

Effect of the voxel size on the accuracy of endodontic length measurements using cone-beam computed tomography: A systematic review conducted according to the PRISMA guidelines and *Cochrane Handbook for Systematic Reviews of Interventions*

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Abstract

Background. The accurate determination of the working length (WL) is imperative for endodontic success.

Objectives. Our objective was to systematically analyze the available evidence on the impact of voxel size variation on the estimation of WL using cone-beam computed tomography (CBCT).

Material and methods. An electronic search of the PubMed, Scopus, Embase, and Web of Science databases was conducted according to specific inclusion and exclusion criteria in March 2022. Studies published in English, comparing the influence of 2 or more voxel sizes on the CBCT assessments of WL in human teeth against physical or electronic methods qualified for inclusion. Multiple authors independently carried out study selection, data extraction and quality assessment.

Results. We included 4 studies involving the assessment of 220 teeth. There were some concerns with regard to the risk of bias in all studies, owing to methodological insufficiencies. Voxel sizes can affect the accuracy of CBCT measurements. All 4 studies reported that the voxel size in CBCT measurements was closely correlated with the estimation of WL. The smallest voxel sizes showed a greater correlation with the actual length (AL). Larger voxel sizes can reduce accuracy by ± 0.05 mm. The differences may be clinically irrelevant. Cone-beam computed tomography assessments correlate strongly with the endodontic WL as measured by electronic apex locators (EALs), but are associated with a larger radiation dose in comparison with periapical radiographs.

Conclusions. Based on the limited evidence available, it can be stated with low certainty that voxel sizes may impact CBCT accuracy. However, the differences may be clinically irrelevant. The pre-existing CBCT scans may be useful in the estimation of WL, rather than additional periapical radiographs.

Keywords: accuracy, voxel, cone-beam computed tomography, endodontics, electronic apex locators

Highlights

- Cone-beam computed tomography (CBCT) offers superior spatial resolution, making it ideal for accurately visualizing root canal morphology and enhancing endodontic treatment planning.
- The voxel size in CBCT scans significantly impacts the precision of working length estimations. Smaller voxel sizes provide higher accuracy, improving the reliability of root canal measurements.
- By integrating conventional electronic apex locators with a patient's pre-existing CBCT data, endodontists can achieve greater precision and accuracy in root canal treatment.

Introduction

The long-term success of endodontic treatment depends on the proper technique and the complete elimination of microorganisms from the root canal system.¹ Several variables can affect the precise identification, disinfection and obturation of the root canal. The accurate determination of the working length (WL) is imperative for endodontic success.² A comprehensive knowledge of the entire root canal system and accurate diagnostic aids are necessary to determine the exact WL.³ The most widely accepted description of the root canal is that the canal tapers apically from its wider coronal orifice to its apical constriction (the minor diameter) and widens in a funnel shape up to the apical foramen (the major diameter).^{4,5} The apical constriction is usually 0.5–1.5 mm inside the apical foramen.⁴ The endodontic WL is the distance from the coronal reference point to the anatomic reference point, i.e., the apical constriction, up to which the endodontic preparation is carried out.⁶

The exact location and morphology of the apical constriction is highly variable, making its exact identification in the root canal challenging.⁷ The correct estimation of WL is required to ensure the proper instrumentation of the root canal system, to avoid iatrogenic injuries, such as perforation and/or the extrusion of debris or intervention into the periapical region, and to ensure complete obturation.⁸ Over the years, several methods to identify the accurate WL have been employed, including and not limited to intracanal tactile sensation, preoperative radiographs, electronic apex locators (EALs), cone-beam computed tomography (CBCT), micro-CT, etc.^{9–12}

For the longest period, endodontists relied on periapical radiographs for determining WL.^{11,13} However, the reliability of the two-dimensional (2D) image of a three-dimensional (3D) structure has always been nebulous due to magnification errors, the superimposition of the surrounding anatomical structures, inter-operator variability, an angulation error, etc.^{14,15} As a supplemental aid for the radiographic methods, EALs are being widely used due to the high accuracy of the device.^{16–19} However, EALs are not infallible and may deliver unstable results, imprecise readings in the presence of metal restorations, etc.^{12,20} As a result, it is advisable to use both radiographic as well as electronic methods for the determination of WL.

