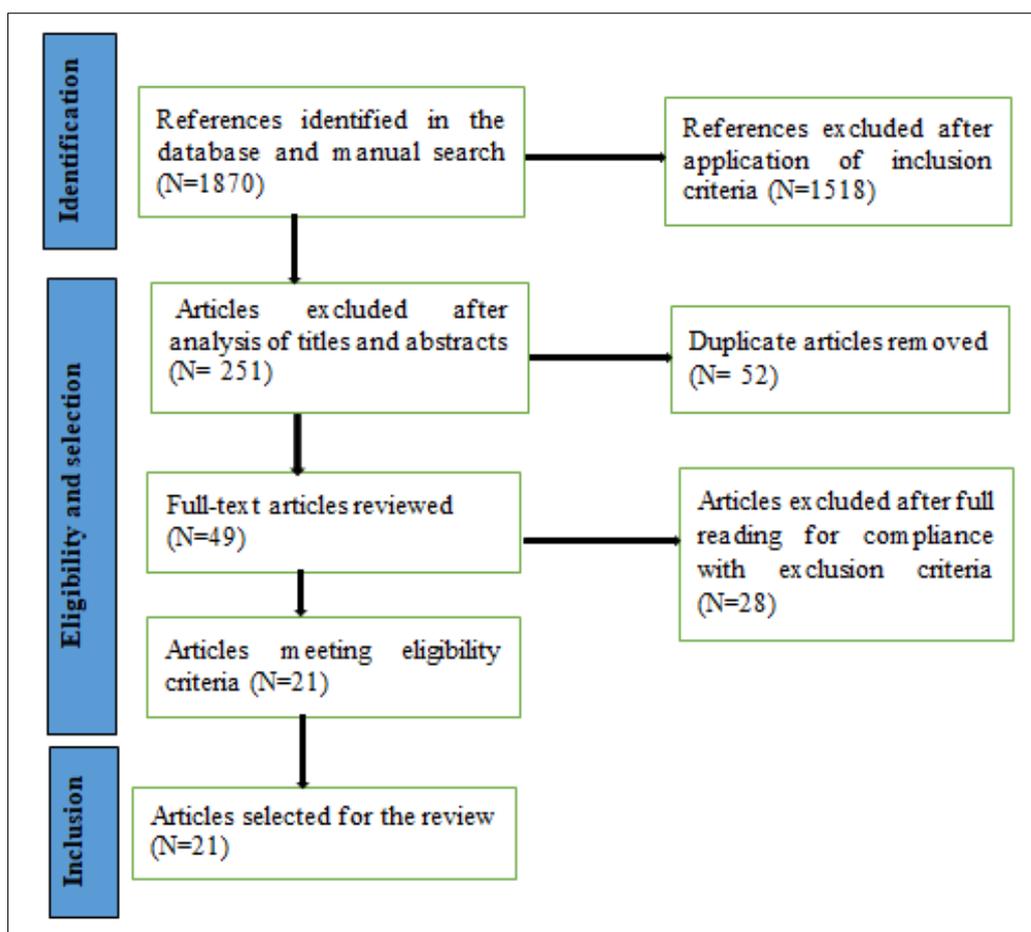

Figure 1: Flowchart

Extracted data:

For each article, the data collected were the name of the author and the year of publication, the title of the article, the name of the journal or newspaper of publication, the study methods used, the teeth studied.

