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SYSTEMATIC REVIEW

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Is cone-beam computed tomography more accurate than periapical radiography for detection of vertical root fractures? A systematic review and meta-analysis

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Abstract

Background This study aimed to conduct a systematic review and meta-analysis to summarize the available evidence comparing the diagnostic accuracy of periapical radiography (PA) and cone-beam computed tomography (CBCT) for detection of vertical root fractures (VRFs).

Methods A search was conducted in PubMed, Scopus, and Web of Science for articles published regarding all types of human teeth. Data were analyzed by Comprehensive Meta-Analysis statistical software V3 software program. The I2 statistic was applied to analyze heterogeneity among the studies.

Results Twenty-three articles met the criteria for inclusion in the systematic review and 16 for the meta-analysis. The sensitivity and specificity for detection of VRFs were calculated to be 0.51 and 0.87, respectively for PA radiography, and 0.70 and 0.84, respectively for CBCT.

Conclusions The sensitivity of CBCT was higher than PA radiography; however, difference between the specificity of the two modalities was not statistically significant.

Keywords Cone-Beam Computed Tomography, Tooth Root, Dental Digital Radiography, Tooth Fractures

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Background

Vertical root fracture (VRF) is defined as a longitudinal fracture in the root that originates from the root canal and extends towards the apical periodontium; it can involve the entire root surface or part of it [1].

Endodontically treated teeth are more susceptible to VRFs (7.2% to 20%) [2]. The occurrence of VRF in such teeth may be due to excessive flaring of the canal, apical condensing forces applied during root canal therapy, or post space preparation [3, 4].

Fractured teeth have a poor or hopeless prognosis, and tooth extraction is often the only available option for their management. Thus, correct detection of VRFs is highly important to prevent misdiagnosis and wrongful extraction of a tooth that has the potential to be treated and retained [5]. The diagnostic modalities that are often used for detection of VRFs include clinical examination, radiography, and invasive options such as exploratory surgery. An important issue with regard to VRFs is that there is no pathognomonic clinical or radiographic feature for a definite diagnosis [4–6]. Definite diagnosis of VRFs on radiographs is based on observation of a radiolucent crack line and radiographic manifestation of separation of root segments, which is often associated with extensive bone loss around the root. However, in order for this radiolucency to be detectable on the conventional radiographs, the passing X-ray beam should be parallel to the crack line or have a ≤ 4-degree angle relative to it. In higher angles, the likelihood of detection decreases [7]. Many authors suggested taking several radiographs with two or three different angles to parallelize the X ray beam to the fracture line [8]. Due to 2D nature of conventional radiography and superimposition of bony structures, correct detection of VRFs by this modality is often difficult [9].

Application of two-dimensional radiographic modalities for detection of VRFs is a debatable topic. Unlike periapical (PA) radiography, cone-beam computed tomography (CBCT) is three-dimensional, and enhanced knowledge about the detection of VRF coupled with the advent of more advanced CBCT scanners and software programs has resulted in a higher diagnostic accuracy as reported in the recent literature [10, 11]. However, artifacts caused by opaque ingredients of endodontic sealers or intra-canal posts or adjacent restorations compromise the quality of CBCT images [12, 13]. Presence of intra-canal posts significantly decreases the diagnostic accuracy for detection of VRFs [14]. Accordingly, several studies compared the diagnostic accuracy of CBCT and PA radiography for detection of VRFs [12, 15–19]. But, the reported results were widely variable, and the higher diagnostic accuracy of CBCT compared with 2D radiography for this purpose remains a matter of question [12, 15].

This study aimed to review the available literature on this topic and compare the sensitivity and specificity of CBCT and PA radiography as the commonly used imaging modalities for detection of VRFs to collect the available information on this topic and help clinicians in selection of the best imaging modality for this diagnostic task. The results may also aid in correct treatment planning in clinical cases suspected for VRFs.

Methods

This systematic review was designed according to the Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) and Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The systematic review was registered in Prospective Register of Systematic Reviews (PROSPERO) with the registration number "CRD42023477634."

The review question according to the PICO strategy was as follows: "Is CBCT more accurate than PA radiography for detection of VRF in human teeth?"

P (population): Human teeth with VRF
I (intervention): CBCT
C (comparison): PA radiography
O (outcome): Detection accuracy of VRFs

Search strategy

A systematic search was conducted in electronic databases of PubMed, Scopus, and Web of Science for relevant articles published up until November 22, 2023. A specific search terminology was considered for each database.

The Scopus search strategy included a combination of the MeSH terms and text words described as follows: TITLE-ABS-KEY which takes the TITLE + ABSTRACT + KEYWORDS fields as whole, (Cone-Beam Computed Tomography OR cone-beam CT OR cone beam CT OR cone-beam OR cone beam OR CBCT) AND (Tooth Fractures OR tooth fracture* OR dental fracture* OR root fracture*) AND (radiography, dental, digital OR dental digital radiography OR radiography dental digital OR digital radiography dental OR intraoral digital periapical radiography) AND (sensitivity OR specificity OR accuracy OR receiver operating characteristics curve).

The PubMed search strategy included a combination of the MeSH terms and text words described as follows: (Cone-Beam Computed Tomography [Mesh Terms] OR cone-beam CT OR cone beam CT OR cone-beam OR cone beam OR CBCT) AND (Tooth Fractures [Mesh Terms] OR tooth fracture* OR dental fracture* OR root fracture*) AND (radiography, dental, digital [MeSH Terms] OR dental digital radiography OR radiography dental digital OR digital radiography dental OR intraoral digital periapical radiography) AND (sensitivity OR specificity OR accuracy OR receiver operating characteristics curve).

The Web of Science search strategy included a combination of the MeSH terms and text words described as follows: TS = (Cone-Beam Computed Tomography OR cone-beam CT OR cone beam CT OR cone-beam OR cone beam OR CBCT) AND TS = (Tooth Fractures OR tooth fracture* OR dental fracture* OR root fracture*) AND TS = (radiography, dental, digital OR dental digital radiography OR radiography dental digital OR digital radiography dental OR intraoral digital periapical radiography) AND TS = (sensitivity OR specificity OR accuracy OR receiver operating characteristics curve). TS searches the title, abstract and author keywords within a record in Web of Science Database.

The retrieved articles were collected in EndNote X8 software (Clarivate Analytics, London, UK).

The bibliography of the articles was also manually searched to prevent missing of relevant articles. The titles and abstracts of the collected studies were independently assessed by two reviewers, and duplicates and irrelevant articles were excluded.

Article selection

Article selection was conducted in two steps. In the first step, after elimination of duplicates, the title and abstract of the retrieved articles were evaluated according to the eligibility criteria, and eligible studies entered the second phase. In the second phase, the full-text of the articles was read, and literature reviews, case series, case reports and studies that did not meet the eligibility criteria were excluded. The remaining articles underwent a systematic review. The number of eligible articles that underwent a systematic review was 23; out of which, 16 underwent a meta-analysis.

