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External and Internal Anatomy of Mandibular Permanent Incisors

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Abstract

A clear understanding of dental root anatomy, external and internal, is an essential prerequisite to all dental procedures. In periodontology, the external root morphology has been proven to have a clinical significance in the predisposing factors of periodontal diseases. Orthodontic literature shows the importance of radicular anatomy in orthodontic mechanics through the concept of anchorage. The significance of internal root anatomy has been emphasized by studies demonstrating that variations in canal geometry before cleaning, shaping, and obturation procedures had a greater effect on the outcome than the techniques themselves. The mandibular central incisor is the smallest tooth in the mouth, but the buccolingual dimension of its root is very large. This tooth is usually single-rooted; however, the root canal system of this group is unpredictable. The incidence of two canals has been reported as low as 0.3% and as high as 45.3%. The wide range of variation reported in literature regarding the prevalence of a second canal has been related to methodological and racial differences. This chapter will summarize the morphological aspects of the root canal anatomy published in the literature of the anterior mandibular teeth. This will provide precious knowledge regarding root canal morphology and its variation among populations.

Keywords: morphology, mandibular incisors, variation, root canal

1. External root morphology

The mandibular central and lateral incisors have a single conical root. The root dimensions of both incisors vary corresponding to the crown. They are narrow in mesiodistal dimension and wide in labiolingual dimension and taper uniformly on both proximal sides from the CEJ to the apex. The apical end may curve slightly to the distal. Longitudinal root depressions can be seen in both incisors from the mesial and distal views. Multiple comparisons revealed that, among all permanent teeth, mandibular central incisor has the shortest root. Furthermore, in contrary to maxillary incisors, the root of mandibular lateral incisor is longer than that of mandibular central incisor [1]. It has been reported that the average lengths of mandibular central incisor and lateral incisor roots are 12.6 mm (7.7–17.9) and 13.5 (9.4–18.1), respectively [2]. Kim et al. [3] measured the mandibular incisor root lengths using CBCT in Korean population and found that no significant differences

in crown and root lengths were noted between the CBCT-based and direct measurements. The R/C ratios were higher for the mandibular lateral incisors (1.4 ± 0.1) than mandibular central incisors (1.3 ± 0.1) [4]. Therefore, crown lengthening may not be possible in the case of traumatic fracture or iatrogenic orthodontic extrusion due to the short root length in these teeth. Variations in root length between males and females have been reported. According to Zorba et al. [5], it was observed that root length was greater in males than in females. Haghanifar et al. [6] found similar results when comparing crown and root lengths between males and females. He found that females had longer crowns while males had longer roots.

Many authors reported that the external crown and root morphology of mandibular central and lateral incisors are similar [2, 7, 8]. Mandibular incisors usually have a single root, which is wider buccolingually than mesiodistally and tapers toward the apex. The lateral incisor root is larger than that of the central incisor in mesiodistal and labiolingual directions [8, 9]. Variation in number of roots has not been reported in literature. However, Loushine et al. [10] have found two rooted mandibular lateral incisors. However, the shape may vary from conical to round in different populations. Sexual variation in the number and shape of roots has not been reported [9]. Mandibular incisor roots are commonly reported to be straight and in rare occasions curved in the apical region. Curvature can be in the mesial, distal, labial, or lingual direction [9].

2. Internal anatomy

2.1 Introduction

Orban stated that the shape of the root canal “to a large degree, conforms to the shape of the root. A few canals are round and tapering, but many are elliptical, broad and thin” [11].