Table I: Articles selected for the literature review

Author/Year	Title	Review/journal	Study methods used	Teeth studied
Wolf, T.G. *et al*., (2025)	Micro-computed tomographic analysis of the morphology of the maxillary canines.	Sci Rep	Micro-CT	Maxillary canines
Aljawhar, A.M. *et al*., (2025)	Micro-computed tomographic evaluation of root and canal anatomy of maxillary first premolars in Iraqi sub-population.	Sci Rep	Micro-CT	First maxillary premolars
Tang, Y. *et al.,* (2023)	A Micro-computed tomographic analysis of the root canal systems in the permanent incisors in a Chinese population.	BMC Oral Health	Micro-CT	Incisors
Jonker, C.H. *et al*., (2023)	A New Methodology to Determine the Orifice for Root Canal Configurations in First Permanent Molar Root and Canal Morphologies Using Micro-computed tomographic	J Clin Med	Micro-CT	First Molars
Sierra-Christancho, A. *et al*., (2021)	Micro-tomographic characterization of the root and canal system morphology of mandibular first premolars in a Chilean population	Sci Rep	Micro-CT	Mandibular First Premolars
Wolf, T.G. *et al*., (2023)	Internal Morphology of Mandibular Second Premolars Using Micro-computed tomographic	J Imaging	Micro-CT	Mandibular Second Premolars
Watanabe, S. *et al*., (2024)	Evaluation of root and root canal morphology in maxillary premolar teeth : A cone-beam computed tomography using two classification systems in a Japanese population	J Dent Sci	CBCT	Maxillary premolars
Chen, Y. *et al*., (2023)	Morphological analysis of anterior permanent dentition in a Chinese population using cone-beam computed tomography	Head Face Med	CBCT	Anterior teeth
Herrero-Hernandez, *et al*., (2024)	Cone-beam Computed Tomography Analysis of the Root Canal Morphology of Mandibular Incisors Using Two Classification Systems in a Spanish Subpopulation: A Cross-Sectional Study	Eur Endod J	CBCT	Mandibular Incisors
Al-Habib, M.A. *et al*., (2024)	Comprehensive Analysis of Mandibular First Molar Root and Canal Morphology in Saudi Patients Using Cone Beam Computed Tomography	Med Sci Monit	CBCT	First Mandibular Molars
Lemos, M.C. *et al*., (2025)	Root canal morphology of 1316 premolars from Brazilian individuals: an in vivo analysis using Cone Beam Computed Tomography	Acta Odontol Latinoam	CBCT	1316 Premolars
Martins, J.N.R. *et al*., (2017)	Root and root canal morphology of the permanent dentition in a Caucasian population: a cone beam computed tomography study	Int Endod J	CBCT	Permanent teeth
Sheth, K. *et al*., (2024)	Distolingual root prevalence in mandibular first molar and complex root canal morphology in incisors: a CBCT analysis in Indian population	Sci Rep	CBCT	First Mandibular Molars, Incisors
Saber, S.M. *et al*., (2023)	Root and canal morphology of mandibular second molars in an Egyptian subpopulation: a cone beam computed tomography study	BMC Oral Health	CBCT	Second Mandibular Molars

Author/Year	Title	Review/journal	Study methods used	Teeth studied
Sadaf, A. *et al*., (2019)	Maxillary Premolar teeth : Root and canal stereoscopy	Khyber Med Univ J	Direct observation, Microscope	Maxillary Premolars
Karobari, M.I. *et al*., (2025)	Comparative evaluation of root canal morphology in mandibular first premolars with deep radicular grooves using direct vision, dental operating microscope, 2D radiographic visualization and micro-computed tomography	PLoS One	Direct vision, Dental microscope, 2D X-ray, Micro-CT	Mandibular First Premolars
Nogueira, B.M.L. *et al*., (2017)	Root and canal morphology of permanent mandibular incisors	Int J Odontostomat	Diaphanization	Mandibular Incisors
Bhat, S.A. *et al*., (2019)	Evaluation of root canal morphology of mandibular first molars in Kashmiri population by clearing technique an in-vitro study	J Adv Med and Dent Scie Res	Lightening technique	First Mandibular Molars
Vachhani, S. *et al*., (2020)	A Comparative Study Of Efficacy Of Methyl Salicylate And Eugenol As Clearing Agent For Teeth Specimen	National J of Integrated Res Med	Lightening agent	Teeth
Spalding, M. *et al*., (2017)	Configuration of Canal System in the Mesiobuccal Root of Maxillary First Molars	Int J Morphol.	Diaphanization	First Maxillary Molars
Rehman, K. *et al*., (2015)	Diaphonization : A Recipe to Study Teeth	J Contemp Dent Pract	Diaphanization	Teeth

Summary of the work: In total, 21 articles were selected for this literature review. The examination of the results made it possible to distinguish several means of studying the root morphology and the anatomy of the canal system of permanent human teeth: *in vivo* means which are carried out in the clinic (by acquisition) and *in vitro* means which are carried out in the laboratory on extracted teeth. Among the *in vivo* methods, Cone Beam Computed Tomography (CBCT) was used in eight (8) studies (Watanabe, S. *et al*., 2024; Chen, Y. *et al*., 2023; Herrero-Hernandez, S. *et al*., 2024; Al-Habib, M.A *et al*., 2024; Lemos, M.C. *et al*., 2025; Martins, J.N.R. et al., 2017; Sheth, K. *et al*., 2024; Saber, S.M. *et al*., 2023). For *in vitro* methods, Micro-tomography was used in six studies (Wolf, T.G. *et al*., 2025; Aljawhar, A.M. *et al.,* 2025; Tang, Y. *et al*., 2023; Jonker, C.H. *et al*., 2023; Sierra-Christancho, A. *et al*., 2021; Wolf, T.G. *et al*., 2023); the Diaphanization method (staining and clarification) in five studies (Nogueira, B.M.L. *et al*., 2017; Bhat, S.A. *et al*., 2019; Vachhani, S. *et al*., 2020; Spalding, M. *et al*., 2017; Rehman, K. *et al*., 2015). One study used the methods of direct vision, Dental Microscope, Two-dimensional Radiography, Micro-tomography (Karobari, M.I. *et al*., 2025). The work of one study was carried out by direct observation and Dental Operating Microscope (Sadaf, A. *et al*., 2019).