Risk of bias of studies was evaluated by two reviewers independently using QUADAS-2. This checklist was used to evaluate the methodological quality of studies and risk of bias in study design, implementation, and analysis. Disagreements were resolved by discussion.

The search was limited to original research articles in English without restrictions on publication date. The inclusion criteria included studies using both CBCT and PA radiography for detection of VRFs in intact or endodontically treated human teeth or teeth with post and core restorations with VRFs. For clinical studies, the diagnosis of VRF had to be confirmed by exploratory surgery or tooth extraction and direct observation. Also, sensitivity to percussion, pain during mastication, bone loss with a J-shape view, and deep and narrow probing at the site of VRF were considered as clinical signs and symptoms of VRFs. In general, studies were included if they contained at least 10 teeth as sample size, presented adequate information regarding the type of CBCT scanner, its exposure settings, and voxel size, and used a reference standard explained in the article for direct assessment of VRFs.

The sensitivity, specificity, and accuracy of the diagnostic modalities had to be reported.

Animal studies, studies regarding non-vertical fractures (such as horizontal root fractures),

non-comparative studies, or those with incomplete data only assessing the positive cases were excluded from this systematic review.

The gold standard was considered as exploratory surgery along with a flap or tooth extraction for in vivo studies, while for the in vitro studies, the gold standard was considered according to the gold standard mentioned in the respective article (visual inspection by methylene blue staining or microscopic assessment).

Quality of data reporting

Two independent reviewers evaluated the titles and abstracts of the eligible articles for relevance. The quality of selected studies was evaluated by two reviewers (observers 1 and 2) according to the QUADAS-2 and PRISMA checklists. In case of disagreement, the opinion of a third reviewer (observer 3) regarding the inclusion/exclusion of the respective study was applied.

An overall estimation of risk of bias (low, moderate, high) was done for each study according to the predefined criteria in the Critical Appraisal Tool. When all the criteria were present, the risk of bias was considered to be low. The risk of bias was rated as moderate when one or several criteria had been partially met. The risk of bias was considered high when one or more criteria had not been met.

Risk of *bias* assessment

The QUADAS-2 includes four domains of patient selection, index test, reference standard, and flow and timing. All of these items were evaluated for each article according to the checklist available at http://joannabriggs-webdev.org/research/critical-appraisal-tools.html. The risk of bias plot (Fig. 2) shows the distribution of biases (low risk of bias, unclear risk of bias, and high risk of bias) for all included studies in a systematic review. “No” for one or more signaling questions indicates risk of bias and does not necessarily mean that it should be regarded as high risk of bias.

Statistical methods for the *meta*-analysis

Data were analyzed by Comprehensive Meta-Analysis statistical software V3 (Biostat, Englewood, NJ). I2 statistic was applied to analyze the heterogeneity among the studies. Also, inverse variance weighted random-effect model was used to control for heterogeneity. Funnel plots were constructed to assess publication bias. For both sensitivity and specificity the standard error of the log odds of the parameter was plotted against the log odds. The P-value for publication bias was obtained from Egger test, with $P < 0.05$ indicating the presence of publication bias.

The included studies were those with full-texts according to the gold standards and also reported true positive (TP), true negative (TN), false positive (FP) and false negative (FN) results or sensitivity and specificity.

Subgroup analysis

Data were analyzed based on presence or absence of root canal filling and overall sensitivity and specificity was calculated for each subset.

Results

Study selection

Figure 1 shows the PRISMA diagram of the phases of article selection. A total of 1,251 articles were identified through an electronic search of the literature; 8 articles were added following assessment of the bibliography of the articles, 1,193 duplicates and irrelevant articles were excluded in the title and abstract screening phase; The full-text of the remaining 33 articles was read; 23 articles underwent qualitative synthesis, and meta-analysis was conducted on 16 articles. Of all, 19 articles had an in vitro design, and 4 were in vivo (Table 1). The majority of the studies were in vitro or ex vivo, and simulated VRFs by applying mechanical force by a hammer chisel or a universal testing machine. Others had an in vivo design and their gold standard was exploratory clinical surgery.

Risk of *bias* within the studies

Figure 2 presents the results of qualitative assessment by QUADAS-2 tool, which was used for diagnostic tests. According to the Fig. 2 most studies (69.6%) are reckoned among low risk group.

Regarding patient selection, the majority of the studies had provided sufficient information, used an acceptable standard reference, and had a low to moderate risk of bias. Studies with minimum bias underwent a meta-analysis.

In all studies, the clinical data and test results had been reported according to the PRISMA checklist.

Synthesis of results

The pooled specificity and sensitivity were separately assessed for both CBCT and PA radiography for detection of VRFs. Paired forest plots (Figs. 3, 4, 5 and 6) show the sensitivity and specificity of CBCT and PA radiography in each study with 95% confidence interval.

According to the Table 2, Based on the results obtained from the random effects model, the overall sensitivity of the CBCT method based on the information of 23 investigated scenarios (16 studies) was 0.708 (95% CI: 0.608, 0.792), and the overall sensitivity of PA method based on 18 investigated scenarios (16 studies) was 0.518 (95% CI: 0.408, 0.626); this difference was statistically significant ($P\text{-value} < 0.05$). In other words, the likelihood of correct diagnosis of VRFs by CBCT was higher than PA radiography.

