Oral Radiology
https://doi.org/10.1007/s11282-025-00821-6

REVIEW ARTICLE

The diagnostic accuracy of cone-beam computed tomography for assessing in vitro osseous alterations of the mandibular condyle: a systematic review and meta-analysis

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Received: 23 November 2024 / Accepted: 20 March 2025

Abstract

Objective To determine the diagnostic accuracy of cone-beam computed tomography (CBCT) in detecting simulated bony changes in the mandibular condyle by assessing the sensitivity and specificity.

Methods This review adhered to PRISMA guidelines. Following predefined eligibility criteria, a search was conducted in four electronic databases in June 2024. The study-level risk of bias was assessed using a diagnostic test accuracy checklist provided by the Joanna Briggs Institute. Pooled estimates of sensitivity and specificity were calculated using a bivariate random-effects model.

Results Among 1,803 potentially eligible references, six met the inclusion criteria for qualitative synthesis, and three for meta-analysis. The meta-analysis revealed that the index test, CBCT, had a low pooled sensitivity of 0.54 and a high specificity of 0.93 for detecting simulated defects of the mandibular condyle. Computed tomography exhibited a lower sensitivity of 0.37, but similar specificity of 0.93 like CBCT. Out of the six studies, five were found to have a low risk of bias.

Conclusions Cone-beam computed tomography is found to be more accurate than other modalities for detecting condylar bony changes, effectively ruling out false positives, but with a risk of missing true positives. A smaller field of view and voxel size may provide more accurate detection.

Keywords Temporomandibular joint · Degenerative diseases · Temporomandibular disorders · Diagnostic accuracy test

Introduction

The temporomandibular joint (TMJ) is a complex synovial joint formed between the temporal bone's mandibular condyle and glenoid fossa that facilitates speech, mastication, and any functions involving jaw movements [1]. Temporomandibular disorders (TMD) are a group of conditions affecting the TMJ commonly characterized by pain, restricted jaw movement, and clicking sounds. Condylar bony changes, such as erosion

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Published online: 02 May 2025

(discontinuity of cortical outline), flattening (loss of convexity), and osteophyte (bony overgrowth) formation, are often observed in patients with TMD [2, 3]. Imaging of TMJ is recommended, besides clinical examination, to evaluate these osseous alterations properly [4, 5]. CBCT is preferable to current imaging methods for assessing the TMD, including panoramic radiography (PAN), TMJ tomography (TOMO), computed tomography (CT), and magnetic resonance imaging (MRI) [6].

Diagnostic accuracy refers to the ability of a test or procedure to correctly identify the presence or absence of a disease or condition. It is typically measured using several statistical metrics, including sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). Sensitivity is the ability of a test to correctly identify those with the disease (true positive rate). At the same time, specificity correctly identifies those without the disease (true negative rate) [7]. A highly sensitive test is beneficial for ruling out a disease when the result is negative, whereas a highly specific test confirms a disease when the result is positive [8]. Several studies have revealed diagnostic accuracy by assessing the sensitivity and specificity of different imaging modalities but are fragmented, resulting in a lack of consensus [9–11]. Some review studies focused on the diagnostic accuracy of different imaging modalities in a frame without synthesizing data from those papers by meta-analysis [12–14]. A comprehensive review of the sensitivity and specificity of all imaging modalities in one study is still lacking. This systematic review with meta-analysis aimed to address the gap by evaluating and synthesizing the available evidence on the diagnostic accuracy of different imaging modalities for assessing simulated bony changes in the mandibular condyle.

Review question

The following research question was posed: Is cone-beam computed tomography more accurate than other radiographic modalities in assessing the simulated osseous alteration involving the mandibular condyle? A subsequent question was posed to identify possible sources of variation: Can hardware settings affect the diagnostic accuracy of cone-beam computed tomography?

Methods

Protocol and registration

This review was reported following the Preferred Reporting Items for a Systematic Review and Meta-analysis (PRISMA) guideline. As this is a systematic review of in vitro studies, Prospero registration is not applicable.

Based on PIRD (population, index test, reference test, and diagnosis of interest):

- Population: mandibular condyle (from cadaveric or dry skull) with simulated bony changes.
- Index test: CBCT.
- Reference test: CT, PAN, and TOMO.
- Diagnosis of interest: detection of simulated bone defects, erosion, osteophytes, and flattening that resemble the degenerative alterations of the mandibular condyle.

Eligibility criteria

The inclusion criteria were:

- In vitro studies that used CBCT to assess simulated osseous alterations of the mandibular condyle, such as erosion, osteophytes, defects, and flattening.
- Diagnostic test accuracy (DTA) studies that compared the diagnostic accuracy of CBCT with other radiographic modalities, including CT, PAN, and TOMO, using sensitivity, specificity, and accuracy.
- Manuscripts that showed a low risk of bias and mentioned the value of sensitivity and specificity for erosion, osteophytes, and flattening for both index and reference tests will be included for meta-analysis.

