Root canal length measurement of molar teeth using cone-beam computed tomography (CBCT): comparison of two-dimensional versus three-dimensional methods

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Introduction

The cone-beam computed tomography (CBCT) is a diagnostic imaging modality that provides a 3-dimensional (3D) visualization of the maxillofacial region. Because CBCT has the advantage of lower radiation dose compared with computed tomography (CT), it has become a useful method for treatment planning in various dental specialties, including endodontics (1-3). Currently, CBCT has an essential role in endodontic research for detecting apical periodontitis in both pre- or post-endodontic treatment, root fractures, perforations, internal/external root resorption, treatment planning in apical surgery or dental trauma cases, as well as exploration of root canal anatomy (4-11).
CBCT has many advantages over periapical or panoramic radiography such as the absence of image distortion, magnification, and superimposition but the radiation dose is significantly higher (12-14). In endodontics, the application of CBCT should be preferred when the third dimension is needed to perform an accurate diagnosis. However, it should not be used routinely (14). Furthermore, already existing CBCT data should be analyzed to obtain additional information within the FOV for details outside the region of interest. This may decrease the need for additional periapical radiographs (15, 16).

CBCT images of the scanned area could be visualized in mesio-distal, bucco-lingual, coronal planes, as well as in three orthogonal planes at the same time. This enables the observer to examine the root canal curvatures and the position of the major foramen location, which is not always possible using periapical radiography (3). Some investigators reported in in-vitro, in situ, and in-vivo studies that the improved visualization of root canal morphology with CBCT could increase the accuracy of root canal length determination (17-25). In most of these studies, single-rooted teeth with straight single root canals were preferred in a vertical position to visualize, whenever possible, the whole length of the canal in a single slice (17, 20, 21, 23-25). Some of these studies concerned the accuracy of root canal length determination with CBCT in multi-rooted or curved root canals (18, 19, 22, 26, 27). Few studies compared 3D and 2D measurements (19, 21). Therefore, the aims of the present study were; first to compare the validity of 2D and 3D CBCT root canal length measurements and second, to evaluate the influence of root canal curvature on the accuracy of both CBCT root canal length measurement methods.

Materials and Methods

Study sample

Approval to use extracted human teeth in this study was granted by the Ethics Committee (Project No: D-KA 17/12). A priori power analysis revealed that the minimum sample size should be 70 root canals for α= 0.05 and to reach the power of 80%. Freshly extracted lower molar teeth were collected. Teeth with cracks, resorption, fractures, immature apexes, previous root canal treatment, amalgam, or crown restorations, extensive coronal caries resulting in loss of cusp structure/ points of reference, signs of hypercementosis, were excluded. Finally, a total of 70 root canals of 24 lower molar teeth were included. The teeth were kept in 10% formalin solution. After cleaning the calculus and soft tissue remnants, each tooth was numbered on the buccal surface and embedded into rectangular models with a height of 3.5 cm and a length of 4 cm, made from silicone putty (Zetaplus, Zhermack, Marl, Germany). A total of 6 silicone models with 4 teeth embedded in each were obtained. Also, a thin metal rod was placed on the front surface of each silicone model to determine the buccal surfaces of the teeth.

Imaging protocols

Preoperatively, teeth were scanned with a CBCT device (Carestream Kodak 9300 C; Rochester, New York, USA) at 80 kV and 10 mA, 8.01 s exposure time, (100x100 mm FOV) and 180 μm voxel size. CS 3D Software (Carestream Kodak 9300 C; Rochester, New York, USA) was used for the reconstruction of the images and the measurements of the root canal curvatures. If the root canal had one curvature and measured <25°, it was classified as ‘straight/curved,’ otherwise it was considered ‘highly curved’ (18). If the root canal had more than one curvature, it was classified as ‘multiple curved’ The open source software OsiriX-Lite DICOM Viewer (Pixmeo, SARL, Switzerland) was used for the measurements of the root canal lengths. A single experienced investigator performed all measurements in the CBCT images.

2D measurements

The 2D measurements of the root canal lengths on CBCT images were performed as described by Janner et al. (23). For the measurement of each root canal length, the coronal reference point was taken as the corresponding/adjacent cusp (buccal cusp for buccal root canal) and the apical reference point was taken as the major foramen. Firstly, the tooth was rotated by the operator to adjust the coronal and axial planes until the long axis of the root canal, the coronal reference, pulp chamber, major foramen, and, if possible, the whole length of the canal in one single slice made visible. The selection of the most suitable slice, either the sagittal or coronal one, was dependent on the curvature of the root and location of the major foramen. In highly curved and multiple curved root canals, the polyline tracing tool was used, following each visible canal curvature in the respective CBCT slice (24). The measurements obtained were recorded as 2D CBCT root canal length (Figure 1). Except for the rotation procedures and saturation/contrast adjustments, the images were not manipulated.