Cone-beam computed tomography provides the 3D images of the anatomical structures, overcoming the limitations inherent to conventional radiography.^{8,21} It permits the 3D localization of structures without magnification errors, allowing rotation. This enables clinicians to view anatomic structures clearly around extraneous formations that would otherwise obstruct the view.

Cone-beam computed tomography can help assess the morphology of a tooth and its root canal.^{22,23} Multiple studies have assessed the accuracy of CBCT, and determined CBCT to have higher accuracy in dentistry and by extension endodontics.^{24,25}

Each CBCT 3D image is made up of volumetric pixels known as voxels, which are the 3D analogs of pixels.²⁶ A voxel is a unit of graphic information in 3D space. In this, it is similar to a pixel, which defines a unit of information in 2D space. Voxels are essentially 3D pixels in a cube shape, i.e., they are isometric.²⁷ Voxel sizes range from 0.075 mm to 0.4 mm. An image resolution of 300 ppi would correspond to a pixel size of 0.085 mm.²⁸ Voxel sizes can influence the accuracy of measurements in CBCT scanning. Artifacts in the image expand in number with an increase in the voxel size. With a decreased voxel size, greater noise is evident, which can lead to errors in measurements.²⁹ The relationship between the voxel size and the radiation dose is inversely proportional, i.e., the smaller the voxel size, the higher the radiation dosage on the patient.^{8,30} The comparison of CBCT assessments with various voxel settings can elucidate the impact of image quality on the accuracy and reliability of the measurements taken.³¹

This review aimed to systematically examine the available evidence on the effect of the voxel size on the accuracy of endodontic length measurements using CBCT.

Methodology

Focus question

This systematic review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement.³²

The focused question was “Does the voxel size and resolution influence the endodontic root canal measurement?”

Search strategy

The inclusion criteria within the PICOS framework were as follows:

- (P) Population: Human teeth;
- (I) Intervention: CBCT scans at 2 or more voxel resolutions;
- (C) Comparator: The endodontic WL determined physically with EAL;
- (O) Outcome: Precision or accuracy in the endodontic WL measurement;
- (S) Study type: Randomized controlled trials (RCTs), controlled clinical trials, cohort studies, in vitro, in vivo, and ex vivo studies published in English

Case reports, systematic reviews, opinion articles, letters to the editor, and articles in languages other than English were excluded.

The electronic databases of PubMed, Scopus, Embase, and Web of Science were searched for eligible studies in March 2022, with no restrictions placed on the start date. The U.S. National Institutes of Health (NIH) register of ongoing trials ClinicalTrials.gov (<https://clinicaltrials.gov>) and the World Health Organization (WHO) International Clinical Trials Registry Platform (<https://trialsearch.who.int>) were searched in April 2022. Forward citation tracking was conducted using Google Scholar. Three authors (S.B., B.R. and S.P.) independently reviewed the search results for study selection. Duplicates and non-relevant articles were discarded. The researchers independently screened the titles and abstracts of the studies for their eligibility. The full-texts of relevant articles were examined for eligibility using the inclusion criteria, and a fourth author (M.C.) was consulted to make a final decision in case of any contention. A supplementary search of the references of the selected articles was conducted manually for additional eligible studies. The search strategy is depicted in Table 1.

Data extraction

Data extraction was independently conducted by 2 authors (K.H.A. and G.M.) and verified by a third author (F.L.) for accuracy. The characteristics of each study, along with the author's name, the year of publishing, the

country of origin, methodological aspects, the sample size, the treatment regimen, and duration, were extracted into a customized template manually.

Assessment of study quality

The quality of the selected studies was independently assessed by 2 reviewers (S.B. and K.H.A.) using the a revised quality assessment tool for diagnostic accuracy studies (QUADAS-2).³³ Four specific domains were used to assess the validity of the studies, including 'sample selection', 'index test', 'reference standard', and 'flow and timing'. The response for each domain based on the signaling questions referred to a high, low or unclear risk of bias, or at a risk of bias. A negative answer in the signaling questions indicates potential bias, which is explored for a 'high' rating. The absence of pertinent information for rendering judgment resulted in a rating of 'unclear' risk of bias. The overall risk of bias was determined using the highest level of risk observed under the domains. Conflicts were resolved through a consensus.