The exclusion criteria:

- Studies involving patients with suspected or diagnosed TMD.
- Reviews, letters, conference abstracts, personal opinions, book chapters, in vitro or in vivo animal studies, protocols, case reports, and case series.
- Studies with unverifiable or inconsistent diagnostic accuracy data such as discrepancies in sensitivity/specificity values across different sections of the manuscript that could not be resolved through clarification from the corresponding author.
- Studies published in languages other than English.

Information sources and search strategy

Data was retrieved from the following databases: Scopus®, PubMed.gov, EBSCOhost Dentistry & Oral Sciences Source, and Web of Science™ (WoS).

Web of Science™ includes the following databases, with translations in English when necessary: Web of Science Core Collection™, Current Contents Connect®, Derwent Innovations Index™, KCI-Korean Journal Database™, MEDLINE®, Russian Science Citation Index™, and SciELO

Citation Index™. The searches were conducted in June 2024, with no restrictions on the publication date of the articles. Specific language and field restrictions were applied to Scopus and Web of Knowledge searches, limiting results to English research within dentistry and healthcare. Two reviewers (first and second authors) independently conducted the search process. Inter-rater reliability was measured using Cohen's kappa (K) coefficient. A third reviewer (corresponding author) resolved all conflicts in the agreement.

Study selection and data collection process

The screening process adhered to PRISMA guidelines. We conducted an a priori search using the manuscript title and research question with a generative AI model (Consensus AI; Consensus Inc., Massachusetts, USA) to determine the data items and summary measures to extract. We removed duplicates and screened manuscripts using a professional systematic review screening platform (Covidence.org; Veritas Health Innovations Ltd., Melbourne, Australia). This platform ensured complete agreement and conflict resolution between the reviewers before allowing eligible manuscripts to advance through the screening process.

Definition of data extraction

Full texts of the eligible studies were analyzed, and data were extracted for the following information: study identification (author, year, country, type of study, sample characteristics, simulated lesion characteristics); image acquisition and viewing protocol for index and reference tests; main results (observer's agreement, sensitivity, and specificity). Both authors (first and second) independently screened all the studies and conducted data extraction individually. In cases of disagreement regarding data extraction, a consensus was reached through discussion with a third reviewer (corresponding author).

Risk of bias and applicability

After completing the study selection process, we used the Joanna Briggs Institute (JBI) critical appraisal checklist for diagnostic test accuracy studies to evaluate the certainty of evidence and assess potential biases. We categorized the risk of bias for each study as "yes," "no," or "unclear." A study had a high risk of bias if it received a "yes" in less than five out of ten categories, moderate if the score was five to seven, and low if the score was eight or higher [15]. Any disagreements between the two reviewers were resolved with input from a third reviewer (corresponding author).

Synthesis of the method

A meta-analysis was conducted using a random-effects model to account for heterogeneity among studies. The sensitivity for each study was calculated with 95% confidence intervals (CI). Subgroup analyses were performed for each type of abnormality (erosion, flattening, and osteophyte). Forest plots were generated to visualize the sensitivity estimates and their CIs for individual studies and pooled estimates for each subgroup. The heterogeneity among studies was assessed using the I^2 statistic, with values greater than 50% indicating substantial heterogeneity.

Results

Study selection

Using the predefined search strategy, we searched four electronic databases, yielding a total of 1,803 references. After separating duplicates, 1043 references were available for further screening. Following the review of titles and abstracts as per the PRISMA 2020 flow diagram (Fig. 1), 25 articles were selected for full-text reading. Among these, 19 were excluded (Supplementary file 2), leaving 6 articles for critical appraisal and review that met the PIRD protocol. The kappa coefficient of agreement was greater than 0.76 for both pairs, indicating excellent agreement

Risk of bias within studies

A JBI-DTA critical appraisal of the articles (Fig. 2) suggested that every study avoided the case–control design, but the sampling method was unclear. Moreover, most of the studies avoided inappropriate exclusions except for two [16] and [17]. In addition, only one study [17] failed to clearly state the observers' blinding for index and reference tests. Though reference tests were different, such as CT, PAN, and TOMO they were likely to classify the target conditions correctly, and the standard interval between index and reference tests was strictly maintained. Pre-specification of the threshold was missing for all the studies as well. Four studies—[12, 13, 18], and [19]—answered "yes" to eight out of ten questions on the JBI DTA checklist, indicating a low risk of bias. Another study, [16], scored 7, reflecting a low risk of bias. However, one study [16] scored 5, indicating a high risk of bias. Detailed individual appraisals are available in supplementary Table 1 and are accessible online.

Study characteristics

This systematic review includes six studies examining the mandibular condyle in dried human skulls. The studies,