The internal anatomy of permanent mandibular incisors does not usually reproduce the simplicity of external anatomy. Its internal anatomy is complicated by the presence of lingual canals, lateral canals, isthmus, and apical deltas [12]. The pulp cavity is the central cavity within a tooth and is entirely enclosed by dentin except at apical foramen. It is divided into coronal portion (pulp chamber) and radicular portion. The pulp chamber is wide and ovoid labiolingually and it tapers incisally. The size of the pulp chamber is not constant throughout life. It decreases in size with aging as a result of secondary dentin deposition [13]. The pulp horn is well developed in this tooth. The root canal systems of these single-rooted teeth often have a single root with a single root canal. However, studies have shown that the root canal anatomy of these teeth is not simple. It may not be single and straight as it appears on the periapical radiograph. Indeed, these teeth have a high prevalence of bifurcation, second canals, lateral canals, and apical deltas which would complicate surgical and nonsurgical endodontic treatment. Mandibular incisor's anatomy presents a challenge when an endodontic access is made, because of its small size and high prevalence of two canals. The main reason for failure in endodontic treatment of mandibular incisors is the inability to detect the presence of a second canal which can then not be prepared and filled during treatment [14]. In literature, the incidence of mandibular incisor teeth with more than one canal has been reported to range from 11 to 68% [15–19]. The differences between these morphology studies may be related to variations of examination methods, classification systems, sample sizes, and ethnic background of tooth sources. Many researchers have studied the prevalence of a second canal in mandibular permanent incisors on different populations and showed that the root canal morphology varies with race, sex, and age [20–24].

2.2 Shape and size of pulp cavity in permanent mandibular incisors

Routine clinical radiographs may mislead clinicians to be under an impression that all root canals are round in shape. A high prevalence of oval root canals in human teeth was reported [25, 26].

The pulp canal of the permanent mandibular central incisor is wider buccolingually than mesiodistally [9]. These dimensions are not constant along the root from the orifice till the apex. Oval canals and long oval canals are the most common canal shape seen in the coronal and middle third [27]. As we approach the apex, the canal shape becomes more rounded [28]. This canal shape morphology corresponds to the shape of the root.

2.3 Number of canals in permanent mandibular incisors

The root canal morphology of mandibular central and lateral incisors is very similar. Although they have only one root and a high prevalence of Type 1 root canal morphology, surgical and nonsurgical root canal treatment may fail in these teeth if there is a lack of awareness in their internal anatomy which is complicated by the presence of the lingual canal, bifurcation, lateral anatomy, and isthmus [17, 29]. The morphological characteristics of the root canal system were studied using a number of techniques [18, 27, 30]. The prevalence of a second canal in mandibular permanent incisors is different between populations. Vertucci [18] reported that the incidence of the presence of a second canal was 25.7% among American population, whereas the incidence in Chinese population for the mandibular central and lateral incisors was 5.71 and 27.36%, respectively [31], 30% in Saudi population [32], 26.2% in north Jordanian population [33], and 36.25% in North-East Indian population [34]. In Iranian population, the incidence of mandibular central and lateral incisors having two canals was 27.3 and 29.4%, respectively [35]. The highest incidence (63%) of a second canal in mandibular incisors has been reported in a study in Turkish population [19].

Rankine-Wilson and Henry [36] filled the root canals of mandibular anterior teeth with radio-opaque material, sectioned them in a horizontal plane, and exposed radiographs. They reported two canals in 40.5% of mandibular incisors. Later, Vertucci [18] studied the root canal morphology of 300 extracted mandibular anterior teeth using the clearing technique. In 30% of mandibular central incisors and in 25% of mandibular lateral incisors, there was a second canal. On the other hand, higher prevalence of a second canal in Chinese population was reported in lateral mandibular incisors 25.5% compared with 10.9% in central mandibular incisors [37].

Many researches have shown that root canal systems also vary according to gender. In Turkish population, Sert and Bayirli [19] reported the incidence of second canal in central incisors in females (70%) was higher than in males (65%). Also in Turkish population, Arslan et al. [38] found the frequency of mandibular incisors with a second root canal in males (63%) was higher than in females (35%). The differences among both studies may be due to the fact that Sert and Bayirli examined the root canal morphology in vitro, whereas Arslan et al. studied the root canal anatomy in vivo. In Chinese population, Zhengyan et al. [30] found a significant difference between sex. The result of his study showed that 9.4% of the mandibular lateral incisors in males had a second canal, whereas this value was 11.9% in females. Among Iranian population, Haji et al. [39] reported that there was no significant difference between males and females in the incidence of a second canal in mandibular incisors.

