EUROPEAN ENDODONTIC JOURNAL

Accuracy of Software-Based Three-Dimensional Root Canal Length Measurements Using Cone-Beam Computed Tomography

JP TCHORZ, KT WRBAS, C VON SEE, K VACH, SBM PATZELT

ABSTRACT

Objective: This study aims to evaluate the accuracy of three-dimensional root canal length measurements performed by dentists with different experience levels using a special software based on cone beam computed tomography (CBCT).

Methods: A CBCT scan of an artificial resin maxillary molar was used to train dentists (n=65) in using the software (3D Endo, DentsplySirona, Ballaigues, Switzerland) as part of a continuing education course. At the beginning, each participant completed a questionnaire on endodontic and CBCT experiences. After comprehensive instructions, each participant performed an entire three-dimensional treatment plan by tracing the root canal anatomy between the apical foramen and the center of the canal orifice and simulating a straight-line access. The final root canal length was indicated after the virtual rubber stop of a simulated instrument was adapted to the adjoining cusp. To evaluate the individual accuracy in terms of trueness and precision, differences between the three-dimensional planning and the actual root canal length (ARCL) were calculated, and statistically analyzed.

Results: Mean absolute differences between the measurements with the 3D Endo™ software (n=260) and the ARCL were 0.30±0.22 mm. All measurements were within a limit of ±1 mm. The accuracy of root canal length measurements was significantly influenced by the type of root canal (p<0.0001). The smallest deviations were observed for the palatal root canal (0.18±0.13 mm), followed by the mesiobuccal (0.26±0.22 mm), the distobuccal (0.32±0.17 mm), and the second mesiobuccal root canal (0.46±0.24 mm).

Conclusion: Within the limitations of this study, the 3D Endo software enables reproducible and accurate root canal length measurements as part of a three-dimensional endodontic treatment plan. However, mea-surements should always be clinically verified, as root canal morphology has a statistically significant influence.

Keywords: CBCT, 3D Endo, root canal length determination

Please cite this article as: Tchorz JP, Wrbas KT, Von See C, Vach K, Patzelt SBM. Accuracy of Software-Based Three-Dimensional Root Canal Length Measurements Using Cone-Beam Computed Tomography. Eur Endod J 2019; 4: 28-32

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Received 22 July 2018, last revision received 28 September 2018,accepted 21 October 2018

Published online: 13 November 2018
DOI 10.14744/eej.2018.46320

HIGHLIGHTS

- A three-dimensional root canal treatment plan using CBCT can make endodontics less mysterious and more predictable.
- The main advantage of the 3D Endo software is its intuitive usability.
- Root canal lengths measured with the 3D Endo Software show a high accuracy in vitro.
- Individual characteristics of the participants, such as experience and specialization, did not have a significant influence on measurements.

INTRODUCTION

A recent survey among Swedish general dental practitioners (GPs) revealed a general negative attitude toward endodontics. Root canal treatments were regarded as complex and mysterious, and according to the participating GPs, were often performed with a feeling of 'lack of control' (1). The main reason for these difficulties can be seen in the variability of root canal configurations, which are not easy to visualize with conventional two-dimensional (2D) radiographic methods (2). Intraoral radiographs, which are usually used in endodontics, have only limited potential to accurately predict the number of roots or root canals, their configuration, and lengths due to superimpositions (2, 3). Although three-dimensional (3D) images such as acquired by cone beam computed tomography (CBCT) have several advantages, they should not be routinely used, and should be limited to complex endodontic situations following the ALARA (As Low As Reasonably Achievable) principles (4). However, in 90% of the cases where CBCT is applied, incidental findings occur that are unrelated to the primary region of interest (5, 6). Some of these findings have an endodontic origin, and consequently, require a root canal treatment. With an increasing number of CBCT applications in dentistry (7), endodontic cases with a pre-existing CBCT may also increase. In these cases, dentist should take the advantage to perform a 3D endodontic treatment plan, and make root canal treatments less mysterious and more predictable (8). The 3D Endo software (DentsplySirona, Ballaigues, Switzerland) is specially designed for these purposes. It has been shown to be a helpful tool in identifying the number of canals, visualizing apical confluences, and measuring root canal lengths in mesial roots of mandibular molars (8, 9).

The aim of this study was to evaluate the accuracy of 3D root canal length measurements performed by dentists with different experience levels using the 3D Endo software for the first time.