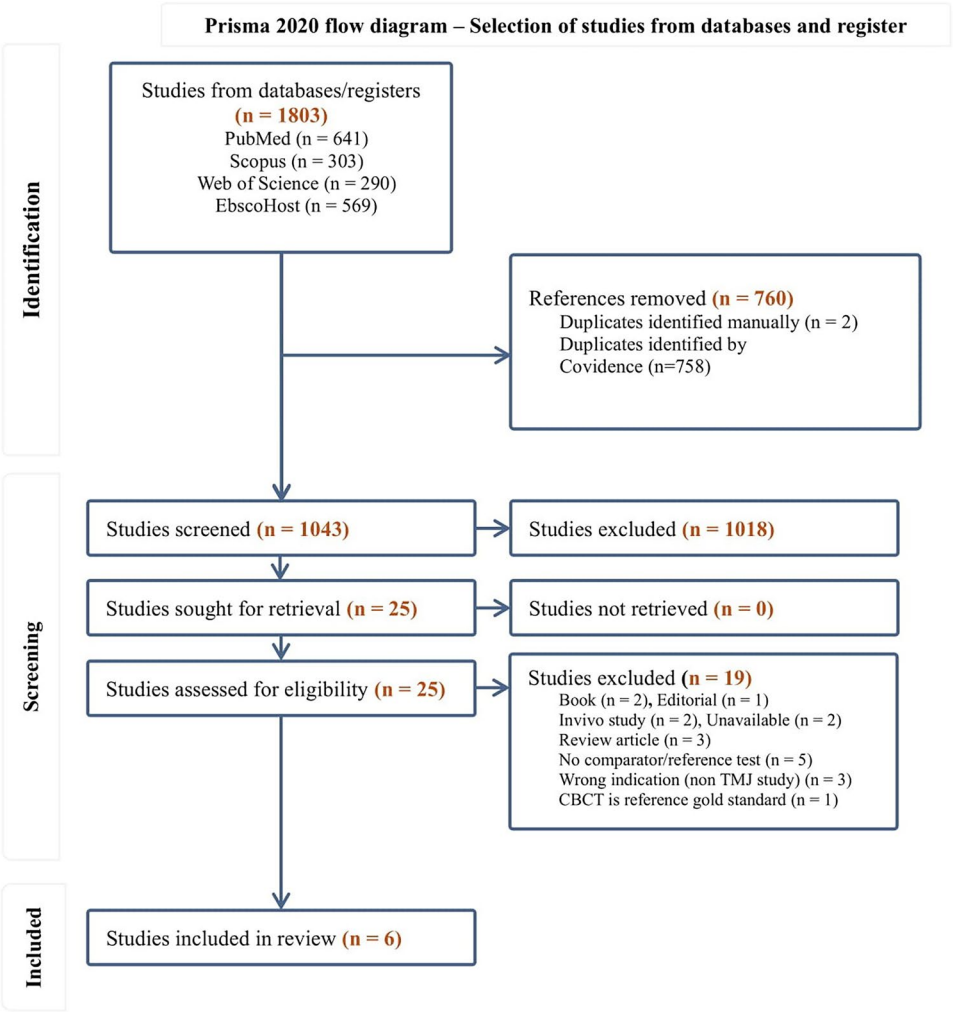

Fig. 1 PRISMA flowchart showing the search results

conducted in English, represent diverse geographic origins: one each from the USA (37 TMJs), Iran (10 TMJs), Japan and Norway (21 TMJs), Saudi Arabia (10 TMJs), India (30 TMJs), and Denmark (159 TMJs). Table 2 provides detailed descriptions of the included studies.

Result of meta-analysis

This meta-analysis evaluated the following simulated lesions: erosion, flattening, and osteophyte. Sensitivity and specificity are pooled for imaging modalities CBCT and CT that are included in the studies. CBCT showed a low pooled sensitivity of 0.54 (95% CI: 0.47–0.60, $I^2 = 86.6\%$) higher than CT as reference tests detecting simulated lesions which showed a lower sensitivity of 0.37 (95% CI: 0.30–0.43, $I^2 = 88.8\%$).

The overall heterogeneity between groups was significant ($p < 0.001$), suggesting that the diagnostic accuracy of these imaging modalities varied considerably across the different simulated lesions (Fig. 3).

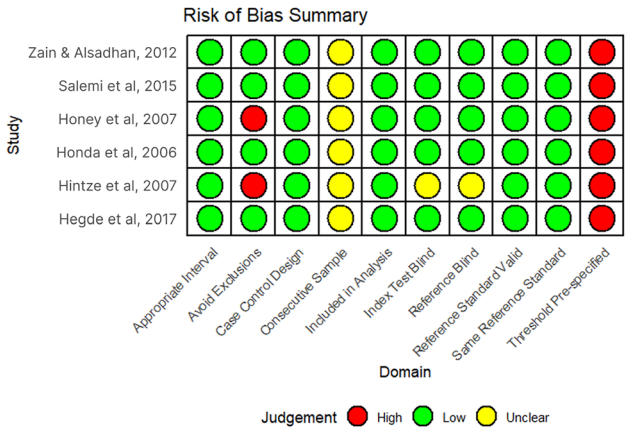

Fig. 2 The figure illustrates the risk of bias assessment of the studies

The forest plot (Fig. 4) shows the pooled specificity among imaging modalities CT and CBCT, both of which have high specificity, with similar pooled estimates of

