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Comparative evaluation of cone-beam CT equipment with micro-CT in the visualization of root canal system

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Summary. The aim of this study was to compare three different cone-beam CT (CBCT) instruments used in dental clinical practice with micro-CT as gold standard. Three female monkeys' *(Macaca fascicularis)* skulls were selected and scanned by the tested CBCT-s. The most apical visible root canal level on the CBCT images was used as reference level (RL). After the image acquisition by CBCT-s dental jaw sections were scanned by micro-CT at a resolution of 17 μm. Out of the left second and third molars 25 root canals were selected and analysed by three observers at RL and following cross sectional parameters were determined: area of the lumen, major and minor diameters, aspect ratio and mean thickness. Results suggest that only high resolution CBCT instruments allow dentists detecting the full length of the root canal.

Key words: micro-CT, cone-beam CT, root canal morphology.

Riassunto *(Valutazione comparativa di strumentazione* cone beam *CT con micro-CT nella visualizzazione del sistema di radici canalari)*. Lo scopo di questo studio è quello di confrontare tre differenti strumenti cone-beam TC (CBCT − tomografia computerizzata a fascio conico) utilizzati nella pratica clinica dentale con la micro-CT come *gold standard*. Sono stati selezionati tre crani di scimmie femmine *(Macaca fascicularis)* e analizzati attraverso il CBCT-s collaudato. È stato utilizzato come livello di riferimento (RL) quello più visibile a livello apicale del canale radicolare sulle immagini CBCT. Dopo l'acquisizione dell'immagine attraverso il CBCT-s, sono state esaminate le sezioni della mascella dentale con la micro-CT con una risoluzione di 17 μm. Sono stati selezionati 25 canali radicolari ed analizzati al livello di riferimento da tre osservatori e sono stati determinati i seguenti parametri della sezione trasversale: area del lume, diametri maggiore e minore, il rapporto e lo spessore medio aspettato. I risultati suggeriscono che solo gli strumenti CBCT ad alta risoluzione permettono ai dentisti di rilevare l'intera lunghezza del canale radicolare.

Parole chiave: micro-TC, tomografia computerizzata a fascio conico, morfologia canale dentale.

INTRODUCTION

The success of endodontic treatments is defined by the knowledge of the dental root canals' morphology and the technique of the preparation and the hermetic obturation [1, 2]. The proper identification of the root canal system (number and shape of canals, accessory canals, etc.) is essential and requires clinical and radiological examinations. Different novel techniques and methods have been introduced and might facilitate the investigation of the root canal morphology [1], the knowledge of anatomic variations and helps in selecting proper instrumentation technique [3] even adequate files which might contribute to the success of the endodontic treatment.

At chairside the dentists should be aware of the variety of the root canals [4-7] during the access cavity preparation of the tooth *a priori*. Using operation microscope [8, 9] or CBCT (cone-beam CT) might simplify the localization and identification of the root canals [1]. A good number of publications deal with the possible varieties of the root canal systems using CBCT-s [1, 10-20]. Three-dimensional imaging has an advantage to define the morphology of a root canal in space [16, 21]. CBCT has the unique feature that eliminates the superimposition of surrounding formulas [16]. It might be useful in detecting the root canal shape, however, only a few studies have been reported on the visualization of the whole root canal shape – from the entrance to the apical foramen – using CBCT equipment yet [22].

In vitro studies focused on root canal morphology still have a continuous interest [22-27]. Over the past few years micro-CT systems have been used for the evaluation of the root canal morphology because of

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its high resolution and its nondestructive nature [28-33], furthermore it allows the observer evaluating the complete root canal system in different planes simultaneously or separately [32, 34]. For these reasons micro-CT is the best technology available now and might be functioned as a gold standard [35] besides using histopathological findings [36] or clinical sectioning [16].

The aim of this study was to compare three differing CBCT instruments with micro-CT as the gold standard to quantitatively determine their proficiencies with respect to imaging root canal systems.

MATERIALS AND METHODS

Three female monkey's (*Macaca fascicularis*) skulls, cultured for other research purpose, were selected and scanned by the following CBCT instruments: Planmeca ProMax 3D Smart (Planmeca Oy, Helsinki, Finland), Classic i-CAT (Imaging Sciences Intenational, Hatfield, USA) and NewTom VG (ImageWorks, New York, USA). The acquisition was taken at the highest respective resolutions for each scanner: 100 μm isometric voxel size using Planmeca (84 kV, 10 mA), 250 μm isometric voxel size i-CAT (120 kV, 36 mA) and 100 × 100 × 150 μm non-isometric voxel size NewTom (110 kV, 0.50 mA). The following preparation was made of the dental jaw sections with the second and third molars. The cut-out samples were scanned using SkyScan 1172 micro-CT (SkyScan, Kontich, Belgium) at a resolution of 17 μm (70 kV, 141μA) isometric cube voxel. The latter were used as a gold standard for comparison.