Methods used to assess the quality of evidence for the outcomes listed in the summary of findings

We followed the GRADE recommendations mentioned in *Cochrane Handbook for Systematic Reviews of Interventions* to assess each outcome.^{34,35} The summary of findings is presented in Table 2. One review author (B.R.) applied the GRADE system, and the evidence ratings were applied after discussion with 2 other authors (F.L. and M.C.). The final rating was decided after the 3 review team members reached a consensus. Evidence for each outcome was graded as 'high quality' at the start in the case of RCTs. The risk of bias, the inconsistency of results, the indirectness of evidence, the imprecision of results, and publication bias were considered. Subsequently, the evidence rating was downgraded by 1 level for serious or 2 levels for very serious concerns regarding the study limitations, inconsistencies in the outcomes, the indirectness of evidence, the imprecision of effect estimates, or publication bias.

Table 1. Search strategy

Database	Search strategy
PubMed	(voxel size) AND (cone beam computed tomography OR CBCT) AND (((endodontic) OR (root canal)) AND (length)) ("voxel" [All Fields] OR "voxels" [All Fields] OR "voxelization" [All Fields] OR "voxelized" [All Fields] OR "voxels" [All Fields]) AND ("endodontal" [All Fields] OR "endodontic" [All Fields] OR "endodontical" [All Fields] OR "endodontically" [All Fields] OR "endodontics" [MeSH Terms] OR "endodontics" [All Fields]) AND ("length" [All Fields] OR "lengths" [All Fields])
Scopus	(ALL (voxel AND size) AND ALL ((cone AND beam AND computed AND tomography) OR cbct) AND TITLE-ABS-KEY (root AND canal) AND ALL (length OR (working AND length) OR (actual AND length))))
Embase	voxel AND size AND cone AND beam AND computed AND tomography AND tooth AND root AND canal
Web of Science	voxel size (All Fields) AND CBCT OR cone beam computed tomography (All Fields) AND (root canal length) OR (working length) OR (root length) OR ((root canal) AND length) (All fields)

Table 2. Quality assessment – summary of findings

Outcome	Risk of bias	Inconsistency	Indirectness	Imprecision	Publication bias	Impact	Number of teeth/studies	Certainty of evidence (GRADE)
Accuracy of the determination of WL	serious*	not serious	not serious	not serious	not serious	our confidence in the effect estimate is limited	220/4	low

WL – working length. * Four studies showed some concerns regarding the risk of bias; the concerns regarding outcome measurement decreased our confidence in the estimate.

Results

The initial search yielded 169 papers. After the removal of duplicates and the screening of titles and abstracts for eligibility, potentially relevant articles were identified. Thirteen full-text articles were selected for a complete review based on the inclusion criteria and the review objective. After evaluating the full texts of the articles, 9 articles were excluded based on the inclusion criteria. In the present review, 4 studies were included, all of which were ex vivo comparative studies.^{36–39} The PRISMA flow diagram is shown in Fig. 1.

Quality assessment

In terms of the overall risk of bias based on QUADAS-2, there were significant concerns regarding the risk of bias

in the majority of studies. For the ‘sample selection’ domain, the risk of bias was low. For the ‘index test’ domain, an unclear risk of bias was concluded, as it was not clear whether the accuracy tests were interpreted blindly to the reference standard. We judged the ‘reference standard’ domain to have an unclear risk of bias owing to inadequate details about the use of the reference standard and its interpretation. These methodological insufficiencies led to the overall rating of unclear risk of bias. The details of the risk of bias assessment, along with a summary, are presented in Fig. 2.⁴⁰

Summary of the characteristics of selected studies

All the studies included in this review were from Asia. Three of these reports were from Turkey (Western Asia)^{37–39} and one from Vietnam (Southeast Asia).³⁶ All reports used extracted human teeth ex vivo. A total of 220 canal WLs were assessed, out of which 70 regarded anterior teeth, 40 – maxillary central teeth³⁸ and 30 – mandibular anterior teeth.³⁷ The majority of teeth assessed were posterior teeth (30 premolars³⁹ and 120 molars³⁶). Table 3 summarizes the characteristics of the included studies.