Table 1 Search strategies used in this study

Databases	Keywords	Studies (*n*)
PubMed	(((Dental[tiab] OR Maxillofacial[tiab] OR Oral[tiab] OR mandib*[tiab] OR Condyl*[tiab] OR "Dentistry"[mh] OR "Temporomandibular Joint"[mh]) AND (Cone beam[tiab] OR CBCT[tiab] OR "Cone-Beam Computed Tomography"[mh])) AND (Magnetic resonance[tiab] OR Orthopantomo*[tiab] OR Panoramic radio*[tiab] OR computed Tomography[tiab] OR Saggital[tiab] OR coronal[tiab] OR "Magnetic Resonance Imaging"[mh])) AND (Degenerative[tiab] OR Preauricular[tiab] OR TMJOA[tiab] OR Osteoarthritis[tiab] OR Mandibular Dislocat*[tiab] OR osseous abnormalit*[tiab] OR "bony alteration*"[tiab] OR lesion[tiab] OR "Osteoarthritis"[mh])	641
Web of Science	Dental OR Maxillofacial OR Oral OR "Temporomandibular joint" (Topic) and "Cone beam" OR CBCT (Topic) and "Magnetic resonance" OR Orthopantomo* OR "Panoramic radio*" OR "computed Tomography" OR Saggital OR coronal (Topic) and Degenerative OR Preauricular OR TMJOA OR Osteoarthritis OR "Mandibular Dislocat*" OR "osseous abnormalit*" OR “bony alteration*” OR “bone alteration” (Topic) and Preprint Citation Index (Exclude – Database) and English (Languages)	290
EBSCOhost DOSS	(TI(Dental OR Maxillofacial OR Oral OR mandib* OR Condyl*) OR AB(Dental OR Maxillofacial OR Oral OR mandib* OR Condyl*)) AND (TI(Cone beam OR CBCT) OR AB(Cone beam OR CBCT)) AND (TI(Magnetic resonance OR Orthopantomo* OR Panoramic radio* OR computed Tomography OR Saggital OR coronal) OR AB(Magnetic resonance OR Orthopantomo* OR Panoramic radio* OR computed Tomography OR Saggital OR coronal)) AND (TI(Degenerative OR Preauricular OR TMJOA OR Osteoarthritis OR Mandibular Dislocat* OR osseous abnormalit* OR “bony alteration*" OR lesion) OR AB(Degenerative OR Preauricular OR TMJOA OR Osteoarthritis OR Mandibular Dislocat* OR osseous abnormalit* OR “bony alteration*" OR lesion))	569
Scopus	(TITLE-ABS-KEY (dental OR maxillofacial OR oral OR "temporomandibular joint") AND TITLE-ABS-KEY ("cone beam" OR cbct) AND TITLE-ABS-KEY ("magnetic resonance" OR orthopantomo* OR "panoramic radio*" OR "computed tomography" OR saggital OR coronal) AND TITLE-ABS-KEY (degenerative OR preauricular OR tmjoa OR osteoarthritis OR "mandibular dislocat*" OR "osseous abnormalit*" OR "bony alteration*" OR "bone alteration")) AND (LIMIT-TO (LANGUAGE, "english"))	303

0.93 (95% CI: 0.90–0.97) and 0.93 (95% CI: 0.89–0.97), respectively, indicating they are reliable in confirming the absence of disease. Significant heterogeneity in CBCT ($I^2 = 75.0\%$) and CT ($I^2 = 66.0\%$) suggests study variability.

Discussion

The current review aimed to identify whether CBCT is diagnostically more accurate than other imaging modalities in vitro. Based on the reports, the results seemed to vary, as discussed below. CBCT showed low sensitivity and very high specificity in identifying the simulated osseous changes of the mandibular condyle, such as erosion, flattening, and osteophyte, which was the highest among other imaging modalities.

Interestingly, the current meta-analysis showed that the pooled sensitivity of all included imaging modalities was low, while the pooled value for specificity was high. The low sensitivity implies that the imaging modalities used in these studies may not effectively identify all true cases of condylar bony changes, which can produce the risk of underdiagnosis. In this case, a comprehensive evaluation that includes clinical examination and multiple diagnostic modalities may be necessary to improve the diagnostic accuracy [5].

In subsequent subgroup analyses, CBCT showed higher sensitivity (54%) than CT (37%). The superimposition of surrounding structures in the condylar head makes it challenging for two-dimensional radiographs to clearly depict bony changes. In contrast, three-dimensional imaging modalities such as CBCT and CT both can produce more accurate details by avoiding the duplication of overlapping structures [20]. Moreover, CBCT outperformed CT, likely due to differences in technical parameters such as spatial resolution, voxel size, and field of view. Its higher spatial resolution and smaller, adjustable voxel sizes allow for the precise detection of degenerative changes in the condylar head. Furthermore, a smaller field of view and collimation capabilities enhance image quality by minimizing scatter radiation and concentrating on the TMJ region. Additionally, cone-beam image acquisition and optimized reconstruction algorithms contribute to the superior high-resolution imaging of CBCT compared to CT [21].

Since specificity is closely aligned with the ability to identify disease-free normal anatomy, both CBCT and CT demonstrated similarly high specificity (93%) in ruling out degenerative changes of the condylar head. This high specificity can be attributed to the superior spatial resolution of CBCT and the advanced texture analysis capabilities of CT, both of which are essential for distinguishing between the affected and normal condylar structures [22, 23].