DISCUSSION

The objective of this study was to identify the work carried out on the means of studying the root morphology and canal anatomy of permanent human teeth.

The studies examined made it possible to distinguish two types of means of studying the root morphology and internal anatomy of permanent teeth: *in vivo* means, carried out in the clinic (by acquisition) and *in vitro* means carried out in the laboratory on extracted teeth.

In vivo methods include two-dimensional (2D) radiography and three-dimensional (3D) radiography. In this review, three-dimensional radiography (Cone beam computed tomography, CBCT) was used in the various works consulted. Indeed, CBCT is a non-invasive technique that provides three-dimensional information of teeth and adjacent structures. Additionally, CBCT images are displayed in coronal, axial, and sagittal sections, reducing the overlap of anatomical structures (Cotton, T.P. *et al*., 2007). Watanabe, S. *et al*., (2024) evaluated the root morphology and canal anatomy of maxillary first premolars in a large Japanese population using CBCT using two classification systems: Vertucci and Ahmed classification systems, focusing on root and canal morphology. Variations were analyzed according to sex and age. The work of Chen, Y. *et al*., (2023) on the analysis of the morphology of the anterior permanent dentition in a Chinese population, used CBCT as a means of study. This was a retrospective study investigating the morphological characteristics of anterior teeth in terms of root length, curvature of the cemento-enamel junction, root furcation and canal variations. Herrero-Hernandez,

S. *et al.*, (2024) in their study, evaluated the root and canal morphology of permanent mandibular incisors by cone beam computed tomography in a Spanish subpopulation. The results of the study were compared with those of the ipsilateral (similarity) and contralateral (symmetry) incisors. In addition, the position of the canal division was measured. The comprehensive analysis of the root and canal morphology of the mandibular first molar in Saudis was performed by Al-Habib, M.A. *et al.*, (2024) using Cone Beam Computed Tomography. The analysis focused on variations in root and canal morphology and right and left symmetry. The distance between the orifices was measured as well as the distance between the cemento-enamel junction and the level of canal bifurcation. Lemos, M.C. *et al.*, (2025) conducted a study on the internal canal anatomy of maxillary and mandibular premolars in a Brazilian subpopulation. They performed an *in vivo* analysis by cone beam computed tomography to establish the prevalence of the different configurations proposed by Vertucci. The work of Martins, J.N.R. *et al.*, (2017) on the root and canal morphology of the permanent dentition in a Caucasian population was carried out using cone beam computed tomography to study the number of roots, the configuration of the canal system and the levels of division and fusion of the root canals. Cone beam computed tomography was used to understand the possible correlation between the prevalence of distolingual roots in permanent mandibular first molars and the associated complicated root canal morphology of mandibular incisors in an Indian population. The prevalence of distolingual roots and the canal anatomy of the mandibular incisors were assessed according to Vertucci's classification, and then the sample was grouped by age, sex and side. Statistical analysis was used to evaluate the possible correlation between the presence of distolingual roots in first molars and the canal morphology of the incisors (Sheth, K. *et al.*, 2024). Saber, S.M. *et al.*, (2023) in their study used cone beam computed tomography to examine the anatomical variations of mandibular second molars in an Egyptian subpopulation. Images were evaluated in terms of number of roots, number of root canals, root cross-sectional area, and prevalence and configurations of C-shaped canals. A statistical analysis was carried out to highlight the differences between the different categories and their prevalence according to gender.

