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EVALUATION OF ROOT CANAL ANATOMY AND ROOT CANAL TREATMENT USING CONE-BEAM COMPUTED TOMOGRAPHY: A REVIEW

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ABSTRACT

A good understanding of root canal anatomy is essential for successful root canal treatment and endodontic procedures. Ignorance of root canal morphology and variation is one of the main reasons for root canal treatment（RCT） failure. In recent years, cone-beam computed tomography (CBCT) has been widely used to study root canal anatomy and guide clinical work.

Keyword: CBCT, Anatomy, Root canal configuration, RCT

INTRODUCTION

From ancient times to the present, many studies have used a variety of techniques, including isolated tooth sections, transparent tooth staining, traditional two-dimensional imaging and the latest three-dimensional imaging techniques namely micro-CT and CBCT to study the root canal system, including accessory root canals, root canal configuration, isthmus and root canal abnormalities[1-6]. Among these research methods, except for CBCT, the others are only suitable for in vitro research.

CBCT, as an emerging examination technique in stomatology, has the advantages of lower radiation dose and higher resolution than traditional CT scans[7]. The data are analyzed and reconstructed using a CT-based algorithm to create a volume of data, which can be viewed in three conventional planes (axial, sagittal and coronal) and multiple alternative planes on manipulation of the data set[8]. The voxel size of the CBCT data set is between 0.08 and 0.4 mm, and the ratio to the projected object is 1:1, which can provide a reproducible, non-destructive a non-invasive method[9]. This article reviews the in vivo study of teeth using CBCT and its clinical application of RCT.

1. BASIC RESEARCH

Clinically, a large database of CBCT images from patients can provide valuable information about the typical tooth canal morphology of a given population, and the existing CBCT volumes can allow the measurement and thus quantitative analysis of the specific canal dentine thickness[10]. Measurements obtained from CBCT images showed agreement with the gold standard (cadaveric specimen measurements) and were considered an acceptable research method for estimating different anatomical landmarks[11]. This article mainly introduces two topics that are currently being studied: root canal configuration and canal wall thickness.

1.1 Root canal morphology

The most important reason for endodontic failure is incomplete root canal preparation, followed by incomplete closure of the root canal space. Lack of knowledge of root canal morphology is an inevitable obstacle to careful cleaning, shaping and sealing of the root canal system of teeth requiring RCT[12]. In recent years, a large number of studies have been published on root canal morphology based on CBCT, mainly studying the number of root canals and the morphology of the root canal system classified by different standards such as the Vertucci standard[13]. Mandibular first molar (MFM), as the first erupted permanent tooth in humans, has a high risk of caries and pulp infection[14]. Therefore, this tooth has the highest rate of RCT, and there are many related studies. Elham et al. used CBCT to analyze the root canal morphology of MFM in the Yemeni population, and pointed out that MFM in Yemenis is dominated by double roots, and 3.2% have distal lingual roots. The cross-section of the mesial root is mainly band-shaped, and the distal root is kidney-shaped. Vertucci type II and type III structures occur more frequently in the mesial and distal roots, respectively[15]. The conclusions based on the CBCT study of MFM root canal morphology in different races are not always the same[3, 16-18].

1.2 Root wall thickness

Since 1980, large-tapered nickel-titanium files have become popular. Stainless steel files have a 2% taper, while nickel-titanium files can reach 12%[19]. The ever-evolving nickel-titanium devices are widely used clinically due to their high efficiency, good bending resistance and formability[20]. However, due to its large taper, the dentin is removed too much in the dangerous area, which is prone to micro-cracks and banded perforations, thereby reducing the fracture resistance of the root[21]. According to Lim and Stock[22], at least 0.3 mm of dentin thickness should be preserved in the canal wall after root canal preparation to withstand the lateral pressure during filling and to prevent vertical root fracture（VRF）. For endodontic teeth requiring post-core crown restoration, the post must be surrounded by at least 1 mm thick dentin to ensure a good restoration prognosis[23]. Studies have shown that the dentin in 2 to 3 mm below the mesial furcation of MFM is thinner, with an average thickness of 0.78 to 1.27 mm, which is a dangerous zone for root canal preparation[24]. Zhou et al. analyzed 1792 CBCT images of MFM in 898 Chinese and measured the minimum dentin thickness of mesiobuccal (MB) and mesiolingual (ML) root canals from 1 mm to 5 mm below the root furcation[25]. The results showed that the thinnest wall thickness area of both root canals is located 3 to 4 mm below the furcation, with an average range of 0.78 to 0.80 mm. It is suggested that large-tapered nickel-titanium instruments should be carefully selected to shape this area. Using CBCT to visually evaluate the wall thickness and the residual canal wall thickness after preparation can provide a reference for clinical operations, and is of great significance for preventing band perforation and VRF.