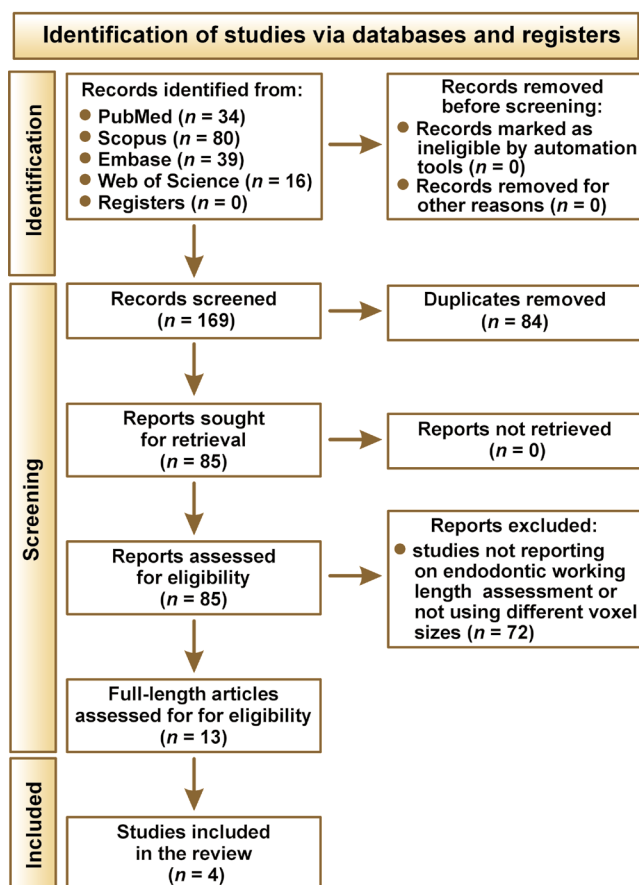


Fig. 1. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart of the study

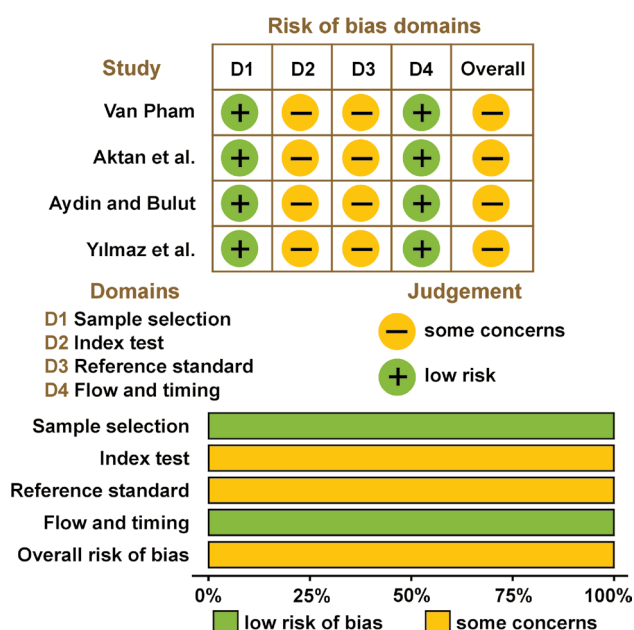


Fig. 2. Risk of bias assessment

Table 3. Characteristics of the selected studies

Author(s)	Year	Country	Sample size	Study design	Intervention	CBCT WL assessment	Control	Outcome
Van Pham ³⁶	2021	Vietnam	120	120 extracted molars the CBCT images were taken and the canal length was measured using Romexis Viewer, and recorded as the conventional CBCT length (3D-CL) the 3D Endo Software reconstructed automatically the 3D image of the canal system, and the canal length was recorded as the corrected length (3D-CL)	CBCT in 3 different voxel sizes: 0.075 mm 0.100 mm 0.150 mm	the measurement made based on the best image of the entire length of the canal in the buccolingual view with the greatest curved angle a line drawn from the occlusal reference to the apical foramen	a K-file #10 with an electronic digital caliper EAL	at the largest voxel size, CBCT showed less accuracy than EAL by ± 0.05 mm, at smaller sizes, CBCT showed greater accuracy the 3D-PL (proposed length) measurements at a voxel size of 0.150 mm and the 3D-CL measurements at a voxel size of 0.100 mm agreed with AL
Aktan et al. ³⁷	2016	Turkey	30	30 human mandibular anterior teeth the arithmetic mean of the buccolingual and mesiodistal measurements was recorded as the CBCT WL	CBCT in 4 different voxel sizes: 0.100 mm 0.150 mm 0.200 mm 0.400 mm	the arithmetic mean of the buccolingual and mesiodistal measurements from coronal, sagittal, axial, and 3D images	a K-file with an electronic digital caliper	the mean absolute difference between AL and the CBCT scan measurements was 0.02 mm for the 0.2-mm voxel size and HD resolution, 0.18 mm for the 0.4-mm voxel size and HD resolution, 0.19 mm for the 0.2-mm voxel size and LD resolution, and 0.26 mm for the 0.8-mm voxel size and HD resolution no significant differences were found between AL and CBCT measurements the 0.4-mm CBCT scans has a slightly lower reliability than the other voxel sizes
Aydin and Bulut ³⁸	2021	Turkey	40	40 maxillary central teeth with straight root canals each tooth was placed in the empty socket of a dry maxilla	CBCT in 2 different voxel sizes: 0.125 mm 0.250 mm EAL measurement with 2 different EALs	the measurements made in the reconstructed sections from the reference plane to artificial root perforation	a K-file #10 with an electronic digital caliper EAL	electronic measurements provided greater values than AL, while CBCT measurement values were smaller than AL no significant differences between the 2 voxel sizes were noted the measurements taken at the 0.125-mm voxel size was closer to AL