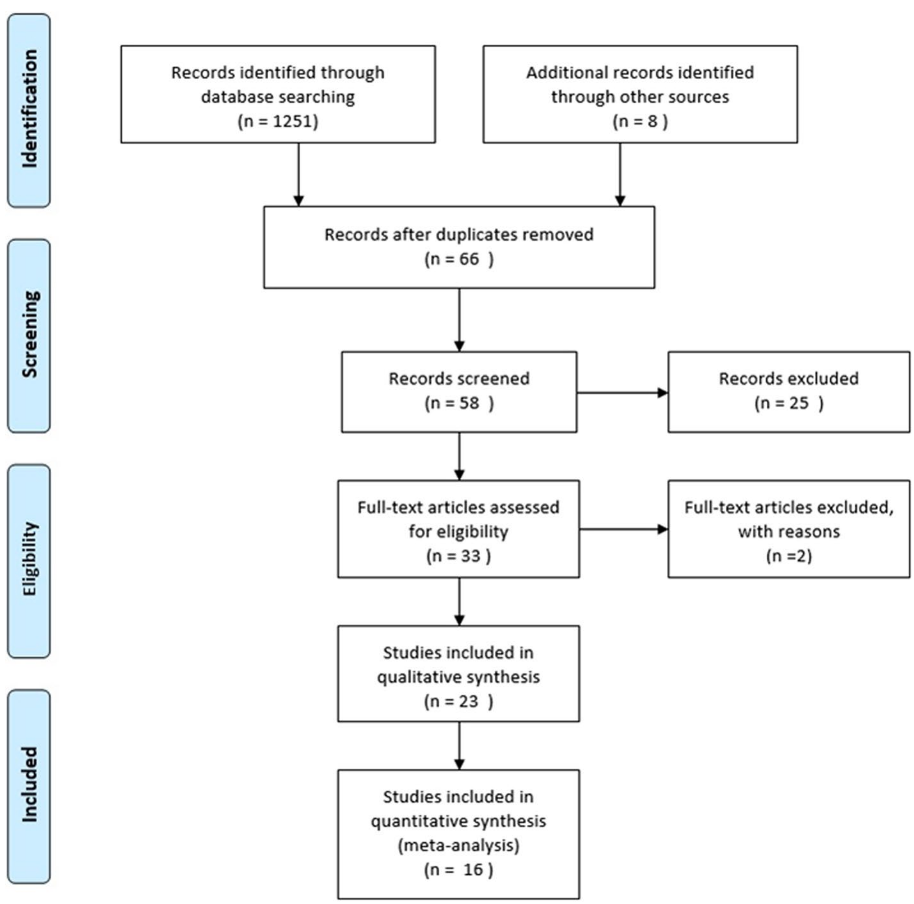

Fig. 1 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Diagram

Table 1 Data extraction checklist for systematic review of articles

	Study Type	Tooth type	PA	CBCT	Gold Standard
Hassan et al. [20] (2009)	In Vitro	Molar/Premolar	Digital Radiography (Siemens Heliodent MD, Erlangen, Germany) and size 2 phosphor-plate-films (Digora, Tuusula, Finland)/parallel technique	I-CAT (Imaging Sciences, Hatfield, PA) 120 kVp, 5 mA, voxel size 0.25 mm	Examination under a stereomicroscope
Bernardes et al. [21] (2009)	In Vivo	All Type	Conventional Radiography periapical film (Kodak Insight, Eastman Kodak, Rochester, NY) Max F1 (J. Morita Mfg Corp Kyoto, Japan) 58 kVp,10 mA pa/parallel technique	Accuitomo 3DX (J Morita Mfg. Corp Kyoto, Japan) 80 kVp, 5.6 mA	Evaluation with clinical symptoms
Kamburglo et al. [22] (2010)	In Vitro	Mandibular Premolars	Digital Radiography AET-Orix 70 (Ardet, Buccinasco, Italy) Max CCD intraoral sensor (Benliog˘lu Dental, Ankara, Turkey) 70 kVp, 8 mA	NewTom 3G (Quantitative Radiology, Verona, Italy) 110 kVp, voxel size of 0.19 mm /Iluma Ultra (Imtec Imaging,Ardmore, OK)120 kVp and 3.8 mA, voxel size: 0.3mm	Creation of VRFs by tapping with a screw-type root canal pin
Varshosaz et al. [23] (2010)	In Vitro	Incisors, Canines And Premolars	Digital Radiography Gendex (Dentsply International Inc. Des Plaines, IL, USA) 7mA and 65 kVp A CCD sensor (Trex-Trophy Radiology Inc., Marne-la-Valee, France)	ProMax 3D (Planmeca, Helsinki, Finland)/76 kVp, 6 mA	Creation of fractures by using a Zwick/Roell Z020 Universal Testing Machine
Valizadeh et al. [24] (2011)	In Vitro	Single Root	Conventional system: Gendex 765DC, Plaines, IL USA.70 kVp and 8 mA Digital system: RVG Trophy, Kodak Company	New Tom 3G (V.G.QR, Inc, Verona, italy) 110 kVp, 1.9 mA	Applying the methylene blue dye
Wang et al. [25] (2011)	In Vivo	All Type	Conventional Radiography Size 2 Kodak E-speed (Eastman Kodak, France) films (Trophy Radiologie/ 60 kVp, 7 mA SA, Croissy-Beaubourg, France)	Accuitomo 3DX (J Morita Mfg. Corp Kyoto, Japan) 80 kVp, 5 mA voxel size: 0.125 mm	Clinical symptoms
Khedmat et al. [26] (2012)	In Vitro	Single-Rooted Teeth	Digital Radiography CMOS detector (Trophy advance technology, Marne la Vale´e, France) (Prodental Equipmentos Odontolo´gicos Ltda, Ribeira˜o Preto, Brasil) 70 kVp, 10 mA	ProMax 3D unit (Planmeca, Roselle, IL, USA)/70 kVp, 4 mA, voxel size: 0.16mm	Examination under a stereomicroscope
Da Silveira et al. [16] (2012)	In Vitro	Single-Rooted	Conventional Radiography (Dental Intraoral D-Speed Film; size 2; Kodak, Rochester, NY, USA)	I-CAT (120 kVp, 3–8 mA; Imaging Sciences International, Inc, Hatfield, PA, USA)	Creation of VRFs by chisel & Inspection under magnification

Table 1 (continued)

	Study Type	Tooth type	PA	CBCT	Gold Standard
Kambugton et al. [27] (2012)	In Vitro	Anterior Or Premolar Tooth	Digital imaging CMOS-based intraoral (Digital Kodak RVG 5000, Eastman Kodak Company, Rochester, NY)66 kVp, 8 mA /and Conventional imaging size 2 F-speed intraoral films (Kodak Insight Dental Film, Eastman Kodak Company). 70 kVp, 8 mA	(Veraviewepocs 3D, J. Morita Mfg. Corp., Kyoto, Japan), / 70 kVp, 3 mA	Creation of VRFs with universal testing machin/Checked with methylen Blue 1%
Gunduz et al. [28] 2012)	In Vitro	Single-Rooted Premolar	Conventional Radiography Kodak film 2200 (Kodak Medical Systems, Paris, France) operated at 65 kVp and 7 mA with a focus object distance of 20 cm.VistaScan PSP (Du¨rr Dental GmbH & Co., KG, Bietigheim-Bissingen, Germany) with 8-bit maximum resolution and 12.5-lm pixel size; a Digital Radiography CCD sensor (Trophy Radiologie Inc., Paris, France)39- µm pixel size	2 system: 3D Accuitomo 170 (J Morita Mfg. Corp., Kyoto, Japan) with two fields of view pixel size of 0.125 (4-cm FOV) and pixel size of 0.125 (6-cm FOV) 65 kVp, 2.0 mA/NewTom 3G (Quantitative Radiology, Verona, Italy) with a 1,000 * 1,000-pixel brilliance amplifier detector; FOVs (6, 9, and 12 in.)110 kVp	Creation of VRFs with finger spreader
Bechara et al. [29] (2013)	In Vitro	Single Root	Digital Radiography set at 63 kVp, 8mA, PSP plates (Air Techniques Inc)	Picasso Master 3D, using a 1637 cm FOV with a 0.2mm voxel size, Promax, using an 838 cm FOV with a 0.2mm voxel size	Creation of fractures by using a tapered nail and tapping with a hammer
Patel et al. [18] (2013)	Ex Vivo	Premolar And Molar	Digital Radiography (PSP) system 65 kVp, 7 mA (Digora Optime; Soredex, Tuusula, Finland)	Accuitomo 3D (J. Morita, Kyoto, Japan) 90 kVp, 3.0 mA	Creation of fractures with a machine and examination under light microscope
Junqueira et al. [17] (2013)	In Vitro	Incisors And Canines	Digital Radiography Gendex Expert DC (Gendex, Des Plaines, IL) 7 mA and 65 kVp and CCD system (Visualix eHD; Gendex)	I-Cat Next Generation (Imaging Sciences)/120 kVp, 8 mA, and 2 different voxel sizes, 0.25 mm and 0.125 mm. International, Hatfield, PA)	Induction of VRFs by means of a chisel and hammer
Brady et al. [30] 2014)	Ex Vivo	Premolar And Molar	Digital Radiography (Heliodent; Sirona, Bensheim, Germany) 65 kVp, 7 mA; PSP (Digora Optime; Soredex, Tuusula, Finland)	3D Accuitomo (Morita, Kyoto, Japan)). (90 kVp, 3.0 mA, resolution fixed at 0.08 mm and the I-CAT Next Generation (Imaging Sciences International, Hatfield, PA, USA) (120 kVp, 5 mA, 0.125 mm resolution selected)	Clinical test & examination under a dental operating microscope
Chavda et al. [15] (2014)	In Vivo	All Type	Digital Radiography (Prostyle Intra X-ray Unit; Planmeca, Helsinki, Finland) 66 kVp, 7.5 mA, CCD sensor (Schick Technologies, New York, NY)	3D Accuitomo (F170; J Morita, Kyoto, Japan) 90 kVp, 5.0 mA	Inspection under a microscope