2.4 Canal configurations in permanent mandibular incisors

It has become clear that teeth have complicated root canal systems rather than simplified canals [40]. Most investigators have shown that the root canal systems for most,

if not all, permanent teeth are complex and canals may branch, divide, and rejoin. In addition to the complexity of root canal anatomy, root canal morphology varies from tooth to tooth. Concerning root canal treatment, these variations in root canal morphology of permanent teeth may result in missing root canals, nonsurgical endodontic treatment failure, and a need for surgical procedures. Weine et al. [41] classified root canal systems into four basic types, but Vertucci [18] subsequently classified them into eight configurations. The Vertucci classification may give consideration to the complex reality of canal systems in a way that the Weine et al. system did not.

Weine [42] described each of the canal types as below:

Type I: Single canal from pulp chamber to apex.

Type II: Two canals leaving the chamber and merging to form a single canal short of the apex.

Type III: Two separate and distinct canals from chamber to apex.

Type IV: One canal leaving the chamber and dividing into two separate and distinct canals.

Vertucci [24] classified canal configurations into eight types as described below:

Type 1: A single canal from the pulp chamber to apex [1].

Type II: Two separate canals leaving the pulp chamber before joining short of the apex to form one canal [2-1].

Type III: One canal leaving the pulp chamber before dividing into two in the root and then merging to exit as one canal [1-2].

Type IV: Two distinct canals that extended from the pulp chamber to the apex [2].

Type V: One canal leaving the pulp chamber and dividing short of the apex into two separate distinct canals with different apical foramina [1-2].

Type VI: Two separate canals leaving the pulp chamber, merging in the body of the root, and re-dividing short of the apex to exit as two distinct canals [2-1-2].

Type VII: One canal leaving the pulp chamber, dividing and then rejoining in the body of the root, and finally re-dividing into two distinct canals short of the apex [1-2-1-2].

Type VIII: Three separate, distinct canals that extended from pulp chamber to apex [3].

Although mandibular incisors are usually single-rooted teeth, their root canal system cannot be predicted not only between different populations but also between the same population, with respect to the Vertucci's configuration. Studies reported that Vertucci's Type I configuration has the highest prevalence among the other Vertucci configurations [43–45]. When a second canal is present, Vertucci's Type III configuration is the most common for central and lateral incisors. Scarlatescu [46] found Type III has higher incidence than Type II, of 25 and 6.3% respectively in a Romanian population. de Almeida [47] reported that Vertucci's Type I and III configurations represented 92% of the sample. Leoni investigated the root canal anatomy of mandibular central ($n = 100$) and lateral ($n = 100$) incisors and founded that Vertucci's Type I (50 and 62%, respectively) and Type III (28%) were the most prevalent canal configurations in incisors [48]. However, researchers found high prevalence of Vertucci's Type II than Vertucci's Type III when a second canal is present. For example, Al-Qudah and Awawdeh [33] reported that the most common root canal configurations were Vertucci's Type I, II, III, IV, and V with a prevalence of 73.8, 10.9, 6.7, 5.1, and 3.6% of mandibular central and lateral incisors respectively in a Jordanian population. Another study done in an Iranian population conducted by Yazdi and Jafari [49] using in vitro radiography, staining, and sectioning technique reported 88, 3.5, 0.5, and 8% prevalence of canal types I, II, IV, and V respectively in mandibular incisors. A similar study done by Miyashita et al. [17] among Japanese population founded central and lateral incisors with

prevalence of Vertucci's Type I, II, III and IV as 87.6, 9.3, 1.4, and 1.7% respectively. These configurations may have an implication in endodontic treatment outcome. A properly executed root canal treatment will lead to success in Type I, II, IV, and VIII canal configurations while the same treatment might lead to unfavorable treatment outcome in Type III canal configuration. Apically dividing systems like Type V, VI, and VII are the most difficult systems to prepare and obturate and may have an influence on the outcome of root canal treatment. Miyashita et al. [17] studied the relationship between canal configuration and external dimension, and found that Type II and III root canal configurations of mandibular incisors were larger in tooth length, and crown width labiolingually and mesiodistally. In cases of nonsurgical root canal procedure, disinfection and obturation of Type I and IV canal systems are relatively simple owing to that each of these configurations having definite canals with separate orifice and apex. Contrarily, Type II, III, and V systems are different because there are areas in the root where the two canals share space and others where the canals are separate. This requires an individualized procedure for preparation and filling in each of these conditions to obtain the most desirable results. Although the incidence of two separate canals is low, ribbon-like canals are detected in cases that were classified as Type I (simple root canal) based on their canal configuration, and this results in enabling the file to touch a large area of the canal walls.