Table 2 Description of the studies included

Author/ year/ country	Sample particulars	Type of simulated lesion	Location of simulated lesion	Image acquisition for index test	Image acquisition for the reference test		Image viewing protocol for the index test	Image viewing protocol for the reference tests	Observers' agreement	Result for both the index and reference tests (sensitivity, specificity, accuracy)		
Hegde et al. 2017, India	30 TMJs from 15 dried human skulls	Simulate bone defects(1 mm)	Anterosuperior, superior, and posterosuperior part of the condyle	CBCT— KODAK 9000C 3D Extraoral imaging system (Carestream Health, Inc. 150 Verona Street Rochester New-York, USA 14608)	CT—SOMATOM Definition AS (SIEMENS AG, Wittelsbacherplatz 2, DE–80333, Muenchen, Germany)	Panoramic—KODAK 9000C 3D extraoral imaging system (Carestream Health, Inc. 150 Verona Street Rochester New York, USA 14608)	CBCT—Syngo software (Siemens) slice thickness 0.076 mm	CT—Syngo software (Siemens) slice thickness 0.06 mm PANORAMIC—Syngo software (Siemens)	Blinded, Kappa values. PANORAMIC 0.37, CT 0.61, CBCT 1.00	CBCT Sensitivity = 100% Specificity = 100% Accuracy = 100%	CT Sensitivity = 97% Specificity = 100% Accuracy = 96.67%	PANORAMIC Sensitivity = 24% Specificity = 100% Accuracy = 24.14%
				Tube voltage: 90 kVp, tube current: 8 mA	Tube voltage, tube current: not mentioned	Tube voltage, tube current: not mentioned						
				FOV: 50 mm × 37 mm	FOV: not mentioned	FOV: not mentioned						
				Voxel: 76.5 × 76.5x76.5 µm	Voxel: not mentioned	Voxel: not mentioned						
				Scan time: 6.1 s	Scan time: not mentioned	Scan time: not mentioned						
Salemi et al. 2015, Iran	10 TMJs from 5 dried human skulls	Erosion and osteophytes	Anterior–superior part of the condyle	CBCT—Cranex 3D (Soredex, Helsinki, Finland)	Tomography—Cranextom (Soredex, Helsinki, Finland)	Panoramic—Cranextom (Soredex, Helsinki, Finland)	CBCT—on demand 3D	Tomography and Panoramic—Digora software for Windows	Blinded, Kappa values 0.76	CBCT Accuracy Erosion = 89% Osteophytes = 91% Sensitivity Erosion = 88% Osteophytes = 91% Specificity Erosion = 30% Osteophytes = 30%	Tomography Accuracy Erosion = 56% Osteophytes = 58% Sensitivity Erosion = 50% Osteophytes = 47% Specificity Erosion = 25% Osteophytes = 25%	Panoramic Accuracy Erosion = 39% Osteophytes = 47% Sensitivity Erosion = 30% Osteophytes = 41% Specificity Erosion = 22% Osteophytes = 22%
				Tube voltage: 90 kVp, tube current: 8 mA	Tube voltage: 57 kVp, tube current: 1.3 mA	Tube voltage: 57 kVp, tube current: 6.4 mA						
				FOV: 61 mm × 78 mm	FOV: not mentioned	FOV: nNot mentioned						
				Voxel: 0.2—0.4 mm	Voxel: not mentioned	Voxel: not mentioned						
				Scan time: 6.1 s	Scan time: 46 s	Scan time: 15 s						
Zain & Alsadhan, 2012 Saudi Arabia	10 TMJs from 5 dried human skulls	Flattening, erosion, and osteophytes	Lateral and medial pole, anterosuperior, and posterosuperior slope of the condyle	CBCT—ILUMA (IMTEC, Ardmore, OK)	MDCT—Light Speed 2002 (General Electric Company (GE), Fairfield, CA)		CBCT—ILUMA Vision 3D, version 1.0.2.5 (IMTEC,Ardmore, OK)	MDCT—Centricity DICOM Viewer (GE, Fairfield, CA)	Blinded, Kappa values 0.20	CBCT—*Observer A* Sensitivity 39.59(1st read) 22.92(2nd read)	MDCT—*Observer A* Sensitivity 25(1st read) 27.08(2nd read)	
				Tube voltage: 120 kVp, tube current: 3.8 mA	Tube voltage: 100 kVp, tube current: 80 mA					Specificity	Specificity	
				FOV: not mentioned	FOV: not mentioned					83.87 (1st read)	87.10 (1st read)	
				Voxel: 0.29 mm	Voxel: 0.2—0.4 mm					90.32 (2nd read)	88.71 (2nd read)	
				Scan time: not mentioned	Scan time: 6.1 s					*Observer B*	*Observer B*	
										Sensitivity 35.42	Sensitivity 50	
										Specificity 90.32	Specificity 85.48	

Table 2 (continued)