Table 1 (continued)

	Study Type	Tooth type	PA	CBCT	Gold Standard
Jakobson et al. [31] (2014)	In Vitro	Single-Rooted Premolars	Conventional Radiography E-Speed Film size no. 2 (Eastman Kodak Company) Kodak 2200 (Eastman Kodak Company, Rochester, NY) 60 kVp, 7 mA Digital Radiography Digora® Phosphor Plate System (Soredex, Tuusula, Finland)	1: (NewTom® 3G; QR Srl, Verona, Italy)110 kVp; 0.3 mA; voxel: 0.2 mm, 2: (I-CAT Next Generation®; Imaging Sciences International, Hatfield, PA)120 kVp; 5 mA; voxel: 0.2 mm; FOV: 16 cm	Examination under a light microscope M900 at 310 magnification
Takeshita et al. [32] (2014)	In Vitro	All Type	Conventional Radiography (DabiAtlante, São Paulo, Brazil). 70 kVp, 8 mA	I-CAT (Hatfield, PA, USA), FOV: 6 cm, Voxel size:0.125 mm, 36.2 mAs exposure	Induction of fractures with universal testing machine and evaluation with a stereomicroscope
Ezzodini et al. [33] 2015)	In Vitro	Single-Rooted Teeth	Conventional Radiography size 2 E-speed Kodak films (Eastman-Kodak Co., Rochester, NY, USA) Planmeca EC Proline (Planmeca, Helsinki, Finland) 60 kVp and 8 mA	Planmeca ProMax 3D (Planmeca, Helsinki, Finland). 66kVp, 8 mA FOV: 8 × 8 cm	Examination under a stereomicroscope
Abdinian et al. [34] 2016)	In Vitro	Premolar And Molar	Digital Radiography (CCD) sensor (RSV; Visiodent, St Denis, France) (Planmeca; Helsinki, Finland) 70 kVp, 10 mA	Cranex 3D (Soredex; Helsinki, Finland) at 89 kVp, 6 mA FOV: 8 × 4 cm; Voxel size: 0.2 mm	Creation of fractures by using a hammer confirmation by using staining method
Taghiloo et al. [19] 2018)	In Vitro	Single Root	Digital Radiography (PSP) and Optime Digora (Soredex, Helsinki, Finland) voltage, 65 kVp, 7.5 mA	NewTom VGi (NewTom, Verona, Italy)	Creation of vertical root fracture by one of the K-Reamers Nos. 90–130
Shaker et al. [35] (2019)	In Vitro	Single-Rooted	Digital Radiography PSP (Vistascan Durr Dental, Germany) (X-mind, Acteon, Satelec, France) 70 kVp;8 mA	(Scanora3D, Soredex, Finland)/ 90 kVp, 10 mA, Voxel size 85 µm, FOV:5 cm × 5 cm	Induction of VRFs by applying excessive forces with posts of large sizes
Mizuhashi et al. [36] (2019)	In Vivo	All Type	Conventional Radiography (HELIODENT Plus; Sirona Dental Systems) 70 kVp, 7 mA	(Fine Cube; Yoshida) 90 kVp, 4 mA; FOV: 81 × 81 mm	Evaluation with clinical symptoms
Sha et al. [37] 2021)	In Vivo	Maxillary Incisors	Digital PR imaging (Minray Soredex) 60 kVp and 7 mA (bisecting angle projection technique) A Soredex™ Digora™ Optime imaging plate	Kodak 9000 Extraoral Imaging System (Carestream) 6.3 mA current, 68 kVp, 0.076 mm voxel size FOV: 5 × 5 cm	By the dentists' visual findings during clinical examination and treatment

Study	Risk of bias					Applicability concerns		
	Patient selection	Index test	Reference standard	Flow & timing	Overall	Patient selection	Index test	Reference standard
Hassan et al.(37) (2009)	-	-	-	-	Low risk	-	-	-
Bernardes et al.(38) (2009)	+	-	Unclear	Unclear	Unclear	-	Unclear	-
Kamburglo et al.(39) (2010)	Unclear	-	Unclear	Unclear	Unclear	+	-	Unclear
Varshosaz et al.(25) (2010)	Unclear	Unclear	-	Unclear	Unclear	Unclear	Unclear	-
Valizadeh et al.(24) (2011)	-	-	-	-	Low risk	-	-	-
Wang et al.(40) (2011)	-	Unclear	-	-	Low risk	-	-	-
Khedmat et al.(41) (2012)	-	-	-	-	Low risk	-	-	-
Dasilveira et al.(16) (2012)	-	-	-	-	Low risk	-	-	-
Kambungton et al.(42) (2012)	-	+	-	-	Low risk	-	Unclear	Unclear
Gunduz et al.(43) (2012)	-	Unclear	Unclear	-	Unclear	-	+	Unclear
Bechara et al.(44) (2013)	Unclear	-	-	-	Low risk	+	Unclear	Unclear
Patel et al. 2013(18) (2013)	Unclear	-	-	Unclear	Unclear	-	-	-
Junqueira et al.(17) (2013)	-	-	-	-	Low risk	-	Unclear	-
Brady et al.(22) (2014)	Unclear	-	-	-	Low risk	-	-	-
Chavda et al.(15) (2014)	-	-	-	-	Low risk	-	-	-
Jakobson et al.(45) (2014)	-	Unclear	-	+	Low risk	-	Unclear	Unclear
Takeshita et al.(46) (2014)	Unclear	Unclear	-	-	Unclear	Unclear	Unclear	-
Ezzodini et al.(47) (2015)	-	-	-	-	Low risk	-	-	-
Abdinian et al.(48) (2016)	-	Unclear	-	-	Low risk	-	-	-
Taghiloo et al.(19) (2018)	-	-	Unclear	-	Low risk	-	-	-
Shaker et al.(49) (2019)	-	-	-	Unclear	Low risk	-	-	-
Mizuhashi et al.(50) (2019)	+	-	Unclear	Unclear	Unclear	Unclear	-	-
Sha et al.(51) (2021)	-	-	-	-	Low risk	-	-	-