MATERIALS AND METHODS

A CBCT scan of a transparent and radiopaque artificial resin maxillary molar (Dentalike, DentsplySirona, Ballaigues, Switzerland) was acquired (Orthophos SL, 5x5 cm volume, 80 µm voxel size; DentsplySirona, Bensheim, Germany), and it was used for 3D endodontic treatment planning with a special soft-ware (3D Endo, DentsplySirona, Ballaigues, Switzerland).

Training

A total of 65 dentists (27 female, 38 male) participated in the training that was part of a continuing education course focusing on the application of CBCT in endodontics. Initially, all participants received a questionnaire on endodontic and CBCT experiences. Each questionnaire was alphanumerically coded. After a comprehensive theoretical instruction, a sample case was used to explain the software, demonstrate each single planning step, and define the reference points. Following the introduction, each participant independently performed the entire treatment planning. A supervisor assisted in case of a software-operating problem, but did not interfere in the actual measurement process. First, the participants were

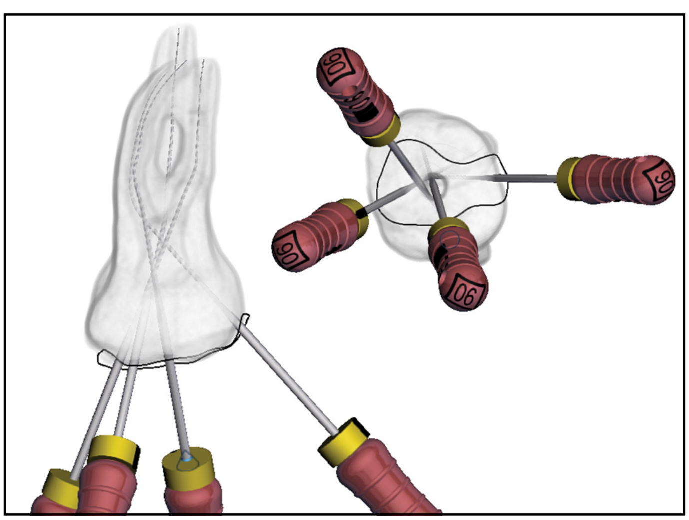

Figure 1. Example of the 3D Endoplanning process. Instruments visualizing the most straight-line access after the root canal was traced between the apical foramen and the canal orifice

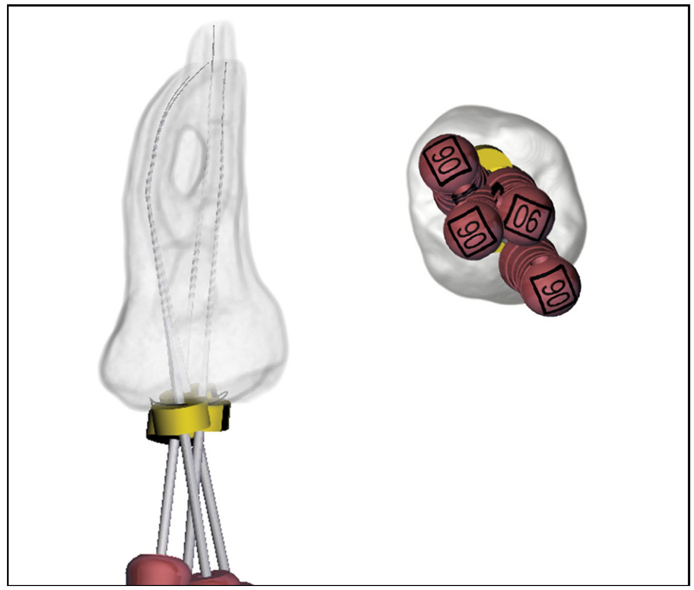

Figure 2. Overlying dentine was virtually removed by straigh tening the coronal part of the instrument along a tangent between the outermost pulp chamber and outer the root canal curvature

instructed to mark the apical foramen and the center of the canal orifice. After the root canal was traced, they were asked to simulate a straight-line access by virtually removing overlying dentine (Fig. 1). For this, a simulated instrument was straightened along a tangent between the outermost pulp chamber and the outer curvature of the root canal (Fig. 2). The final root canal length was indicated after the virtual rubber stop was adapted to the adjoining cusp. During the entire treatment planning process, the participants did only see the CBCT scan of the actual artificial tooth. They had no access to the actual transparent artificial tooth, and could not visually identify the root canal morphology. For statistical analyses, the participants saved their treatment planning using their individual anonymized alphanumeric code.