Author/year/country	Sample particulars	Type of simulated lesion	Location of simulated lesion	Image acquisition for index test	Image acquisition for the reference test		Image viewing protocol for the index test	Image viewing protocol for the reference tests	Observers' agreement	Result for both the index and reference tests (sensitivity, specificity, accuracy)		
Honda et al., 2006. Japan and Norway	21 TMJ from autopsy specimen	Erosion, osteophyte, and sclerosis	Mandibular condyle	CBCT—3DX	Helical CT—Lemage SXE helical scanner (GEYMS, Tokyo, Japan)		All images were printed and interpreted	All images were printed and interpreted	Blinded, Kappa values Not mentioned	CBCT Sensitivity = 0.80 Specificity = 1	CT Sensitivity = 0.70 Specificity = 1	
				Tube voltage: 80 kVp, tube current: 2 mA	Tube voltage: 120 kVp, tube current: 80 mA					Accuracy = 0.90	Accuracy = 0.86	
				FOV: 30 mm × 40 mm	FOV: 50 mm							
				Voxel: 0.125 mm	Voxel: not mentioned							
				Scan time: 17 s	Scan time: not mentioned							
Honey et al. 2007. USA	37 TMJs from 30 dried human skulls	Simulate bone defects	Lateral pole of the mandibular condyle	CBCT—iCAT	Tomography—Quint Sectograph (model QS 10-1627W; Denar, Anaheim, Calif)	Panoramic—Orthopantomograph OP 100 (Instrumentarium Imaging/GE Medical Systems, Milwaukee, Wis)	CBCT—Proprietary software (VixWin 2000, version 1.2; Gendex/Kavo). And DenOptix imaging system (Gendex/Kavo, Des Plaines, Ill)	PAN and TOMO—Proprietary software (VixWin 2000, version 1.2; Gendex/Kavo). And DenOptix imaging system (Gendex/Kavo, Des Plaines, Ill)	Blinded, Kappa values 0.35–0.79	CBCT Accuracy—interactive = 0.946, static = 0.774	Tomography Accuracy = 0.576	Panoramic Accuracy Normal = 0.644, TMJ = 0.545
				Tube voltage:120 kVp, tube current: 3–8 mA	Tube voltage, tube current: not mentioned	Tube voltage, tube current: not mentioned						
				FOV: 17 cm × 13.2 cm	FOV: 6 inch × 12 inch	FOV: 8 inch × 10 inch						
				Voxel: 0.125 mm	Voxel: not mentioned	Voxel: not mentioned						
				Scan time: 20 s	Scan time: not mentioned	Scan time: not mentioned						
Hintze et al., 2007. Denmark	159 TMJs from 80 dried human skulls	Flattening, defect, and osteophytes	Mandibular condyle	CBCT—NewTom 3G (NIM s.r.l.,Verona, Italy)	Tomography—Cranex Tome X-ray unit (Soredex, Helsinki, Finland)		CBCT—NewTom 3G software (NIM s.r.l.,Verona, Italy)	Tomography—Digora software for Windows	Not blinded, Kappa valuesNot mentioned	CBCT Lateral projection (sensitivity, specificity) Flattening = 0.23,0.87 Defect = 0.15, 0.95 Osteophytes = 0.15, 0.96 Frontal projection (sensitivity, specificity) Flattening = 0.40,0.90 Defect = 0.20, 0.96	Tomography Lateral projection (sensitivity, specificity) Flattening = 0.11,0.95 Defect = 0.15, 0.97 Osteophytes = 0.15, 0.99 Frontal projection (sensitivity, specificity) Flattening = 0.23,0.94 Defect = 0.21, 0.95	
				Tube voltage: 110 kVp, tube current: 0.5 mA	Tube voltage, tube current: not mentioned							
				FOV: not mentioned	FOV: not mentioned							
				Voxel: not mentioned	Voxel: not mentioned							
				Scan time: not mentioned	Scan time: not mentioned							

Note: Here, CBCT stands for cone-beam computed tomography, CT for computed tomography, PAN for panoramic radiograph, TOMO for tomogram, and FOV for field of view

The low sensitivity of CBCT can significantly impact the diagnostic accuracy and treatment plan as well. However, studies indicate that larger voxel size, larger field of view, and image noises from the machine due to lack of calibration and patient movement during the scan may contribute to low sensitivity in detecting degenerative changes of the mandibular condyle [21, 24]. Additionally, the variability in the presentation of degenerative changes further may complicate the detection process [22]. For included studies, simulated mild surface osseous changes in samples and soft tissue compensation with water might be the reason for the low sensitivity for all imaging modalities [19]. However, it is known that the field of view can also affect sensitivity, which some investigators have not mentioned resulting in exclusion from the current meta-analyses [16, 17, 19]. The smaller field of view (FOV) with a smaller voxel size enhances the visualization and detail when evaluating defects on the condyle surface [21]. The FOV sizes varied substantially, with the smallest being 3 cm × 4 cm [17] and the largest being 17 cm × 13.2 cm [15]. While the differences in FOV were substantial, the variations in sensitivity were approximately 10%. A small FOV, along with a small voxel size, can produce outstanding sensitivity (100%) [12]. Advanced image processing techniques such as deep learning reconstruction algorithms and fractal analysis can enhance the diagnostic accuracy of CBCT to detect osseous alteration of the mandibular condyle [25, 26].