(+) = high risk of bias / (-) =low risk of bias

Fig. 2 Qualitative assessment by Quality Assessment of Diagnostic Accuracy Studies (QUADAS) -2 tool

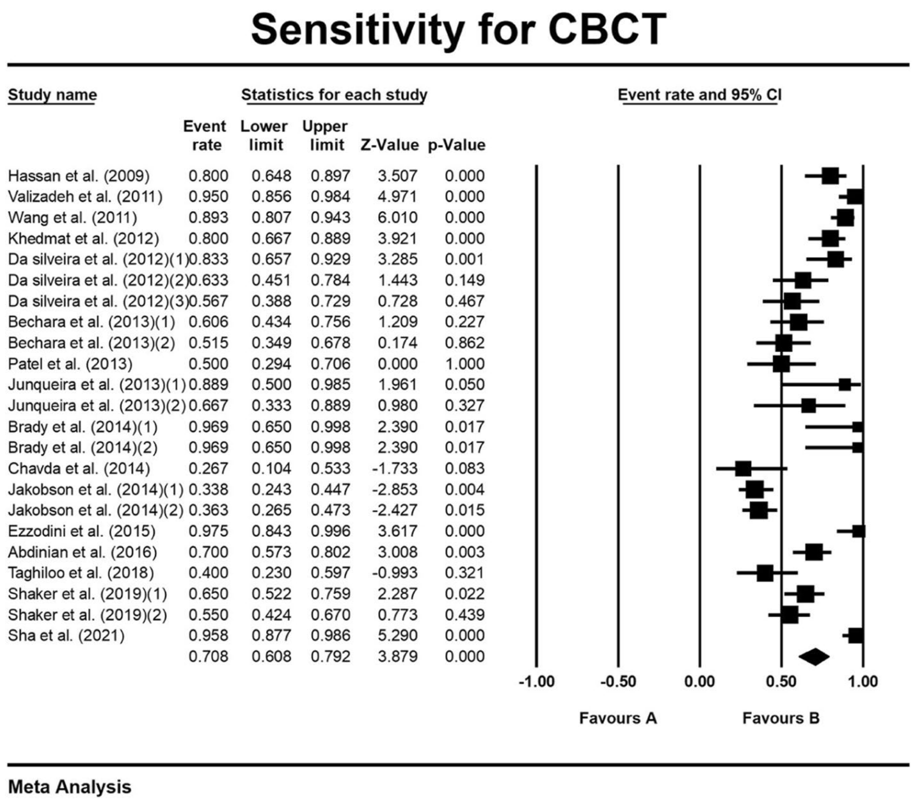

Fig. 3 Forest plot displaying the sensitivity of studies for detection of VRFs by CBCT

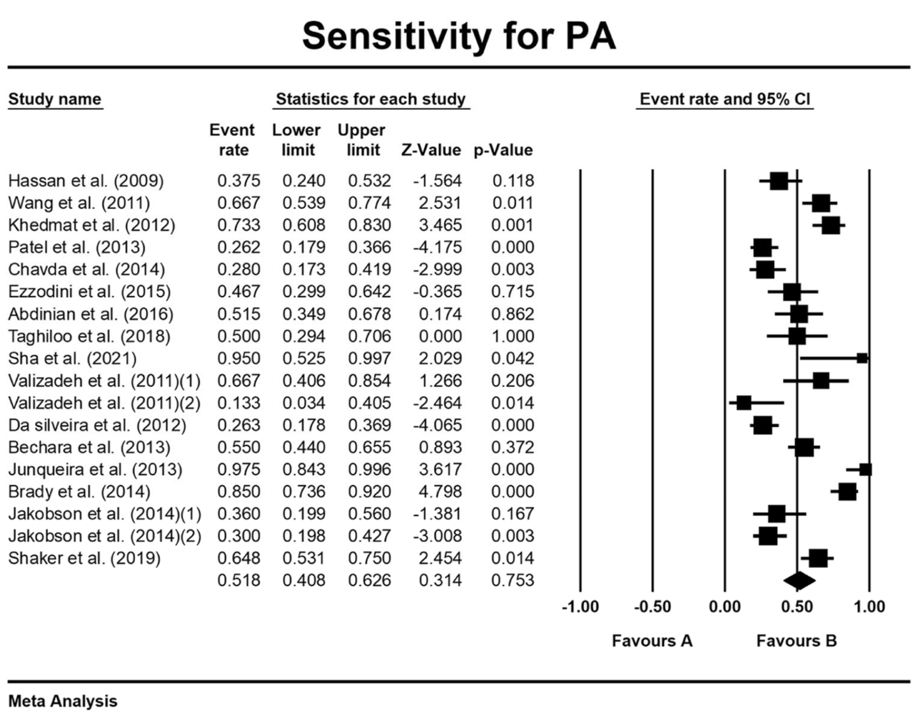

Fig. 4 Forest plot displaying sensitivity of studies for detection of VRFs by PA radiography

