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Review article

MICRO-COMPUTED TOMOGRAPHY ASSESSMENT OF THE ROOT CANAL SYSTEM

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ABSTRACT

Introduction: The root canal system (RCS) is among the complex parts of the body that consists of several anatomical variations. The RCS has also been classified according to different classifications. In one of the classification systems, the RCS consists of the main canal, lateral canal, collateral canal, secondary canal, intercanal, accessory canal (AC), and recurrent canal, whereas in the other classification system, which was presented by the American Association of Endodontists (AAE) in 2020, the RCS consists of the C-shaped canal, lateral canal, furcation canal, and AC. Many researches have already been conducted on using micro-CT in describing the RCS classification in various teeth groups in the jaws.

The micro-CT is a method used for the endodontic study, including the morphological study of the RCS. It is one of the non-destructive and high-resolution techniques that is beneficial in obtaining three-dimensional (3D) teeth structures. The method is similar to computed tomography and allows obtaining sections as well as 3D reconstruction of the studied object.

Based on the above-mentioned findings, the authors discussed that canals are usually more long oval or ribbon-shaped at the coronal levels, then become oval or round shaped about 1 mm from the apical foramen, indicating that canal shape and number change in the apical third.

Conclusion and future perspectives: The micro-CT could be a useful technology in the clinical study of canals, developmental grooves, and comparison of treatment and diagnostic strategies.

Keywords: accessories canals, apical third, micro-CT, premolars, root canal system,

INTRODUCTION

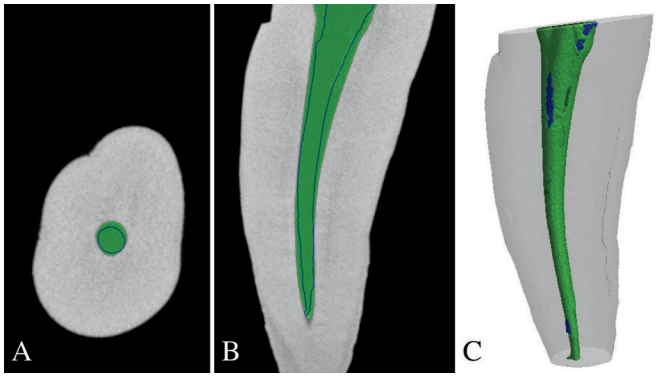
The root canal system (RCS) is among the complex parts of the body that consists of several anatomical variations [1]. The root is divided into three areas for better analysis of the vertical form of branched canals. These three locations include the apical third, the middle third, and finally, the coronal third [1, 2]. The RCS has also been classified according to different classifications. In one of the classification systems, the RCS consists of the main canal, lateral canal, collateral canal, secondary canal, intercanal, accessory canal (AC), and recurrent canal [2, 4], whereas in the other classification system, which was presented by the American Association of Endodontists (AAE) in 2020, the RCS consists of the C-shaped canal, lateral canal, furcation canal, and AC [4].

Among all these canals in the classifications of the RCS, ACs have the highest chances of being present in the apical third [3, 5, 6], which is considered one of the most complex structures in the RCS [7, 8]. The study of the apical third is critical in determining the appropriate intervention for the issues associated with the RCS [9].

An increase in the chances of finding ACs in the apical third has been supported by several studies, including the studies conducted by Degerness and Bowles [10] and Ordinola-Zapata et al. [11]. Degerness and Bowles reported about 80% of the chances of ACs in the apical third, and Ordinola-Zapata et al. reported about 76% of the chances of ACs in the apical third. Nevertheless, the ACs are derived from the secondary canal and move towards the external root; these canals are also considered as the divisions of the primary pulp chamber or canal communicating with the external root [3]. The study of ACs is essential as they are associated with biological variations from the original dental biology [12]. They are commonly found in human teeth. Their incidence may range from 40% to 80% in different dental groups [13], so their study with micro-computed tomography (micro-CT) could be of significant help in the research on the RCS as well as apical third features [3].