Out of the six studies reviewed, one presented a high risk of bias [17]; another study assessed bony changes, but failed to specify relevant forms such as erosion or osteophytes [11]. Additionally, one study focused solely on accuracy, omitting sensitivity and specificity values [16]. The study with unverifiable or inconsistent specificity values across different sections of the manuscript that could not be resolved through clarification from the corresponding author also needed to be excluded [13]. Only the remaining two studies were sufficiently homogenous to be included in the meta-analysis [18, 19]. This study exclusively included in vitro research, as such studies provide precise data on lesions due to the controlled, simulated conditions, allowing them to be considered gold standards for reference. In contrast, in vivo studies lack a true gold standard, making it difficult to accurately assess bone changes in real patients, which could influence sensitivity, specificity, and accuracy calculations.

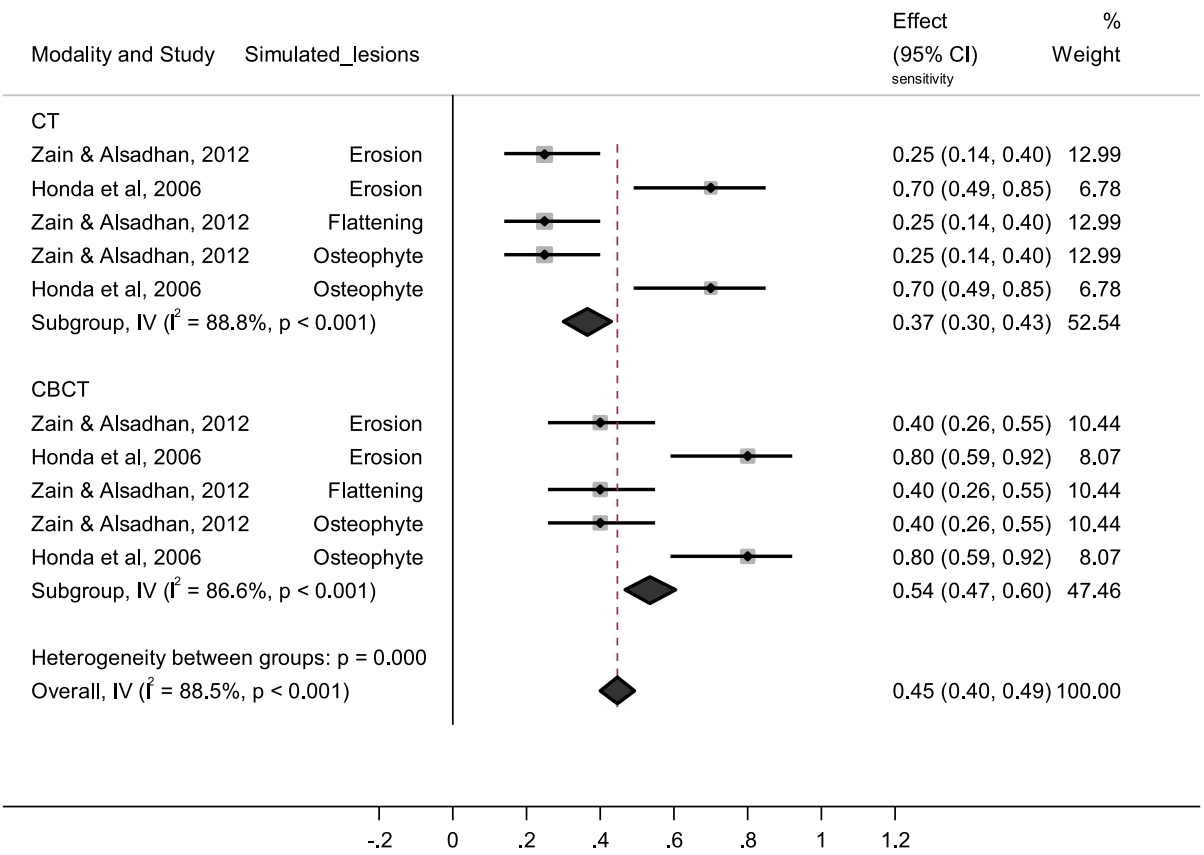

Fig. 3 Forest plot for sensitivity assessment, categorized by the type of imaging modalities and simulated lesion

However, dry human skulls in vitro may not fully replicate clinical conditions due to the absence of soft tissue, potentially leading to higher accuracy than in vivo studies. Additionally, the small sample sizes used in some studies [13, 19], limit the generalizability of the findings. One study employed gross examination of bone surface structures under a magnifying loupe with threefold magnification as the gold standard [19]. However, this level of detail may exceed the resolution of imaging modalities, making direct comparisons challenging and potentially limiting the clinical applicability of the findings. Several included studies assessed the detection rate of simulated defects of 1 mm [12, 13]. These conditions do not adequately reflect real-world clinical scenarios. Furthermore, Variations in CBCT devices, imaging protocols, and parameters (e.g., FOV, voxel size) across studies may also contribute to inconsistent diagnostic outcomes and high heterogeneity in the meta-analysis. While a funnel plot could theoretically assess publication bias, the limited number of studies restricts its reliability. This limitation underscores the need for standardized study protocols in future research.