3D measurements

The 3D measurements of the root canal lengths on CBCT images were performed as described by Tchorz et al. (19). The major foramen, as the most apical reference point, was detected in the sagittal and axial planes. The center of the root canal in all following axial slices were pointed in regular intervals until the coronal reference point is reached. The coordinates of all points were documented and the 3D CBCT root canal length measurements were obtained by adding the distances between adjacent points (Figure 2). The 3D measurements were performed 2 weeks after the 2D measurements are completed. Reproducibility of all CBCT measurements was determined by repeating the measurement procedures after 1 month.

Actual root canal length measurements

The specimens were removed from their models, and the endodontic access cavities were prepared. The pulp tissues were removed using barbed broaches. After controlling the patency with the #8 K-File (Dentsply Maillefer), coronal flaring was performed using SX rotary files (ProTaper, Dentsply Maillefer, Ballaigues, Switzerland) to gain straight-line access. The actual root canal lengths were determined by a different blinded investigator, by inserting the 10 K-file into
the root canal until the file tip became visible at the apical foramen under 4x magnification using an operating microscope (Leica Microsystems, Wetzlar, Germany). The rubber stop was placed at the predefined coronal reference point, and the actual root canal length was measured using an electronic digital caliper with a resolution of 0.01 mm (Allen-dale Electronics Ltd, New Scotland, Canada). After repeating the measurements, the average of two measurements was recorded as the actual root canal length.

Statistical analysis

IBM SPSS Statistics 22 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp, USA) software was used for statistical evaluation. Intraclass correlation coefficients (ICCs) were used to analyze the reproducibility of both 2D and 3D CBCT root canal length measurements, and also to assess the reliability of CBCT in measuring root canal length. In addition, chi-squared and McNemar tests were used to evaluate the differences between the actual and CBCT root canal lengths if the CBCT measurements were within acceptable limits of ±0.5 mm. Significance was assessed at p <0.05 level.

Results

According to the root canal curvature classification; 35 (50%) of the root canals were ‘straight/curved,’ 24 (34.3%) were ‘highly curved,’ and 11 were (15.7%) ‘multiple curved’ root canals (Figure 3). Since an excellent reliability was observed between the first and second values of the CBCT 3D (ICC =0.992; CI 95%: 0.988-0.995, p: 0.000) and 2D measurements (ICC = 0.965; CI 95%: 0.944-0.978; p: 0.000), the first measurements were used in the other comparisons of the study.

Mean variation between measurements of actual root canal lengths and 2D CBCT root canal lengths was 0.5 mm (ICC = 0.943; CI 95%: 0.910-0.964; p: 0.000) and for 3D CBCT root canal lengths it was 0.28 mm (ICC = 0.979; CI 95%: 0.968-0.986; p: 0.000). In 60 root canals (85.7%), measurements of 3D CBCT root canal length were within acceptable limits (±0.5 mm); in 10 root canals (14.3%), 3D CBCT measurements were short. In 46 root canals (65.7%), measurements of 2D CBCT root canal length were within acceptable limits; in 5 root canals (7.1%), 2D CBCT measurements were long, while in 19 root canals (27.1) 2D CBCT measurements were short. According to these findings, measurements of 3D CBCT root canal length were significantly more accurate than the measurements of 2D CBCT (p:0.005; p<0.05; McNemar Test).

In ‘straight/curved’ and ‘highly curved’ root canals, both 2D and 3D CBCT root canal length measurements presented strong, positive, and significant correlations with actual root canal lengths (p: 0.000, p<0.05). In ‘multiple curved’ root canals, 3D CBCT root canal length measurements presented excellent reliability (ICC= 0.930; CI 95%: 0.867-0.964; p: 0.000) with actual root canal lengths, whereas 2D CBCT root canal length measurements presented substantial reliability (ICC= 0.698; CI 95%: 0.204-0.909; p: 0.006). Between the subgroups of curvature classification, in comparisons according to acceptable limits, 2D CBCT measurements showed a significant difference (Table 1), unlike 3D CBCT measurements (Table 2). In two-paired comparisons, the differences between ‘straight/curved’ and ‘highly curved’ root canals were found to be significant (p:0.006; p<0.05).