Actual root canal length

The actual root canal length (ARCL) of the artificial tooth was measured after preparing a straight-line access and preflaring of the coronal third using a rotary file (ProTaper Shaping file SX, DentsplySirona, Ballaigues, Switzerland). The amount of cervical preflaring was analogous to the guidelines given to the participants and checked radiographically by a CBCT. The extent of preflaring was calculated by overlapping two separate screenshots with the exact same orientation from the 3D Endo software and measuring the degree between the initial and the straightened visualized instrument at a 90° angle toward the straightening direction (Fig. 3). The ARCL was measured by inserting a size 10 K-file into the root canal until its tip was visible at the apical foramen under a stereomicroscope (Leica WILD M3Z; Leica Mikrosysteme Vertrieb, Wetzlar, Germany). The rubber stop was then adjusted to the same predefined coronal reference, and the actual canal length was determined using a digital caliper.

Statistical analysis

To evaluate the accuracy of measurements, differences and absolute differences between the 3D planning and the ARCL

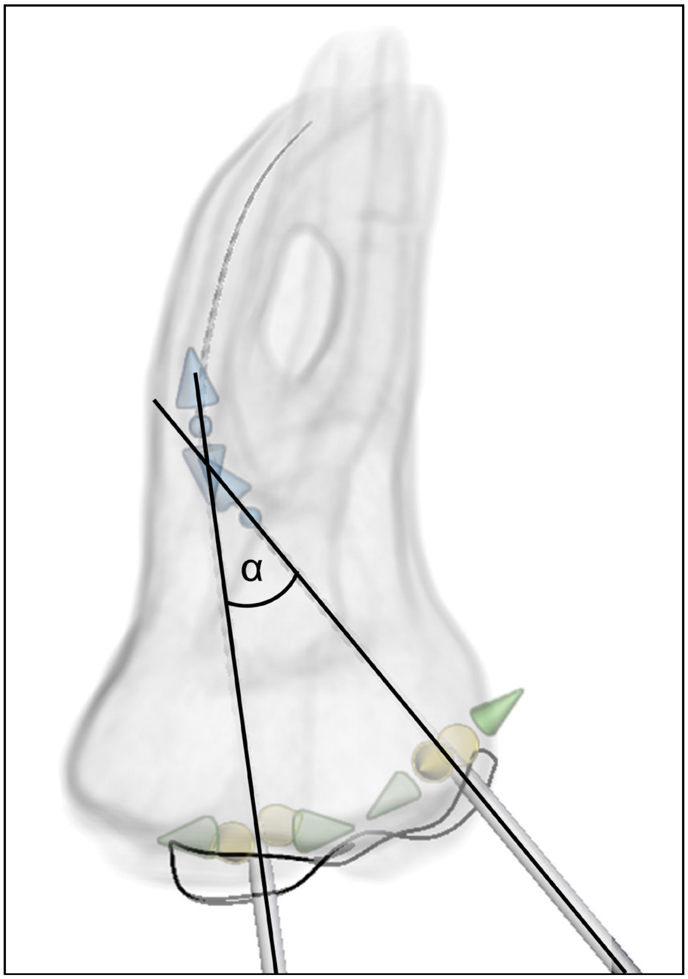

Figure 3. The a mountof preflaring was calculated by measuringt he degree (α) between the visualized instrument before and after straigh tening

were calculated and statistically analyzed. For descriptive analyses, the medians, means, and standard deviations (SD) were computed. A linear mixed model with random intercepts was fitted for each participant to evaluate the method effects. Furthermore, pairwise comparisons between different methods were done. The method of Scheffe was applied to adjust the p-values due to the multiple testing problems. The level of significance was set to $p<0.05$. All calculations were performed with the statistical software STATA 14.2 (StataCorp LP, College Station, TX, USA).