The micro-CT is a method used for the endodontic study, including the morphological study of the RCS [14-17]. It is one of the non-destructive and high-resolution techniques [16-19] that is beneficial in obtaining three-dimensional (3D) teeth structures (Fig. 1).

Fig. 1. Micro-computed tomography (micro-CT) of a mandibular premolar: **A/** Cross section from the middle third; **B/** Longitudinal micro-CT image of the premolar; **C/** 3-D reconstruction with prepared (*green*) and unprepared areas (*blue*).



The method is similar to computed tomography and allows obtaining sections as well as 3D reconstruction of the studied object. One of the main parameters of the study is the "voxel." It is a term from computer science and 3D computer graphics that refers to an element in three-dimensional space. The term is composed of the English word "volume" and the word "element" by analogy with a pixel from two-dimensional bitmaps (bitmap). Like pixels, voxels do not explicitly encode their position (coordinates) and value. Instead, the position of a voxel is derived based on its location relative to other voxels, i.e., its place in the data structure that describes the volumetric image [20].

When examining a root canal filling, a section of interest can be selected and presented as a two-dimensional figure showing the dentin, the canal filling agent, and cavities (internal - completely lined with canal filling material and external - when the cavity communicates with the tooth dentin. For better image quality, different filters and different radiation parameters are used to find the most suitable ones. Nowadays, Micro-CT is considered the most important and accurate scientific method to study endodontic anatomy [21].

Takabayashi et al. investigated root canal obturation as part of dental student training. The micro-CT system (*ScanXmate-L090H; Comscantecno Co. Ltd., Yokohama, Japan*) was used. The dimensions of the cavities located between the enamel-cementum border and the apex were investigated. The results show the possibilities of the method in teaching students. After the initial obturation of canals and visualization of cavities, the next obturation is with a significantly smaller amount of empty spaces [22]. Fragachán et al. investigated the obturation of artificially created lateral canals, one in every one-third of the main root canal with microCT. Three different obturation techniques are used, with the best results being seen with warm condensation. The study was performed using the MultiTom Core and X-ray Engineering (XRE) system. Finally, a distinction was made between the hard dental tissues and the canal filling agent using Avizo software. After the studies, the filling volume in the different lateral canals was successfully calculated, and the methods were compared against each other [23]. Castagnola et al. compared two different canal filling techniques: Single-cone technique and GuttaCore obturation system. A CT scanner (*SkyScan 1072; SkyScan, Kartuizersweg, Belgium*) was used to evaluate the results. The analysis of the voids in the canals was performed with CTAn software (*Skyscan)*, taking into account internal and external voids. Three sectors of the root canal are examined: 0mm-3mm from the apex, 3-6mm from the apex, and 6-9mm from the apex [24].

Many researches have already been conducted on using micro-CT in describing the RCS classification in various teeth groups in the jaws [3]. Clinically, the findings associated with RCS classification are beneficial, as they provide details regarding the location and presence of accessories and lateral canals in various tooth groups in human beings that would be in addition to the classification systems found in the literature at this time [3]. Aside from the RCS classification, the micro-CT has also been utilized in the study of apical delta morphology in human teeth, as noted by Gao et al. [25]. They have also noted that the findings associated with using micro-CT in the apical delta morphology are clinically significant as they can be used in the improvement of treatment strategies, especially those related to failures for root canal therapy in the mesiobuccal root because of inadequate debridement of the apical delta [25].

On a further note, Berutti et al. [26] described the usage of micro-CT in the assessment and comparison of marginally invasive systems for shaping in relation to mandibular first molars. The study compared a modified form of the ProTaper Next shaping technique (PTNm) with the TruNatomy (TN) regarding lower molar mesial curved canals. They found that these techniques were equally helpful in shaping the canals [26]. The use of micro-CT in comparing the intervention or diagnosis techniques is also reported by Alshehri et al. [27] and Saberi et al. [28]. Nevertheless, micro-CT can also be used in the morphological research of the apical third of RCS in premolars [28, 29]. Therefore, this study explores the literature regarding micro-CT assessment of apical third morphological features of RCS in premolars.