2. CLINICAL APPLICATION

2.1 Confirmed extra root canals

Missed root canals are one of the common causes of RCT failure and are usually associated with periapical lesions[26]. The two-dimensional nature of radiographs means they cannot consistently reveal the actual number of root canals present in a tooth. This can lead to clinicians not being able to identify all root canals, which can ultimately lead to incompletely RCT[27].

2.1.1 Direct Diagnosis

The accuracy of using CBCT to detect extra root canals in permanent teeth has been affirmed clinically[28]. Usually, MFM has three canals, as well as the mesiobuccal （MB） canal, mesiolingual（ML） canal, and distal canal. The mesiomedial canal（MMC） and the distal lingual canal are easily missed[16]. The prevalence of MMC varies by ethnicity, but is approximately equal to 7% globally[29, 30]. A series of Taiwanese studies assessed the prevalence of the distal lingual canal in MFM by conventional radiographs and CBCT and found that the prevalence assessed by the two methods was 21% and 33%, respectively[31]. Matherne et al performed an in vitro study comparing a charge-coupled device and photo-stimulated fluorescent plate digital radiography system with CBCT to detect the number of root canals in 72 extracted mandible incisors, first premolars, and maxillary first molars. They found that, compared with CBCT, endodontists had difficulty identifying extra canals despite the x-ray taken at different angles[32]. A number of similar studies have assessed the prevalence of mesiobuccal second (MB2) canals in maxillary first and second molars[33, 34].

2.1.2 Indirect diagnosis

In recent years, deep learning systems, one of artificial intelligence（AI） methods, have been introduced for clinical work. Deep learning systems can automatically classify data sets and learn features contained in the data in depth by using multi-layer convolutional neural networks (CNN). They have been effectively used in image-based automatic diagnosis in various fields[35]. Validation of the diagnostic performance of a deep learning system for assessing the number of distal roots of MFM using panoramic radiographs using CBCT images as the gold standard. The results showed that the deep learning system demonstrated a high level of performance in distinguishing whether the MFM distal root was single or had an extra root, comparable to or slightly better than that of experienced radiologists[36]. If the root canal morphology is predicted by panoramic and periapical radiographs before treatment, the frequency of using CBCT can be reduced.

2.2 Guided endodontic techniques

The application of digital planning and guidance technology in endodontics makes the outcome of RCT predictable. The advancement of CBCT equipment and software can truly restore the internal anatomy of the root canal, which is associated with 3D planning and printing technology, and promotes the development of guided minimally invasive endodontics[37]. The preparation of personalized 3D guides can ensure safer operation steps in the process of handling complex endodontic cases, and its main indications are calcified endodontic access, endodontic surgery in difficult-to-access areas, and access abnormal development of teeth such as dens invaginatus.

2.2.1 Calcified root canals

Severely calcified canals may cause deviation during root canal preparation, band perforation, instrument separation, and asymmetric dentin removal. Designed by overlaying cone-beam computed tomography scans with the patient's intraoral scan, the personalized 3D guide enables clinicians to directly create access to occluded root canals. Pujol et al. used 3D guides and custom-made 1 mm diameter cylindrical burs to create root canal access for 7 severely calcified teeth, demonstrating that the use of guides was safe and fast, minimizing iatrogenic complications[38].

2.2.2 Dens invaginatus（DI）

DI is a dental abnormality thought to result from the inversion of the enamel organ towards the dental papilla during tooth development. The invagination area full of microorganisms and their products may aggravate the infection and lead to pulp necrosis[39]. Therefore, specific treatment method should be chosen according to the degree of invagination, type of DI and pulp condition. The complex anatomy of DI makes treating difficult and unpredictable. According to the Endodontics Case Difficulty Evaluation Guidelines from American Association of Endodontics (AAE), treating DI belongs to the high difficulty level, which is difficult for even the most experienced endodontists to manage. Using CBCT can show the location of invagination extension and associated apical inflammation or periodontal inflammation in more detail[40]. At the same time, using 3D printing guide can reduce iatrogenic damage to the tooth while accurately entering the invagination area[41].

3. SUMMARY

CBCT is the basis for guided digital planning in endodontics. It provides detailed anatomical information of the tooth and adjacent structures, which is useful for endodontists in detecting the number of root canals, and determining the different degrees of calcified occlusion and root wall thickness. It is expected that the lower radiation dose and higher resolution will increase the frequency of using CBCT in the future, so as to facilitate the development of personalized treatment according to the different conditions of the affected teeth.

Conflict of interest statement

The authors report no conflicts of interest.

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