2.5 Lateral canals in permanent mandibular incisors

Lateral canals are accessory canals located in the coronal or middle third of the root, extending horizontally from the main canal to the external surface of the root. Their formation is due to the entrapment of periodontal vessels in Hertwig's epithelial root sheath or when blood vessels running from the dental sac through the dental papilla persist during calcification [50]. Lateral canals communicate with the periodontal ligament space and this increases risk of spread of periodontal disease into the pulp canal. According to their location, Vertucci classified lateral canals into coronal, middle, apical, or furcation. He observed lower occurrence of canal ramifications in the middle 11.4% and coronal 6.3% thirds compared to the apical 73.5% third [18, 24]. Recent micro-CT studies on root canal morphology of mandibular anterior teeth reported that lateral canals are rare [48, 51]. Miyashita et al. [17] reported that out of mandibular incisors with lateral branches, single lateral branch had the highest prevalence (82.2%) and multiple branches were extremely narrow. Al-Qudah and Awawdeh [33] found that there was an increasing prevalence of lateral canals toward the apical third of the root with approximately 64% occurring in the apical part of the roots. On the other hand, other studies reported that lateral canals were frequently found in the middle of the canal [34, 46]. Clinically, lateral canals are not usually visible in preoperative radiographs, but its presence can be suspected when there is a localized thickening of the periodontal ligament or a lesion on the lateral surface of the root [50]. It is also important to note that lateral canals cannot be instrumented. Its contents can only be neutralized by the action of effective irrigation with appropriate tissue dissolvent properties and antimicrobial activity solution or with the addition of use of intracanal medications.

2.6 Apical deltas in permanent mandibular incisors

Apical deltas are defined as an intricate system of spaces within the root canal that allows free passage of blood vessels and nerves from the periapical compartment to the pulp tissue [52, 53]. The apical delta is different from the accessory canal in which the main pulp canal is still distinguishable. The prevalence of

apical deltas in human permanent teeth varies among populations, and the type and locations of tooth and methods of study. High prevalence of apical deltas is found in maxillary second premolars, mandibular lateral incisors, and mandibular second premolars [22]. Among American population, Vertucci [18] reported that the incidence of apical deltas was 5, 6, and 8% in the mandibular central incisors, lateral incisors, and canines, respectively. However, Çalışkan et al. [22] reported that the prevalence of apical deltas in those teeth was 9.8, 23.5 and 7.8% in a Turkish population. Apical deltas have been reported to be of great importance in endodontics because they are difficult to be instrumented during chemical-mechanical preparation. Furthermore, their long vertical extension may cause failure of the apical surgery if not involved during apical resection [54]. Gao et al. [55] reported that the median vertical distance of the apical delta was 1.87 mm with 13% of them more than 3 mm. Therefore, resection of the apical 3 mm of a root may include the whole apical delta and residual microorganisms from 87% of roots with apical delta.