RESULTS

The questionnaire revealed the following characteristics of the participants (Table 1). Among the participants, 58.5% stated to be endodontic specialists, and 43.1% had a CBCT in their private practice. A total of 30.8% participants answered that they have not yet performed CBCT scans with a primarily endodontic focus, and only 13.8% of the participants applied CBCT in more than 20% of their endodontic cases. Specialists with access to a CBCT used it more often in endodontic cases than GPs did. Absolute differences between measurements are shown in Table 2. The overall absolute mean deviation of the 3D root canal measurement was 0.30±0.22 mm (n=260). A total of 80% of the measurements were within a limit of ±0.5 mm, and no measurement exceeded ±1 mm. Whereas individual characteristics such as gender, experience, and specialty had no significant influence, the type of root canal significantly influenced the accuracy of measurements ($p<0.0001$). The highest accuracy was observed in the palatal (P) root canal, followed by the first mesiobuccal (MB1), the distobuccal (DB), and the second mesiobuccal (MB2) root canal, respectively. When differences between the 3D Endo Software and the ARCL were calculated, a tendency toward smaller measurements was observed (Fig. 4).

TABLE 1. Characteristics of the participants (n=65) and influence on the measurement accuracy

Gender	27 female 38 male	p=0.674
Mean years of practice	15.5 (1-30)	p=0.381
<5 years	9	
>15 years	35	
Specialty	27 general dental practitioner 38 endodontic specialist	p=0.732
CBCT in office	28	p=0.861
Frequency of CBCT application in endodontics	average 9.3% (0-90%)	p=0.260
<5% of the cases	18 general dental practitioner 15 endodontic specialist	
>15% of the cases	2 general dental practitioner 12 endodontic specialist	

TABLE 2. The degree of virtual preflaring for each root canal and mean absolute differences [mm] between CBCT measurements with the 3D Endo software and the actual root canal length (ARCL)

Type of root canal	n	Degree of preflaring	Mean	SD
Mesiobuccal	65	14.31	0.26	0.22
Second mesiobuccal	65	31.34	0.46	0.24
Distobuccal	65	16.59	0.32	0.17
Palatal	65	11.42	0.18	0.13
Total	260		0.30	0.22

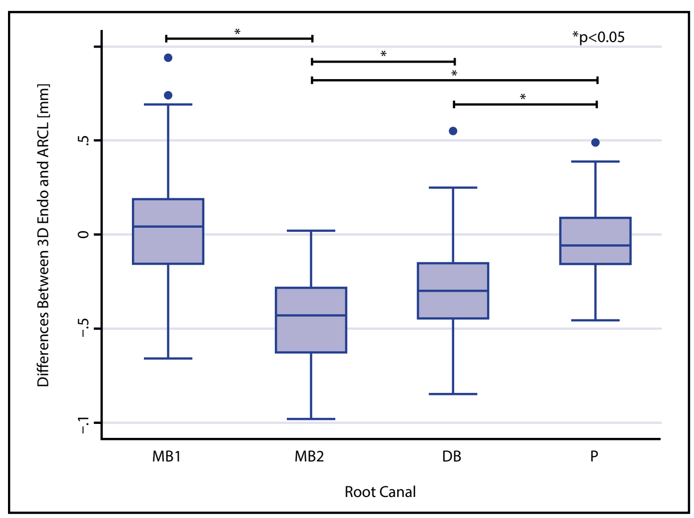

Figure 4. Comparisons of differences between 3D Endo measurements and the ARCL in the first mesiobuccal (MB1), second mesiobuccal (MB2), distobuccal (DB), and palatal (P) root canal of anartificial resin tooth. Asterisks (*) represent statistically significant differences

DISCUSSION

With an increasing variety of CBCT indications and an increasing number of applications in dentistry, endodontic cases with a pre-existing CBCT may increase as well due to a high frequency of incidental findings (5-7, 10, 11). In these cases, also GPs without access to a CBCT and less experience will have the opportunity to benefit from the available 3D information in terms of endodontic decision making and software-based treatment planning (8, 12). Therefore, the objective of this study was to evaluate the accuracy of 3D root canal length measurements as an integral part of the treatment planning process, using the 3D Endo software in a group of dentists with different experience levels.