In vitro methods are also used to study root morphology and canal anatomy of permanent teeth. They are performed in the laboratory on extracted teeth. Micro-computed tomography (micro-CT) is a non-destructive method that provides an extremely precise and reproducible qualitative and quantitative representation of root and canal anatomy (Wolf, T.G. *et al.*, 2016). Nowadays, micro-CT is considered the reference method for the study of the anatomy of the canal system in the laboratory (Saber, S.M. *et al.*, 2023). However, it is a time-consuming and expensive technique that requires complex image acquisition and reconstruction procedures requiring a well-trained operator and in-depth knowledge of dedicated software (Martins, J.N.R. *et al.*, 2017; Ahmed, H.M.A. 2022). Wolf, T.G. *et al.*, (2025) in their work examined the morphology of maxillary canines by means of micro-computed tomography (micro-CT). The root canal configurations of maxillary canines from a mixed Swiss-German population were analyzed by micro-CT. After representing the internal morphology by 3D software imaging, the results of the root canal configurations were described using a four-digit system code indicating the main root canal from the coronal third to the apical third and the number of the main foramen. The study by Aljawhar, A.M. *et al.*, (2025) examined the canal morphology and fine anatomical features of maxillary first premolars in an Iraqi subpopulation using micro-computed tomography (micro-CT) and classified using the systems of Vertucci and Ahmed *et al.*, Also, Tang, Y. *et al.*, (2023) conducted an in vitro study that aimed to identify the anatomical characteristics of the canal systems of mandibular incisors in a Chinese population, using micro-CT. The teeth were scanned by micro-CT scanner and then reconstructed three-dimensionally. The canal configuration was detected by Vertucci classification, the number and location of accessory canals were also identified. Micro-focused computed tomography (micro-CT) was used by Jonker, C.H. *et al.,* (2023), to describe a range of accurate methods to define the transition from the pulp chamber to the root canal in different root morphologies of maxillary and mandibular first molars. In order to analyze the root anatomy and the morphology of the canal system of the first mandibular premolars in a Chilean population, Sierra-Christancho, A. *et al.*, (2021) scanned the teeth by microscanner and reconstructed them in three dimensions. The morphology of the root canal system was classified according to the Vertucci and Ahmed criteria. The root grooves were categorized according to the ASUDAS system and the presence of an abnormal Tomes root was associated with the Ahmed score. Similarly, Wolf, T.G. *et al.*, (2023) examined the canal morphology of mandibular second premolars of a mixed Swiss-German population by micro-computed tomography (micro-CT). Some authors have used the diaphanization method to study the anatomy of the canal system of permanent teeth. Indeed, diaphanization is a known method which consists of making the dental model transparent in order to visualize the canal morphology. This method provides a 3D view of the root canal without damaging the exterior of the tooth. Therefore, it remains one of the preferred educational tools (Singh, S. *et al.*, 2020). Nogueira, B.M.L. *et al.*, (2017) in their study, evaluated the prevalence of canal ramifications in the lower incisors of the population of northern Brazil, by the scaling and diaphanization method. In addition, external measurements were performed and the direction of the apical foramen was observed. The work of Bhat, S.A. *et al.*, (2019) on root canal morphology in an in vitro study, evaluated the canal anatomy of two and three-rooted mandibular first molars in Kashmiri population, by a

clearing and staining technique. To conduct a comparative study of the effectiveness of methyl salicylate and eugenol as a clarifying agent for tooth specimens, Vachhani, S. *et al*., (2020) devitalized teeth to study root canal morphology. The teeth were divided into two groups and devitalized with methyl salicylate and eugenol. The transparency and haziness of the root canal were evaluated. Spalding, M. *et al*., (2017) in a study, analyzed in vitro the configuration of the mesial root canal system of 180 maxillary first molars taken from a Brazilian sample. The teeth were diaphanized to confirm the presence of the mesiovestibular canal and to determine the internal anatomy. Also, Rehman, K. *et al*., (2015) in their work, briefly presented the application of different decalcification and diaphanization techniques carried out in an educational institution in Karachi, Pakistan to study teeth. They gave the percentages of the different chemicals used and the time of immersion of the teeth in these agents. The work of other authors focused on direct observation (direct vision), the dental microscope and two-dimensional radiography to study the morphology and canal anatomy of the teeth. Indeed, a study was conducted by Karobari, M.I. *et al*., (2025) to evaluate the effectiveness of clinically applicable diagnostic methods, such as direct vision, dental operating microscope and two-dimensional radiographs, for the detection of canal orifices and root configurations of mandibular first premolars with deep root grooves. The study also aimed to compare these methods with micro-computed tomography (micro-CT) to better understand their diagnostic capabilities and to assess the applicability of the Ahmed, H.M.A. *et al*., (2017) classification system to different imaging modalities. Sadaf, A. *et al*., (2019) identified and compared the variations in root and canal morphology of maxillary first and second premolars among the population of two cities in Pakistan, namely Peshawar and Kohat. Maxillary premolars were collected from six hospitals and clinics. Demographic data collected from patients included linguistic ethnicity and gender. External morphological parameters (length, root shape, mesial surface depression) were observed by eye. They were then observed under a stereomicroscope to identify internal root morphology, including canal shape, lateral canals, and canal isthmuses.

CONCLUSION

From this literature review, it should be noted that the means of studying the root morphology and canal anatomy of teeth are *in vivo* means (two-dimensional and three-dimensional radiographs) and *in vitro* means (direct vision, molding, operating dental microscope, two-dimensional radiography, diaphanization, anatomical sections, micro-computed tomography).

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