Future research should address several key areas to improve the diagnostic accuracy and generalizability of CBCT. For example, conducting studies with larger sample sizes could provide more robust conclusions regarding the diagnostic accuracy of CBCT. This would help ensure the findings are generalizable to a broader population and clinical settings. While smaller FOV (field of view) and smaller voxel sizes are known to produce good scans, future research with similar voltage, FOV, and voxel size on different sample populations can minimize the heterogeneity of outcomes.

Conclusions

Based on the findings of the current review, the following conclusions were drawn:

1. Cone-beam computed tomography is more accurate in ruling out false positives, but there is a significant risk

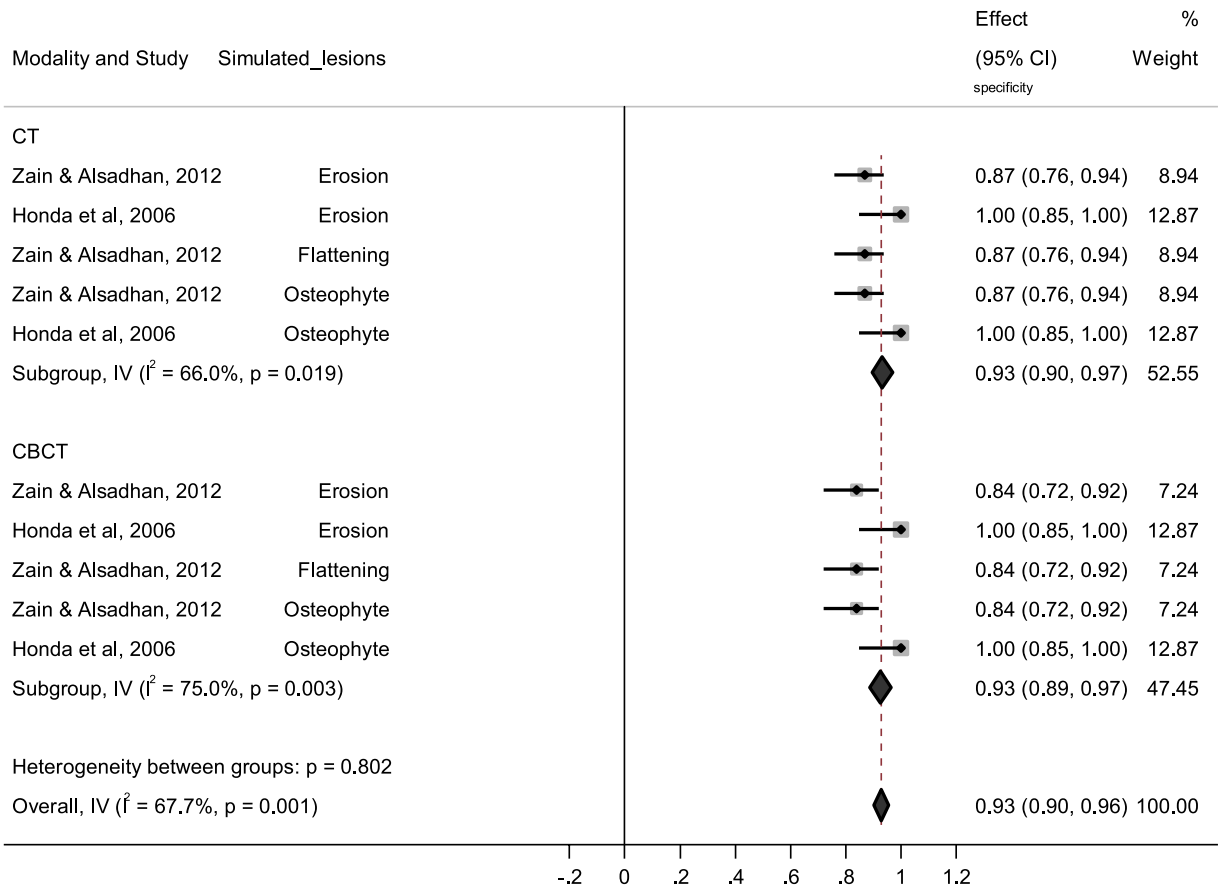

Fig. 4 Forest plot for specificity assessment, categorized by the type of imaging modalities and simulated lesion

of missing true positive cases of bony change of the mandibular condyle.
2. Cone-beam computed tomography is comparatively more accurate than computed tomography, panoramic, and tomogram in detecting condylar bony changes.
3. The smaller field of view and smaller voxel sizes can provide greater accuracy.

Acknowledgements The authors thank Al Mahmud from the School of Dental Science, Health Campus, Universiti Sains Malaysia, Kelantan 16150, Malaysia, for his statistical assistance. Nur Al Amin is the recipient of the Graduate Fellowship USM (GFUSM) Scholarship of Universiti Sains Malaysia.

Funding This research received no specific grant from public, commercial, or non-profit funding agencies.

Data availability The datasets generated and analyzed during the current study are available from the author upon reasonable request from the corresponding author.

Declarations

Conflict of interest The authors have no financial or personal relationships that could inappropriately influence or bias the content of this paper.

Ethical approval Not applicable.

Informed consent Not applicable.

Research involving human and animal participants This article does not contain any studies with human or animal subjects performed by any of the authors.

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