Janner et al. (13) published the first study comparing the accuracy of working length measurement in pre-existing CBCT scans with standard techniques such as electronic apex locators (EAL), and they observed a high correlation between both methods. Jeger et al. (14) performed two separate length measurements in adjusted vestibulo-oral and mesio-distal planes, and counted the number of curvatures in each plane. They chose the CBCT sections with the highest number of root canal curvatures and the best visualization of the whole canal, and compared these measurements with results clinically obtained with an EAL. Using this method, they observed a mean discrepancy of 0.51 mm. However, 5 of 40 CBCT measurements exceeded the EAL results by more than 1 mm. Following studies observed slightly higher accuracies with mean differences of 0.41–0.46 mm, when comparing measurements in CBCTs and root canal length determination by EAL (15, 16). Despite these promising previous results, their clinical relevance has to be critically interpreted because mainly single-rooted teeth with straight roots were investigated (13-15, 17). Comparing the CBCT measurements performed in different types of teeth in a single 2D adjusted plane, Liang et al. (15) observed a higher discrepancy in molars (0.51 mm) compared to that in premolars (0.42 mm) and anteriors (0.42 mm). A possible explanation for this variance and the differences observed between single-rooted teeth and molars might be the 2D measurement approach. Measuring accurate root canal lengths in a single 2D adjusted plane requires straight root canals and references that can be displayed in the same plane. Especially in molars, however, this is often impossible due to their complex anatomy, and this consequently leads to significantly shorter measurements (18).

This study confirmed an overall high accuracy of root canal measurements using the 3D Endo software. Eighty percent of the measurements were within a limit of ±0.5 mm, and no measurement exceeded ±1 mm. The high accuracy of measurements observed in this study that was not significantly influenced by individual characteristics of the participants, such as experience and specialization, may be attributed to the intuitive usability of the software and a high image quality in terms of resolution and contrast. This allowed the examiner to easily identify all root canals and the relevant anatomical structures, such as apical foramen, root canal orifice, and cusp. The underestimation observed in MB2, DB, and P was consistent with that in other studies (15, 17). Only MB1 showed a tendency toward longer measurements (Fig. 4). The reproducibility of measurements was evaluated through comparison of SD, which revealed great differences between the root canals. As both apical and coronal references were well defined and eas-ily located due to a high image quality in this in-vitro setup, the major source of error is possibly the extent of virtual and clinical preflaring. This is an important step during the 3D planning process because straightening of curved root canals during clinical instrumentation may lead to working length alterations and accidental over-instrumentation (19). To evaluate its influence, the extent of preflaring was calculated by measuring the degree between the initial and the straightened visualized instrument. In this study, significant differenes regarding the accuracy of measurements were observed between the different root canals. The discrepancy increased with an increasing degree of the initial curvature, which required a greater extent of simulated and clinical preflaring. As only one set of measurements of novice users was analyzed, we cannot determine whether a higher accuracy could be achieved with greater experience in software usage.

The CBCT scan of an artificial endodontic training tooth was used in this in-vitro study to allow for comparison with the ARCL instead of using EAL measurements as performed in other studies (14, 17). As the main objective of this study was to evaluate the accuracy of the actual planning process, the ARCL was chosen as the gold standard. It is more suitable and accurate in this respect because root canal lengths determined with an EAL show deviations themselves, and are only reproducible within a certain range (20, 21). Although the treatment planning with the 3D Endo software was shown to be accurate in terms of trueness and precision, root canal length should still be clinically verified. Not only because the extent of virtual and clinical preflaring might vary, but also because of the risk of artifacts in CBCT images and thus adverse effects on the image quality resulting in difficult localizations of anatomic landmarks (17, 22). Therefore, further studies are needed to validate the accuracy of a software-based 3D endodontic treatment planning in a clinical setting.

CONCLUSION

Within the limitations of this in-vitro study, it can be concluded that the 3D Endo software enables for accurate 3D root canal length measurements. However, root canal lengths should be controlled consequently and repeatedly during root canal treatment using an EAL to detect possible length variations due to straightening of curved root canals. Following the ALARA principle, the application of CBCT exclusively for root canal length measurement is not recommended yet, as the benefits of additional radiation should always outweigh the potential risks. In cases, where a CBCT is already available, the 3D Endo software is a useful tool to plan the endodontic treatment, visualize complex root canal anatomies, and estimate root canal length.

Disclosures

Conflict of interest: The authors deny any conflicts of interest.

Peer-review: Externally peer-reviewed.

Financial Disclosure: The authors declared that this study has received no financial support.

Authorship contributions: Concept – J.P.T., S.B.M.P.; Design – J.P.T., S.B.M.P.; Supervision – J.P.T.; Data collection &/or processing – J.P.T.; Analysis and/or interpretation – K.V.; Literature search – J.P.T.; Writing – J.P.T.; Critical Review – K.T.W., C.V.S.

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