DISCUSSION

Micro-CT is one of the techniques that has been applied to assess apical third morphological features of the root canal system. As noted earlier, AC can be found anywhere along the root length, but it frequently occurs in the apical third of the root. Therefore, in studying the morphological features of the apical third of the root, the study of ACs can be of sufficient help [16]. Ting Xu et al. researched the morphological features of accessary canals (ACs) utilizing the micro-CT method. They studied apical root systems with unobstructed ACs. In this regard, they investigated the shape, length, diameter, and undulation of 178 unobstructed ACs. They found that the predominant shape of unobstructed ACs was oval; the median diameter was approximately 67.0 μm; the mean length was approximately 786.6 ìm, and the undulation was tortuous and not straight

[16]. Keles et al. also studied apical third canal orifices at non-bifid and bifid mesial roots. They found that many samples had 2 to 4 orifices linking to the apical third [30]. The researchers also found root canals commonly found in the apical third related to the mandibular central incisor. They studied the volume and surface area (SA) values of central and lateral incisors and found that those teeth were not statistically significantly different ($p > .05$). At the apical third, they conducted the 2-D morphometric assessment of the root canal. They found that the root canal area gradually increased in these teeth in the coronal direction. The canal shapes (associated with roundness) were not the same from one level to another, and they showed a flat-shaped or oval-shaped canal configuration in the apical third of the teeth groups, as also noted by Ordinola-Zapata et al. [31]. In this regard, Fumes et al. reported that the apical third has flat-shaped canals concerning the mandibular molars, whereas oval- and ribbon-shaped canals concerning the maxillary molars [32]. Regarding the roundness of the canal shapes, it has been found that the apical third showed an oval shape compared to the cervical and middle thirds [33-35]. Furthermore, some authors reported that canal curvatures and roundness were significantly greater in the apical third of mesiobuccal root canals compared to the middle third and coronal third ($p < 0.05$). The curvature is gradual and smooth in the apical third [34, 36, 37].

Based on the above-mentioned findings, the authors discussed that canals are usually more long oval or ribbon-shaped at the coronal levels, then become oval or round shaped about 1 mm from the apical foramen, indicating that canal shape and number change in the apical third. The variation in the shape of the root canal into a more oval shape has also been noted by Craciunescu et al. [38].

Studying oval canals using micro-CT, those previous studies have shown difficulties in studying oval canals concerning the mandibular incisors using manual instruments, nickel-titanium rotary techniques, or even obturating them. Aside from the study of oval canals, researchers have also noted that cone-beam computed tomography (CBCT) is not of sufficient help in providing information regarding apical third minor root canal structures [39, 40].

CONCLUSION AND FUTURE PERSPECTIVES

The RCS is one of the complex parts of the body that consists of several anatomical variations. In the RCS, the apical third is also a complex body part. However, micro-CT is among the latest technologies that can help in the study of morphological features of the apical third of the RCS in premolars. This technology has already been used in the clinical study of canals, developmental grooves, and comparison of treatment and diagnostic strategies. Nevertheless, the use of micro-CT has helped in the study that ACs are most commonly found in the apical third. On a further note, the quantity of orifices changes from 1 to 4 in the apical third. The apical third has a more oval shape in comparison to the cervical and middle thirds. Moreover, canals are usually oval or ribbon-shaped at the coronal levels, then become oval or round-shaped at approximately 1 mm from the apical foramen, indicating that canal shape and number change in the apical third. In the future, large-scale randomized controlled trials can be conducted to assess the differences in the morphological features of the apical third in two or more races or ethnicities. These studies could help in optimizing the diagnostic and intervention strategies according to different races or ethnicities. Moreover, a large-scale study could help in increasing the generalizability of findings.

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