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![Figure 1](image1.png)

**Figure 1.** Representative illustration of a two-dimensional cone-beam computed tomographic measurements of root canal length.

![Figure 2](image2.png)

**Figure 2.** Representative illustration of a three-dimensional cone-beam computed tomographic measurements of root canal length.

![Figure 3](image3.png)

**Figure 3.** Sagittal slices of a root canal with multiple curves.

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**Table 1.** Evaluation of the accuracy (±0.5 mm) between the measurements of actual and 2D CBCT root canal lengths according to curvature classification Chi-Square test (*p<0.05*).

<table>
<thead>
<tr>
<th>Curvature Classification</th>
<th>Within acceptable limits (±0.5 mm)</th>
<th>Longer than actual root canal lengths (&gt;0.5 mm)</th>
<th>Shorter than actual root canal lengths (&lt;0.5 mm)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n (%)</td>
<td>n (%)</td>
<td>n (%)</td>
<td></td>
</tr>
<tr>
<td>Straight Curved</td>
<td>27 (77.1%)</td>
<td>4 (11.4%)</td>
<td>4 (11.4%)</td>
<td>0.039*</td>
</tr>
<tr>
<td>Highly Curved</td>
<td>13 (54.2%)</td>
<td>0 (0%)</td>
<td>11 (45.7%)</td>
<td></td>
</tr>
<tr>
<td>Multiple Curved</td>
<td>6 (54.5%)</td>
<td>1 (9.1%)</td>
<td>4 (36.4%)</td>
<td></td>
</tr>
</tbody>
</table>
are both reproducible and successful methods for predeter-
mining root canal length in molar teeth. However, the 3D method displayed significantly more accurate root canal length determination, and excellent reliability compared to the 2D method. In ‘multiple curved’ root canals, the 3D method presented more reliable measurements than the 2D method. The 2D method showed a tendency for under-
estimation of the ‘highly curved’ root canals compared to ‘straight/curved’ root canals (Table 1).

In most of the previous studies on the predetermination of root canal length using CBCT, teeth with straight and sin-
gle root canals have been used, and 2D measurements have been performed in 3D environment (17, 20, 23-25). Only one study compared 2D and 3D CBCT approaches for predeter-
mination of root canal length in molar teeth (19). According to the findings of that one, which are in agreement with ours, differences between actual root canal lengths and 3D measurements were significantly less than those seen with 2D measurements. Mean discrepancies were 0.32 and 0.58 mm, respectively. A high correlation was found between the actual root canal length and 3D measurements, and 80% of the 3D measurements were within acceptable limits.

In previous in-vitro studies using the 2D approach, Lucena et al. (18), Connert et al. (22), and Metska et al. (26) (in-situ) reported the mean discrepancies of 0.59 mm, 0.41 mm, and 0.74 mm for anterior, 0.51 mm for posterior teeth between the measurements of CBCT and actual root canal lengths, re-
spectively. On the other hand, in a very recent in-vitro study, Yilmaz et al. (20) have found that measurement of root canal length with CBCT at different voxel sizes resulted in underes-
timation of between 1.16 and 1.63 mm. In addition, in clini-
cal studies that used the 2D approach, Janner et al. (23) and Jeger et al. (24) reported a mean discrepancy of 0.4 mm and 0.51 mm between the measurements of CBCT and electron-
ic apex locator, respectively. Similarly, Ustun et al. (25) found no significant difference between CBCT measurements and electronic apex locator (25). These researchers commonly concluded that existing CBCT images might be useful for endodontic working length determination.

Since CBCT became popular in endodontics as the imag-
ing modality for treatment planning in complex cases, most patients who apply for root canal treatment might already have an existing CBCT (14). The incidental appearance of the endodontic treatment planned tooth in the field of view (FOV) would provide valuable information about the complexities such as curvatures, confluences and predetermi-
nation of the root canal length (15, 16, 20, 22). While most of the CBCT software currently in use can measure 2D root canal length with the linear measurement tool, it is impossi-
ble to measure 3D root canal length with the same practical-
ity. Drawing a point-route by following the canal trajectory from axial sections and measuring each points distance will be very difficult and time-consuming when considering the clinical reality. Besides, measurements with non-automated programs can be affected by the skills and experience of the operator. Based on this fact, a new CBCT software that pres-
ents automated functions for preoperative root canal length measurement has been developed and the predeter-
mination of the root canal lengths was found to be reliable (21, 27, 28).

Based on the results obtained from both previous stud-
ies and the present study, an already existing CBCT image can be useful in predetermining the working length in end-
donotic clinics and may result in the need for fewer periapi-
cal radiographs, which will support the ‘as low as reasonably achievable’ (ALARA) principle of radiology (15, 17-28).