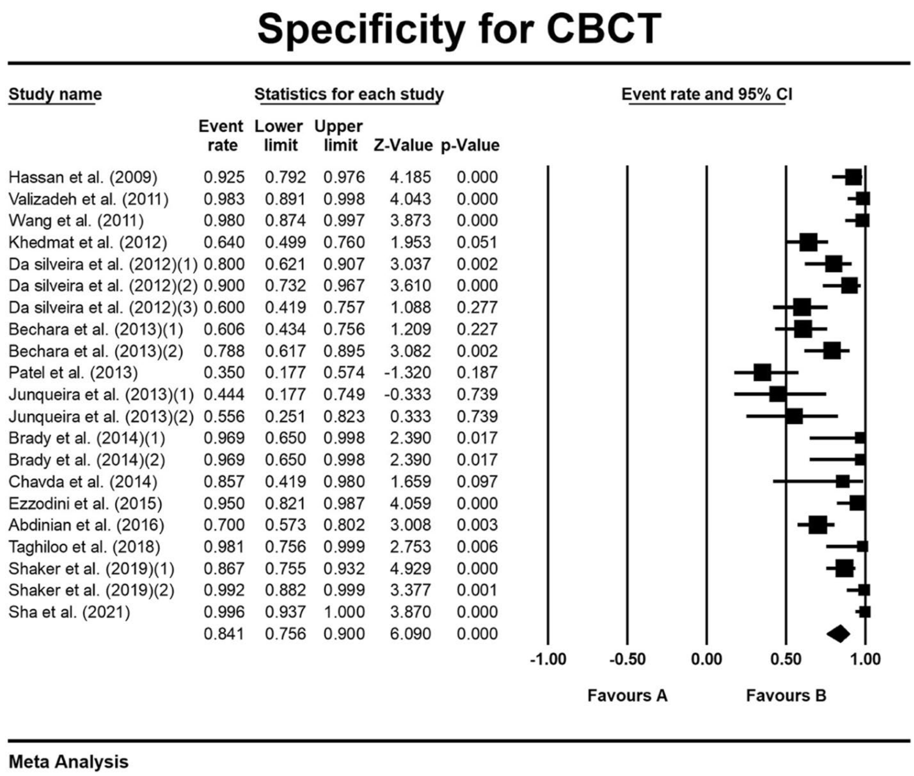

Fig. 5 Forest plot displaying specificity of studies for detection of VRFs by CBCT

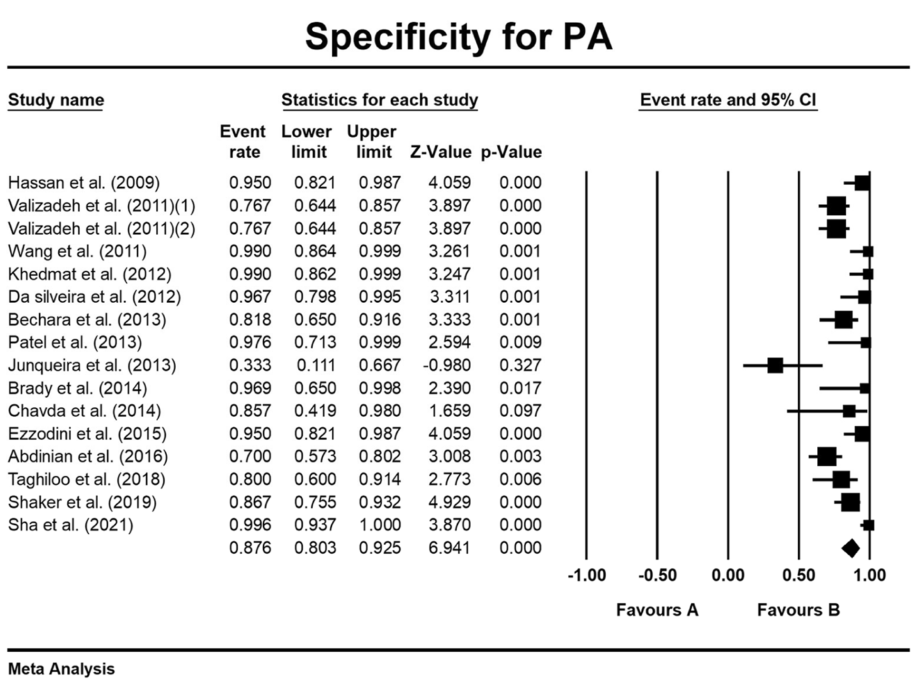

Fig. 6 Forest plot displaying specificity of studies for detection of VRFs by PA radiography

Table 2 Comparison of sensitivity and specificity indices in CBCT and PA modalities for included studies in the meta-analysis

Parameter	Modality	Effect size and 95% interval				Test of null (2-tail)		Heterogeneity	*P*-value
		Number Studies	Point Estimate	Lower Limit	Upper Limit	Z-value	P-value	I-squared	
Sensitivity	CBCT	23	0.708	0.608	0.792	3.879	< 0.001	86.089	0.011
	PA	18	0.518	0.408	0.626	0.314	0.753	86.833	
Specificity	CBCT	21	0.841	0.756	0.900	6.090	< 0.001	78.374	0.460
	PA	16	0.876	0.803	0.925	6.941	< 0.001	70.654	

CBCT Cone Beam Computed Tomography, *PA* Periapical Radiography

Based on the results obtained from the random effects model, the overall specificity of the CBCT method based on the information of 21 investigated scenarios (15 studies) was 0.841 (95% CI: 0.756, 0.9), and the overall specificity of the PA method based on 16 reviewed scenarios (15 studies) was 0.876 (95% CI: 0.803, 0.925); this difference was not statistically significant (P-value = 0.46).

Based on the results obtained from the random effects model, the overall sensitivity and specificity of both modalities for root filled and non-root filled subgroups is depicted on Table 3. For CBCT, both sensitivity and specificity of non-root filled group was higher than root filled group (P-value < 0.001). For PA radiography such significant difference was only obtained in specificity rate between two subgroups. (P-value < 0.001).

Figures 7, 8, 9 and 10 represent funnel plots for CBCT and PA Sensitivity and Specificity respectively.

Funnel plots for CBCT sensitivity and specificity and PA Specificity are asymmetrical, that reveals the presence of publication bias. Egger test results show that publication bias can be conceived for CBCT Sensitivity, CBCT Specificity and PA Specificity ($p < 0.05$).

Discussion

Correct detection of VRFs is a challenge for dental clinicians. In most cases, a diagnosis can be made based on the information obtained from clinical and radiographic examinations.

CBCT is expected to serve as a diagnostic aid for detection of VRFs. Comparison of the diagnostic accuracy of CBCT and PA radiography for detection of VRFs is highly challenging.

Despite the capabilities of CBCT, no consensus exists regarding the diagnostic accuracy of CBCT for detection of VRFs. Some studies showed higher accuracy of CBCT than PA radiography [23, 24, 30, 38–40]. Others found no significant difference between them [15, 41], while some researchers concluded that CBCT was not a reliable modality for detection of VRFs. This systematic review and meta-analysis analyzed the available in vivo and in vitro studies published up until November 2023 aiming to help dental clinicians to find the best imaging modality for detection of VRFs.