2.7 Intercanal anastomosis in permanent mandibular incisors

A thin communication can occur between two or more canals in the same root or between vascular elements in tissues [56]. Green [23] described this corridor as a “ribbon shaped passage.” He found this corridor in 22% of mandibular incisors. An isthmus is formed when an individual root projection is unable to close itself off. Any root that contains two root canals has the potential to contain an isthmus [57]. It may contain tissue remnants and necrotic debris, which participate in microorganisms’ growth resulting in root canal treatment failure [58]. Therefore, knowledge of the root canal anatomy is essential for complete cleaning of the root canal and successful endodontic treatment [11]. Isthmus classification was described by Hsu and Kim et al. [59]. They classified isthmus into five types: Type I—two canals with no notable communication; Type II—a hair-thin connection between the two main canals; Type III—differs from Type II because of the presence of three canals instead of two; Type IV—an isthmus with extended canals into the connection; and Type V—there is a true connection or wide corridor of tissue between two main canals. Mauger reported that isthmus was present in 20% of the teeth at the 1-mm level, 30% at 2 mm, and 55% at 3 mm [27]. Estrela et al. [60] demonstrated high prevalence of both partial and complete isthmii in mandibular lateral incisors (47.6%) compared with mandibular central incisors (33.3%). On the other hand, Arslan et al. [38] found a low incidence (3.7%) of intracanal communication among Turkish population. A similar study done by Haghanifar [61] found the prevalence of complete isthmus in the mandibular anterior teeth ranged from 3 to 5%.

2.8 Anatomy, number, and position of apical foramina in permanent mandibular incisors

As a result of large width of the root canal buccolingually than mesiodistally, mandibular incisors have oval and flattened canals [25]. The overall prevalence of long oval root canals in the apical region in mandibular incisors is >50% [25]. When using rotary files, these oval-shaped canals are a challenge for proper shaping of the canal. This is because rotary instrumentation cannot touch all the canal walls, leaving behind untouched area. To improve mechanical apical debridement, the use of instruments up to an ISO size 100 is required to avoid leaving untouched area on the buccal and/or lingual walls of the canal [62]. However, using files with large taper or tip may cause lateral or apical perforation of the root as the root has a narrower

diameter in the mesiodistal direction. Therefore, it stresses the use of good chemical disinfection protocol on these teeth. Canals are considered as oval, long oval, and flattened when the ratio between the maximum and the minimum cross-sectional diameter is $<2:1$, $2-4:1$, and $>4:1$, respectively. Apical foramina are the main apical opening of the root canal. It is the main exit of the root canal onto the external root surface. Variation in the number and position of apical foramina is especially seen in mandibular incisors with two canals. The apical foramen coincides with the anatomical apex in 17–52.2% of the cases [19, 22, 33, 57, 63].

A number of studies (17.33%) reported that the position and the number of the apical foramen vary according to the race. Al-Qudah and Awawdeh [33] reported that more than half of the roots (52.2%) had centrally located foramina and 47.8% had laterally located foramina. Apical deltas were observed in only eight teeth (1.8%), and among mandibular incisors with two canals, single foramen was more prevalent than two apical foramina. Miyashita et al. [17] reported that only 3% of the mandibular incisors containing two canals had two foramina. He also found that 67.9% of mandibular incisors with curved root had eccentrically located foramina toward the labial direction and none of the canals were curved lingually.

According to Walker [63], the distance between the apical foramen and the most apical end of the root ranges between 0.2 and 2.0 mm. The diameter of the apical foramen of mandibular incisors has been reported to be as 262.5 μm .

2.9 Anomalies in permanent mandibular incisors

Anomaly (Gk, anomalos; irregular) is a deviation from what is regarded as normal [64]. These abnormalities may occur, in terms of size or shape, to either crown or root. WHO listed the following dental anomalies: concrescence, fusion, gemination, dens evaginatus, dens in dente, dens invaginatus, enamel pearls, macrodontia, microdontia, peg-shaped teeth, taurodontism, and tuberculum paramolare [65]. Anomalies of permanent mandibular incisors regarding the crown and root shape are extremely rare. However, few case reports have registered anomalies associated with mandibular incisors. As an example, dens invaginatus, a deep surface invagination of the crown or root, which is lined by enamel and resulting from the invagination of the enamel organ into the dental papilla during odontogenesis, can be seen in these teeth [66]. Dens invaginatus has been classified into three categories according to the depth of invagination and communication with the periapical tissue or periodontal ligament [67].

Type 1: The invagination ends as a blind sac confined to the crown.

Type 2: The invagination extends apically beyond the external CEJ, ending as a blind sac and never reaching the periapical tissues.

Type 3: The invagination extends beyond the CEJ and a second “apical foramen” is found in either the periapical tissues or the periodontal ligament.