Conclusion

3D measurements of root canal length in molar teeth are more accurate than 2D measurements and already available CBCT scans could be an alternative method for predeter-
nation of root canal length in molar teeth. Further clinical studies using the 3D method will also contribute to clarify-
ing this issue.

Table 2. Evaluation of the accuracy (±0.5 mm) between the measurements of actual and 3D CBCT root canal lengths according to curvature classification (Chi-Square test).

<table>
<thead>
<tr>
<th>CBCT 3D</th>
<th>Within acceptable limits (±0.5 mm)</th>
<th>Longer than actual root canal lengths (&gt;0.5 mm)</th>
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<td></td>
<td>n (%)</td>
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<td>Straight/Curved</td>
<td>30 (85.7%)</td>
<td>0 (0%)</td>
<td>5 (14.3%)</td>
</tr>
<tr>
<td>Highly Curved</td>
<td>21 (87.5%)</td>
<td>0 (0%)</td>
<td>3 (14.2%)</td>
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<tr>
<td>Multiple Curved</td>
<td>9 (81.8%)</td>
<td>0 (0%)</td>
<td>2 (18.2%)</td>
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Discussion

Our results suggest that 2D and 3D CBCT measurements are both reproducible and successful methods for predeter-
mination of root canal length in molar teeth. However, the 3D method displayed significantly more accurate root canal length determination, and excellent reliability compared to the 2D method. In ‘multiple curved’ root canals, the 3D method presented more reliable measurements than the 2D method. The 2D method showed a tendency for under-
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Türkçe Özet: Konik-ışnili bilgisayarlı tomografi (kbt) kullanılarak molar dişlerde kök kanal uzunluğunu ölçümü: iki boyutlu ve üç boyutlu yöntemlerin karşılaştırılması. Ayrıca: Bu çalışmada amaç, büyük azi dişlerin 2 boyutlu (2D) ve 3 boyutlu (3D) konik-ışnili bilgisayarlı tomografik (KIBT) yöntemleriniyle gerçekleştirdiklerini kök kanal uzunluğunu ölçümlerini, gerçek kök kanal uzunluklarıyla uymumun incelenmesidir. Gerçek ve yöntem: 24 büyük azi diş ağız altı kök kanal KIBT ile tanrın ve kök kanalların eğimlerine göre “Düz”, “Aşın Kurvatureu” ve “Birden fazla Kurvatureu Sahip” olarak sınıflandırılmıştır. 2D ölçümler, uygun bir KIBT kestirinde, kök kanalının forma apikalesi ile ılgili kanalının tüberkül tepesi referans alınarak yapılmıştır. 3D ölçümler, aynı referans noktaları arasındaki düzeneği aralıklarla ilerleyen aksiyal kesitPCR içerisinde gerçekleştirmiştir. KIBT ile ölçüm yönteminin tekralanabilirliği ve güvenilirliği analizinde Snif için Korelyasyon Katsayısı kullanılmıştır. Gerçek kök kanal uzunluğu ve KIBT ile kök kanal uzunluğu ölçümlerini arasındaki farkların kabul edilebilir sınırlara dahilinde (±0,5 mm) olup olmadığı ki-kare ve McNemar testleri ile değerlendirilmiştir. Bulgu lar: Her iki yöntemin de tekrarlanabilir olduğu ve mümkünken güvenilirlik sağladığı gözlemlenmiştir. Bu nedenle, 3D yöntemi ile elde edilen ölçümler % 85,7 oranla kabul edilebilir sınırlar dahilinde bulunmuştur ve 2D yöntemi ile arasındaki fark istatistiksel olarak anlamlı bulunmuştur (<0.05). “Birden fazla Kurvatureu Sahip” kök kanallarında, 3D yöntemi ile yapılan kök kanal uzunluğu ölçümleri 2D metodundan daha güvenilir bulunmaktadır. “Düz” kök kanallar için 2D yöntemi “Aşın Kurvatureu” kök kanallarına kıyasla gerçek kök kanal uzunluğuı önemli ölçüde yakın sonuçlar vermiştir (<0.05). Sonuç: 3D yöntemi ve 2D yönteminde kısaca daha doğru kök kanal uzunluğu ölçümler elde edilir. Hali hazırda mevcut bir KIBT görüntüüsü varsa, büyük azi dişlerinde kök kanal uzunluklarının teda-
vieyi belirlemesinde alternatif olarak kullanılabilir.
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