Yilmaz et al. ³⁹	2017	Turkey	30	30 mandibular premolars the CBCT images of the teeth inserted in the mandible were obtained	CBCT in 4 different voxel sizes: 0.080 mm 0.125 mm 0.160 mm 0.250 mm	the average of 2 measurements made from the buccal tip point to the radiographically visible apex	a K-file #15 with an electronic digital caliper EAL	there were no significant difference between the average CBCT measurements obtained at 4 different voxel sizes accuracy increased with smaller voxel sizes, without statistically significant differences

CBCT – cone-beam computed tomography; EAL – electronic apex locator; AL – actual length; HD – high definition; LD – low definition.

Comparator

The 4 studies varied in their estimation of WL. Three studies compared CBCT assessments to the measurements taken using a K-file and EALs.^{36,38,39} One study only compared manual measurement and CBCT.³⁷

The working length was measured using a K-file and digital calipers. Since they were all *ex vivo* studies, errors in the WL measurement were avoided, as it was possible to directly visualize the location of the tip of the K-file within the apex of the tooth. Three of these studies used the length from the occlusal reference point to the coronal most border of the apical foramen as a reference, while one study used the distance from the occlusal reference point to 1 mm short of the apical foramen.

The various EALs used in the studies were Propex Pixi,³⁶ DentaPort Root ZX^{38,39} and Gold Reciproc Motor (GRM).³⁸

CBCT systems and software

The studies differed in the radiographic systems used to capture CBCT data. Two studies used ProMax® 3D (Planmeca, Helsinki, Finland),^{36,37} while the other two used the i-CAT CBCT system (Imaging Sciences International, Hatfield, USA)³⁸ and 3D Accuitomo 170 (J. Morita Tokyo, Tokyo, Japan).³⁹

The studies used different software based on their CBCT systems to examine the CBCT data. Two studies assessed the CBCT images with the Planmeca Romexis® Viewer,^{36,37} while the other two used the i-CATVision imaging software³⁸ or i-Dixel 2.0.³⁹ Only one study compared 2 different programs, i.e., Romexis Viewer and the 3D Endo™ Software (Dentsply Sirona, Johnson City, USA).³⁶