The root canal systems were dynamically analysed using CTAn v.1.1. software (SkyScan, Kontich, Belgium). The evaluation was made from coronal to apical level, in three plains from reconstructed images by three independent observers, two of whom have more than ten years experience in oral radiology and endodontology. The observers were not provided with results from related micro-CT analyses. The most apical level, where the root canal lumen was visible on the coronal plane of the CBCT images, was used as the reference level (RL). Root canal lumen was analysed at the RL on the axial planes of the reconstructed images taken by the micro-CT. Reconstruction of the micro-CT raw images was made by NRecon v.1.6 software (SkyScan, Kontich, Belgium). Manual tresholding of images was made, then the area of the lumen, the major and minor diameters, the mean thickness and the aspect ratio were subsequently determined.

RESULTS

The left upper second and third molars' mesiobuccal and distobuccal and the left lower second and third molars' mesial root canals (12 molars, 24 root canals and one accessory canal) were evaluated. Examining the images made by the Planmeca instrument, only one root canal apical end was invisible from 1.80 mm coronal to the apex *(Table 1)*. NewTom VG showed a total of 11 apical root canal lumen being invisible, with a mean RL-apex distance of 2.79 ± 1.34 mm. Finally, i-CAT images showed 16 apical root canals being invisible, with a 3.62 ± 1.45 mm mean length for invisible parts. The cross section parameters of the root canal lumen were as follows: the mean minor diameter was 121.87 ± 86.85 μm and 69.46 ± 43.56 μm while the major diameter was 335.32 ± 210.69 μm and 187.07 ± 82.08 μm on i-CAT and NewTom images, respectively. The aspect ratios representing the cross sectional shape of the lumen were 3.11 ± 1.39 and 3.00 ± 0.98, respectively. Mean thickness of the root canal lumen at RL was 95.05 ± 44.34 μm and 55.06 ± 18.52 μm for i-CAT and NewTom, respectively.

DISCUSSION

The increasing importance and applications of CBCT-s can't be emphasize enough in everyday dental clinical practice and dental research [37]. In endodontics it might aid the diagnosis of periapical lesions, identificiation of their origins and observing the canal morphology noninvasively [21, 38]. Nevertheless these instruments are not able to define the working length of a root canal.

Considering the results the instrument's resolution and the isotropic nature of the voxel size might be essential factors for detecting the full length of a root canal: with Planmeca only 4% (only one root canal apical end), with i-CAT 64% and with NewTom 44% of the 25 root canals' apical end was invisible. The reason of the high amount of the invisible apical ends might be that at the reference level some of the parameters describing the root canal might be smaller than the voxel size, among our selected parameters it was the minor diameter. This may certify the impor-

Table 1 | *Cross sectional parameters at the most apical visible level (RL) of the root canals*

		Parameters					
Equipments	**no.**	**RL (mm)**	**Area (μm²)**	**Major Φ (μm)**	**Minor Φ (μm)**	**Mean thickness (μm)**	**AR**
Planmeca	1	1.8	7243	125.27	34.74	34.75	3.6
NewTom	11	2.79 ± 1.34*	21162 ± 14737	187.07	69.46	55.06 ± 18.52*	3
iCAT	16	3.62 ± 1.45*	65378 ± 65792	335.32	121.87	95.05 ± 44.34*	3.11

*RL = reference level; AR = aspect ratio; *p < 0.05.*

tance of selecting high resolution (smaller pixel size) in order to help in the visualization of the specimen. Michetti *et al.* [22] scanned 9 extracted human teeth using Kodak 9000 3D (Kodak Carestream Health, Trophy, France) at a resolution of 76 μm isotropic voxel size and validated by histologic sections. This study concluded that using high resolution CBCT instrument offers a noninvasive and detailed imaging method for exploring the complete root canal system's anatomy in 3D. This statement is in line with our Planmeca results, however Mitchetti used extracted teeth unlike us. In the planning phase of our study we focused on the possibility of spreading the availability of CBCT units in everyday endodontic practice. Hence the surrounding hard and soft tissues were kept, thus the noise of the scanned images was dramatically increased similar to CBCT images taken from living patients.

On the other hand partial volume effect also aids the visualization of the root canal's apical end on a CBCT image, but it does not provide reliable information on the thickness and contour of the root canal and may distort some variances of the cross sectional shapes. Moreover it is difficult to estimate which diameters define the visibility of the root canals. Further on, no one can determine – to date – the level where the partial volume effect starts on a visible root canal path.

To be aware of all these micro-CT is an important tool in order to detect the complete root canal system, though it is not available in clinical practice [33, 39]. Results indicate that micro-CT seems to be a useful tool for determining accuracy of clinically used CBCT instruments in a comparison. Within present techniques dentists should settle for detecting the entire length of root canal path. Solely high resolution CBCT instruments might help in the reliable visualization of the root canal improving the outcome of the endodontic treatment.

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Conflict of interest statement

There are no potential conflicts of interest or any financial or personal relationships with other people or organizations that could inappropriately bias conduct and findings of this study.

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