The prevalence of this anomaly has been found to range from 0.25 to 5.1% of the population [66]. More commonly, dens invaginatus occurs in the maxillary permanent lateral incisors. Also, it may occur in maxillary central incisors, premolars, canines, and molars. It usually occurs unilaterally, but bilateral cases have also been reported [68]. Occurrence of dens invaginatus in mandibular teeth is very rare. When it occurs in mandibular incisors, the central incisor has a higher incidence compared with lateral incisor [69, 70].

Talon cusp is also a rare developmental anomaly defined as an additional cusp that projects predominantly from the labial or lingual surface of primary or permanent anterior teeth [71]. Mellor and Ripa [72] named this anomaly “talon cusp” as it resembles the shape of an eagle’s talon. Talon cusp was classified by Hattab [73] as follows:

Type 1: True talon cusp—this is a morphologically well-delineated additional cusp that prominently projects from the palatal surface of a primary or permanent anterior tooth and extends at least half the distance from the CEJ to the incisal edge.

Type 2: Semi talon cusp—this is an additional cusp of size a millimeter or more but extending less than half the distance from the CEJ to the incisal edge.

Type 3: Trace talon—this is enlarged or prominent cingula and their variations (i.e., conical, bifid, or tubercle-like).

Radiographically, the talon cusp may appear typically as a V-shaped radiopacity, starting from the cervical third of the crown. Most of the talon cusps occur in the maxillary lateral incisors (55%), followed by maxillary central incisors (32%) and maxillary canines (9%) [71]. Although it is rarely seen in mandibular teeth [74], Gündüz and Celenk [43] studied the site distribution of talon cusp among Turkish population and found only 3% of talon cusp was seen in the mandibular right central incisors.

Another rare developmental anomaly that has been reported to occur in mandibular central incisor is “Gemination” [75]. It is a rare anomaly that arises when the tooth bud of a single tooth attempts to divide. The structure most often presents as two crowns, either totally or partially separated, with a single root and one root canal [76]. In the anterior region, gemination can cause poor esthetic appearance due to irregular morphology. In addition, these teeth are more susceptible to periodontal disease and caries, if deep groove is present [77, 78].

Fusion is another developmental anomaly which can occur in these teeth. Contrary to gemination, fusion is defined as the union of two or more separately developing tooth germs during odontogenesis, when the crown is not yet mineralized at the dentinal level, yielding a single large tooth [79]. Depending on the stage of development at the time of union, the pulp might be merged or separated [80]. Fusion is more frequently seen in primary dentition, but it may occur in both dentitions. If it occurs in permanent dentition, the vast majority of permanent teeth fusion cases are seen in maxillary teeth. Although, the incidence of fusion of mandibular incisors is rare, mandibular central incisors have been reported to fuse with a supernumerary tooth [81] and bilaterally with the adjacent lateral incisor [82].

It should be emphasized that special attention is required during root canal treatment owing to the abnormal morphology of the crown and the complexity of the root canal system in fused teeth.

3. Clinical recommendation relevant to the mandibular incisors' anatomy

Mandibular incisors are prone to endodontic treatment as a result of several reasons. Due to their location in the jaw, they are prone to traumas that result in tooth fracture which may necessitate root canal therapy. Moreover, their proximity to the opening of the sublingual and submandibular ducts increases the incidence of dental caries as a result of lingual deposition of calculus. Therefore, an accurate knowledge of the external and internal anatomy of these teeth is an essential prerequisite to carry out root canal treatment. They often have two canals that are buccolingually located and the lingual canal usually is missed. Therefore, the dentist should extend the access preparation in lingual direction to locate the lingual canal which is usually below the cingulum. In case of two canals, Type II canal is the most prevalent configuration where the buccal canal is the most straight and easiest to be located. Consequently, it is recommended to instrument and fill these canals till the apex whereas the lingual canal merges with the labial canal. Presence of an isthmus

may complicate the root canal disinfection as it may contain tissue remnants and necrotic debris, hence irrigation and activation are very essential to overcome these anatomical difficulties.

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