For CBCT measurements, the teeth were embedded in various materials during scanning. Two studies used the sockets of the prepared dry maxilla³⁸ and mandible.³⁹ One study used plastic molds with wax and light impression silicone,³⁶ while the other study used the silicone putty.³⁷

One study made the 3D reconstruction of the tooth to measure WL.³⁶

Characteristics of the intervention

All 4 studies used different voxel sizes to compare.^{36–39} Overall, 9 different voxel sizes were evaluated [mm] – 0.075,³⁶ 0.080,³⁹ 0.100,^{36,37} 0.125,^{38,39} 0.150,^{36,37} 0.160,³⁹ 0.200,³⁷ 0.250,^{38,39} and 0.400.³⁷ A variable range of field of view (FOV) values [mm³] were used in the selected studies – 40 × 40,^{38,39} 50 × 50,³⁶ 50 × 80,³⁷ 60 × 60,³⁹ 80 × 80,³⁹ 80 × 100,³⁷ 100 × 100,³⁹ and 100 × 150.³⁷ Two studies mentioned the exposure time of the CBCT images,^{38,39} which makes it easier to assess radiation exposure, while 2 studies failed to mention the exposure time.^{36,37}

Outcome assessment

Two of the studies had single observers assessing the data,^{36,37} with only one of the 2 studies mentioning the repetition of the assessment to check for intra-observer reliability.³⁶ The other two studies had 2 different observers corroborating the data, with the assessment repeated after 1 month to check for intra-observer and inter-observer reliability.^{38,39}

Characteristics of the outcomes

Voxel sizes can affect the accuracy of CBCT measurements. All studies found that CBCT measurements were closely correlated with WL. The smallest voxel sizes showed a greater correlation with the actual length (AL).

At a voxel size of 0.150 mm, Aktan et al. found the measurements to be accurate in 50% of the cases, while they were short in 37% of the cases and long in 10% of the cases.³⁷ Van Pham found the accuracy of CBCT WL at a voxel size of 0.150 mm to be 3%; CBCT assessments were short in 55.6% of the readings and long in 41.4% of the readings.³⁶ At a voxel size of 0.075 mm, the accuracy of CBCT WL determination with the proposed length (3D-PL) was 7.3%, while in 74.1% of the times CBCT assessed the value to be longer and in 18.5% of the times it was shorter. The corrected length (3D-CL) was accurate in 9.1% of the readings, while it was short in 55.9% of the readings and long in 34.9% of the readings.³⁶ At a voxel size of 0.080 mm, CBCT estimated WL short by a mean of 1.16 mm.³⁹

As the voxel sizes increase, the correlation between the CBCT and AL values decreases. The 0.1-mm voxel size was studied by Aktan et al.³⁷ and Van Pham.³⁶ The former group of researchers found the CBCT WL determination to be accurate in 70% of the measurements, while it was short in 17% of the measurements and long in 13% of the measurements.³⁷ Van Pham found the accuracy of CBCT WL at the 0.1-mm voxel size to be 4.0% for 3D-CL; 3D-CL was short in 48.3% of the readings and long in 46.8% of the readings.³⁶

For the 0.125-mm voxel size, the means of the measurements were –1.19 mm,³⁹ and 0.19 ± 1.89 (0.4 mm artificial root perforation (ARP)) and 0.14 ± 0.41 (1.0 mm ARP).³⁸

At a voxel size of 0.160 mm, CBCT estimated WL short by a mean of 1.47 mm.³⁹ At a voxel size of 0.200 mm, the measurements were accurate in 53% of the cases, short in 30% of the cases and long in 17% of the cases.³⁷

Two studies evaluated the accuracy of CBCT WL at the 0.25-mm voxel size, and determined the mean difference to be –1.63 mm,³⁹ and 0.22 ± 1.89 (for 0.4 mm ARP) and 0.21 ± 0.61 (for 1 mm ARP).³⁸ One study evaluated accuracy at the 0.4-mm voxel size, and determined the readings to be accurate in 67% of the time, while it was short in 23% of the time and long in 10% of the time.³⁷

Three studies found no statistically significant difference between AL and CBCT WL measurements