The present systematic review compared the sensitivity and specificity of CBCT in comparison with PA radiography for detection of VRFs. Since CBCT plays an important role in detection of endodontic complications [42, 43], this systematic review aimed to compare its diagnostic accuracy in comparison with PA radiography for detection of VRFs. Enhanced knowledge about the detection of VRF and advent of more advanced modalities such as CBCT resulted in higher prevalence of VRF reported in recent studies [23]. However, artifact generation is a drawback of CBCT, which can occur due to the presence of intra-canal posts and root filling materials or restoration of adjacent teeth and may compromise the

Table 3 Comparison of sensitivity and specificity indices in CBCT and PA modalities based on subgroup analysis

Parameter	Modality	Sub group	Rate	Lower Limit	Upper Limit	Z-value	*P*-value
Sensitivity	CBCT	RF	0.758	0.648	0.819	6.083	< 0.001
		Non-RF	0.911	0.828	0.956	6.011	
	PA	RF	0.452	0.334	0576	-0.752	0.546
		Non-RF	0.637	0.510	0.748	2.116	
Specificity	CBCT	RF	0.774	0.681	0.847	5.072	< 0.001
		Non-RF	0.937	0.900	0.961	10.606	
	PA	RF	0.819	0.714	0.891	4.959	< 0.001
		Non-RF	0938	0.890	0.966	8.492	

CBCT Cone Beam Computed Tomography, *PA* Periapical Radiography, *RF* Root Filled, *Non-RF* Non Root Filled

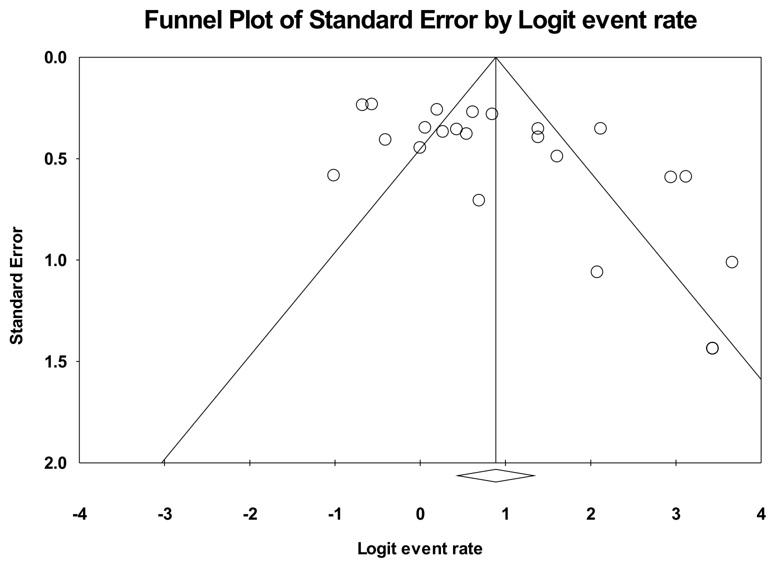

Fig. 7 Funnel plot of log Odds ratio and standard error for CBCT Sensitivity

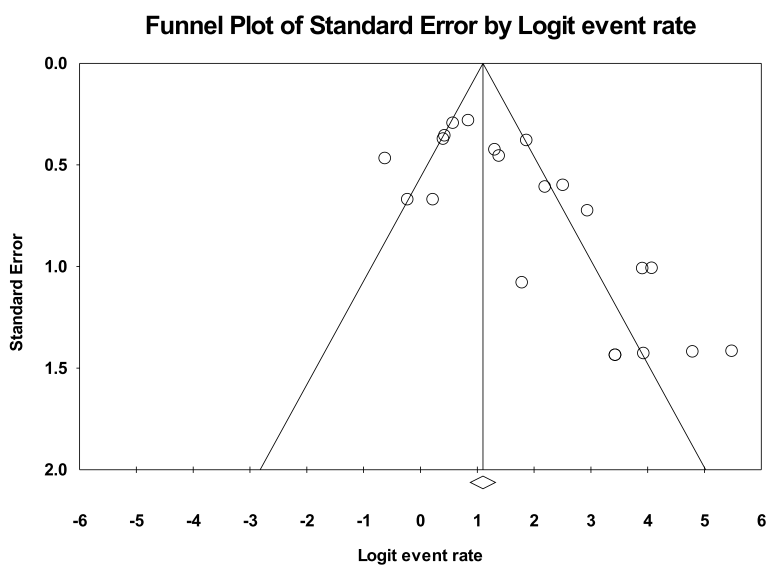

Fig. 8 Funnel plot of log Odds ratio and standard error for CBCT Specificity

diagnostic accuracy of CBCT for detection of VRFs [39]. It has been reported that the majority of VRFs in endodontically treated teeth occur due to weakening of root walls in the process of root canal instrumentation and post space preparation especially in teeth reconstructed with a metal post [44, 45].

The results indicated that VRFs were not detected in 27% of the teeth; this finding may be due the fact that VRFs usually occur in endodontically treated teeth, and artifacts caused by gutta-percha and metal posts can lower the diagnostic accuracy of CBCT for detection of VRFs [45]. PA radiography correctly detected VRFs in 51% of the cases but could not detect the fracture in 49% of the teeth. As mentioned earlier, one reason for this finding may be the X-ray beam angulation. Thus, multiple PA radiographs may be required for teeth suspected for VRF to maximize the likelihood of—ray beam becoming tangent to the fracture line, and its subsequent visualization and detection; otherwise, fracture line observation and detection would be difficult or even impossible as a result of superimposition of structures. Additionally, dehiscence or bone defects may mimic a