($p > 0.05$),^{36–38} while one study found the difference to be statistically significant ($p < 0.05$).³⁹ Among the studies, 3 found no statistically significant differences in the CBCT WL measured at different voxel sizes ($p > 0.05$),^{37–39} while one study found the differences between the voxel sizes to be statistically significant ($p < 0.05$).³⁶ The study comparing the direct CBCT WL measurement and the measurement of the 3D reconstruction found that the direct CBCT WL measurement (Romexis software) did not significantly differ from AL ($p > 0.05$), whereas in the case of the 3D reconstructed tooth measurement, the difference from AL was statistically significant ($p < 0.05$).³⁶

Discussion

Maintaining an accurate WL during endodontic treatment is crucial to ensure therapeutic success and minimal post-operative complications. Conventional techniques involve the use of EAL, followed by a periapical radiograph with a file instrument. Technological advances have allowed greater precision in measurements. Research has shown that the CBCT assessment of WL is as accurate as in the case of EALs.^{41–45} Cone-beam computed tomography provides a higher spatial resolution as compared to CT, making it better suited to examine the dental region and enabling the accurate visualization of the root canal morphology. Cone-beam computed tomography imparts a significantly lower radiation dose to the patient, aligning with the ALARA (As Low As Reasonably Achievable) principle, a cornerstone in clinical radiology. The quality CBCT images are predicated on the voxel size and the acquisition parameters. Our objective was to systematically analyze the available evidence on the impact of voxel size variation on the estimation of WL using CBCT.

Four studies that examined the influence of 2 or more voxel sizes on the CBCT assessments of WL in human teeth against physical (a K-file) or electronic methods (EALs) were included in this review. We found that image quality and the accuracy of CBCT measurements were affected by the voxel size used for imaging.^{46–50} Smaller voxel sizes were correlated with greater precision.^{36–39} While all studies found that there were differences between AL and CBCT WL assessments, these differences did not demonstrate statistical significance. The CBCT images obtained at different voxel sizes showed an underestimation (from -1.63 mm to -1.16 mm), with no distinction between various voxel sizes.³⁹ In comparison with CBCT, EALs showed less variation (-0.098 mm) from the direct measurement. Three studies found no statistically significant difference between AL and CBCT WL measurements.^{36–38} Yilmaz et al dissented from this view and reported that there was a significant difference between the CBCT measurement and physical measurements.³⁹ This may be due to the fact that in a CBCT scan, the operator has to scroll through several sagittal views,

negatively impacting repeatability. The accuracy of CBCT was not affected by perforations. The direct measurement of CBCT WL (Romexis software) showed no statistically significant difference with regard to AL; however, the measurements taken on a 3D reconstructed tooth showed significant differences from AL,³⁶ implying that the number of views may impact reliability. This is of paramount importance during scanning and reconstruction. Among the studies, 3 found no statistically significant differences in the CBCT WL measured at different voxel sizes,^{37–39} while one study found the differences between the voxel sizes to be statistically significant.³⁶ Larger voxel sizes are associated with a decreased spatial resolution and can reduce accuracy by ± 0.05 mm. Discrepancies less than 0.5 mm may not be clinically relevant.

The findings of our review show that CBCT measurements correlate strongly with endodontic WL as measured by EALs. This accords with earlier observations by Liang et al.⁵¹ and Connert et al.³ that CBCT is as accurate or more accurate than EALs. Lucena et al. dissented from this view, reporting that CBCT measurements were frequently shorter than AL by 0.59 mm.⁵²

The results of this review are in agreement with the findings of Sherrard et al., who reported that CBCT tooth length and root length measurements were not significantly different as compared to physical methods, with the mean differences being ± 0.3 mm.⁵³ Higher voxel sizes were correlated with greater inaccuracy.⁵³ Overall, the findings of this review are consistent with the previous literature, showing that a change in the voxel size during CBCT scanning impacts the accuracy of length and volume measurements, along with the quality of the models.^{54–56} Low-certainty evidence indicates that while the size of voxels may affect the accuracy of the CBCT estimations of WL, the differences do not approach statistical significance.

Overall completeness and applicability of evidence

Among the selected studies, only one study mentioned the radiation dosage experienced by the subject during CBCT imaging.³⁹ The effect of the voxel size on the radiation dose is a pertinent question in this regard. The radiation dose of CBCT is 43 – 50 μSv ,⁵⁷ which is extremely high as compared to a periapical radiograph, i.e., 1 – 3 μSv .⁵⁸ The reduction of the voxel size for improving image quality will increase the radiation dosage the patients will be subjected to.^{59,60} This may preclude the use of smaller voxel sizes. According to the American Association of Endodontists (AAE), the risks are too high in comparison with the benefits to make CBCT a routine screening tool.⁶¹ Current recommendations by the European Society of Endodontology (ESE) suggest the use of EAL, followed by confirmation with a periapical radiograph.⁶² The radiation dose and cost of CBCT screening

are considered disadvantages in their routine use for the estimation of WL. Diagnostic examinations should strive to follow the ALARA principle and use the lowest reasonably achievable dose of radiation.³⁰

All studies included in this review found a strong correlation between a smaller voxel size and accuracy. Similar to the voxel size affecting the radiation dose, the FOV chosen may impact the effective radiation dose and the quality of the images, directly affecting the spatial resolution and accuracy of the images.

Several other factors may have impacted image acquisition, quality and measurements. Each study used different software. Similarly, the simulated clinical conditions during scanning varied with each study. Two studies used human dry maxilla³⁸ and mandible,³⁹ while the remaining studies used wax³⁶ and silicone.³⁷ This may have prevented artefacts in the image due to absence of motion and contralateral structures. The selected teeth varied among the studies, with only one study using multirrooted teeth with curved canals.³⁶ It is unclear whether these factors may have affected accuracy.⁶³ The acquisition parameters (the duration of exposure, voltage and amperage) may impact the overall accuracy of measurements.⁶⁴

The CBCT imaging has the advantage of archiving and communication in medicine. The DICOM models of CBCT scans can be shared between specialists to facilitate communication and treatment planning. In the case of patients having earlier relevant CBCT scans, it may be prudent to use these for the estimation of WL rather than subject a patient to further periapical radiographs. This review also highlights a dearth of studies in this area of concern. Overall, there was a paucity of well-designed studies examining the accuracy of CBCT in endodontic length and volume measurements.

Quality of evidence

The certainty for the evidence was downgraded by 2 steps, once for bias and once due to all studies being non-randomized. We found the quality of evidence for the outcome to be low due to the risk of bias. It could be argued that the use of EALs and physical measurements with a K-file and digital calipers should be assessed as high quality. However, there are concerns regarding the inconsistency of results across a small number of included studies. Three studies had low sample sizes. With only 4 studies included, there may be a large potential impact if one of the studies differs in size or direction. We urge a cautious interpretation of these results due to the small number of studies and since there are negative effects for CBCT with regard to the radiation dose. Several factors limited the interpretation of the data, including the lack of a uniform gold reference standard. The majority of studies used EALs for the determination of WL. While the available evidence on their accuracy is short with a considerable risk of bias, they can predict WL.¹²

A combination of methods to assess WL may be more reliable than a single technique alone. In this regard, EALs may be combined with the patient's pre-existing CBCT data for accuracy.

The strength of this review is the comprehensive searches, and stringent adherence to the inclusion and exclusion criteria. Multiple authors independently conducted study selection, data extraction and quality assessment to minimize the selection bias. A limitation of our review is that only English language articles were considered for selection due to the lack of availability of translational resources. Excluding languages other than English may have introduced the language bias.

Conclusions

Based on the limited research available, there is low-certainty evidence suggesting that the size of voxels may affect the accuracy of the CBCT estimations of WL. However, these differences do not approach statistical significance and may not be clinically relevant. In the case of patients with the pre-existing CBCT scans, the data may provide additional information for WL estimation rather than additional periapical radiographs.

Ethics approval and consent to participate

Not applicable.

Data availability

The datasets supporting the findings of the current study are available from the corresponding author on reasonable request.

Consent for publication

Not applicable.

Use of AI and AI-assisted technologies

Not applicable.

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