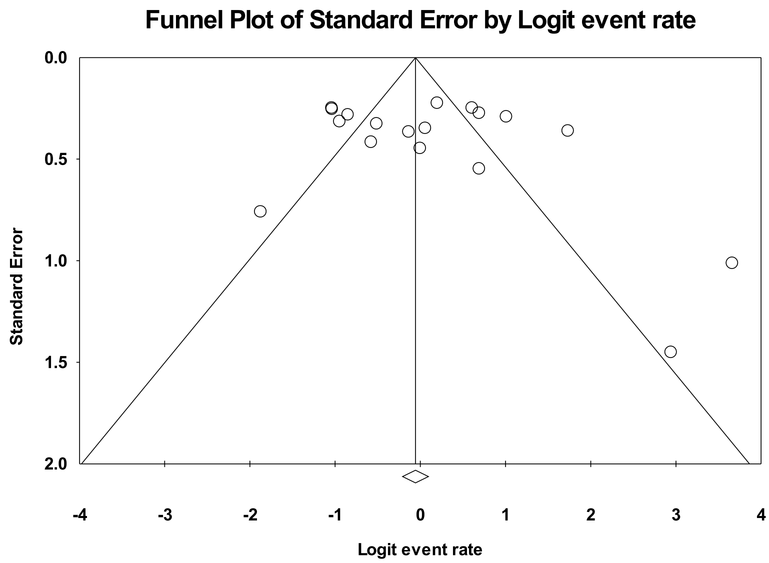

Fig. 9 Funnel plot of log Odds ratio and standard error for PA Sensitivity

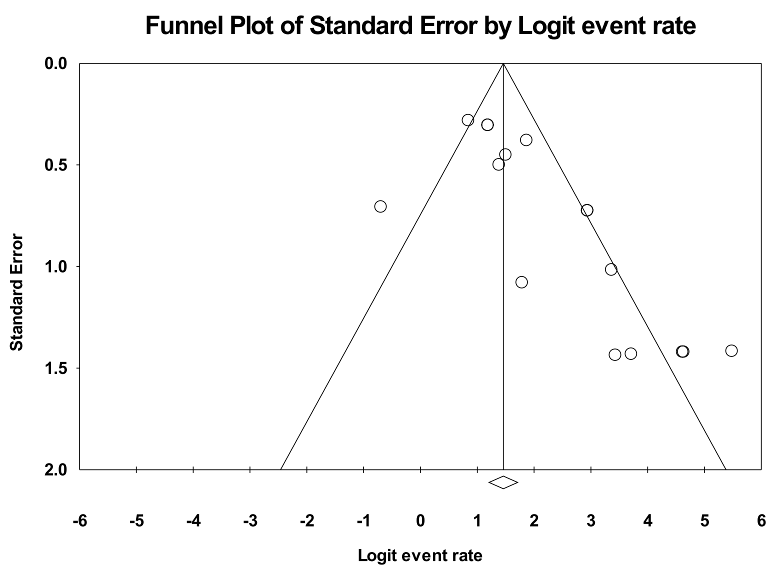

Fig. 10 Funnel plot of log Odds ratio and standard error for PA Specificity

VRF, or superimposition of bone or exostosis may mask the fracture line [46].

In the present study, the results revealed higher sensitivity of CBCT compared with PA radiography. However, CBCT had lower specificity (0.84) than PA radiography (0.87).

Moreover, the subgroup analysis results show significantly higher diagnostic operation for CBCT in non-root filled teeth. Generation of metal artifacts in teeth with post or gutta-percha can be responsible for this finding.

Presence of high-density materials can cause stellate lines that may mimic the fracture line. This resemblance can result from more absorption of higher-energy photons compared to lower-energy photons by dense objects including root filling materials and leads to produce beam hardening artifacts. Such phenomenon can be visualized in two forms: distortion of metallic structures (cupping artifacts) and formation of dark bands (extinction artifacts) [7].

Sensitivity and specificity are the most commonly used indices for evaluation of diagnostic accuracy. In CBCT, the ratio of specificity (the ability to detect TN) to total sensitivity (the ability to detect TP) is larger than this ratio in PA radiography.

The only reason for selection of CBCT as the imaging modality of choice for assessment of VRF may be provision of 3D images of the region of interest. It can directly visualize the fracture line and overcome the problems of magnification, distortion, and superimposition of anatomical structures. Different CBCT scanners have differences that can affect their diagnostic accuracy. Some studies attributed the differences in performance of different CBCT scanners in detection of VRFs to the type of detector [47, 48]. Flat-panel detectors have a superior performance for detection of VRFs due to lower level of noise and artifacts.

The majority of eligible studies that were included in this review were in vitro studies and only 5 had an in vivo design. All in vivo studies concluded that CBCT was more efficacious for detection of VRFs and had high sensitivity and specificity for this purpose. Although such studies provided high level of evidence, further in vivo studies are required regarding the diagnostic accuracy of CBCT.

It should be noted that in vitro conditions may be different from the clinical scenarios since a number of degrading factors such as greater volume of hard and soft tissues for the X-ray beam to pass and patient movements in the clinical setting decrease the image quality and subsequent detection of details [46, 49]. Even heartbeat alone induces a slight movement that causes motion blur and decreases the "nominal spatial resolution" to the extent that the observers stated that they were not able to even assess the presence of fractures due to low image quality [50].

Twenty-three studies were evaluated in the present systematic review after applying the eligibility criteria, which had high level of heterogeneity. Such a high level of heterogeneity could be due to a number of factors such as differences in sample size, type of CBCT scanners or PA X-ray systems (conventional or digital), different testing parameters, in vitro, ex vivo, or clinical design of the studies, differences in study populations, and specialty, experience, and expertise of the observers. CBCT, compared with PA radiography, creates optimal imaging parameters for accurate detection of VRFs. Thus, the current investigation focused on the key aspects of different CBCT scanners such as voxel size, field of view, and exposure parameters for detection of VRFs and compared the accuracy of CBCT with PA radiography for this purpose. Heterogeneity across the studies and different methodologies can affect the results of meta-analyses. The present results clearly revealed the differences among the studies but strongly supported the use of CBCT for detection of VRFs.

Results of this study show publication bias for CBCT sensitivity, specificity and PA specificity.

One possible explanation for this is that small studies reporting poor sensitivity or specificity may be less likely to be submitted or accepted for publication. If this is the case then the values for pooled sensitivity and specificity may represent over-estimates.

One limitation of this systematic review was high heterogeneity probably due to the following parameters, which are suggested to be further evaluated in subgroup analyses in future studies:

Sample size was the first parameter. Some studies evaluated 21 teeth [15, 30], and thus, their results could be different from the findings of studies conducted on over 110 teeth [24]; such a difference in sample size could be one reason for high heterogeneity.

Type of CBCT scanner was the second parameter. Use of different CBCT scanners with different hardware, voltage (kVp), amperage (mA), exposure time, voxel size, patient position during imaging, FOV, and software programs could cause variations in diagnostic accuracy for detection of VRFs. Also, different PA radiography units (conventional or digital) with different exposure parameters could be responsible for heterogeneity.

The third parameter was different testing conditions. The gold standard was different in vivo and in vitro, and also different methods (such as different types of electron microscopes with methylene blue staining) were used in vitro for detection of fracture, which could be another source of heterogeneity in meta-analyses.

Specialty, experience, and expertise of the examiner can be named as the fourth parameter. Specialty, level of experience, and expertise of the examiners were variable in different studies, and could have affect the diagnostic accuracy of the modalities serving as a source of heterogeneity.

An additional consideration is that a significant number of studies in literature have been undertaken on endodontically treated teeth or teeth with posts which exhibit a greater likelihood of root fracture, coupled with the challenging nature of VRF diagnosis due to the artifacts generated by opaque materials within the canal in such cases. To ensure a comprehensive survey with more eligible studies, this systematic review considered studies on both intact and endodontically treated teeth. Presumably this factor can be responsible for heterogeneity. Other Future studies should take into account all these parameters.

Conclusions

Although CBCT has advantages such as provision of high-resolution 3D images and does not have the shortcomings of conventional radiographic modalities such as the superimposition of anatomical structures, it should be borne in mind that CBCT still has a higher radiation dose and this modality should not be prescribed until after conducting a precise clinical examination for finding any manifestation of fracture line, and not as an initial radiographic technique [51].

The present results indicated that in general, the overall sensitivity of CBCT was significantly higher than PA radiography for detection of VRFs; however, the specificity of the two techniques was not significantly different.

Abbreviations

CBCT	Cone-beam computed tomography
PA	Periapical radiography
VRF	Vertical root fracture
FOV	Field of view
3D	Three dimensional
TP	True positive
TN	True negative
FP	False positive
FN	False negative

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