A Systematic Review on the Association Between Clinical Symptoms and CBCT Findings in Symptomatic TMJ Degenerative Joint Disease

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Submitted June 3, 2021; accepted July 23, 2021.

Aims: To evaluate the association between clinical signs/symptoms and bone changes on CBCT images in patients with degenerative joint disease (DJD) of the temporomandibular joint (TMJ). **Methods:** An electronic literature search of the MEDLINE, PubMed, EMBASE, Scopus, and Web of Science databases, as well as Google Scholar for gray literature, was conducted to identify relevant articles on February 26, 2021. Risk of bias was evaluated using the Joanna Briggs Institute critical appraisal tools. The GRADEpro (Recommendation, Assessment, Development, and Evaluation) system instrument was applied to assess the level of evidence across studies. **Results:** Nine papers assessing clinical signs/symptoms and CBCT findings were included. TMJ pain (arthralgia) and TMJ noises carried the strongest associations with various CBCT findings, each of which were supported by four studies with significant associations. Only one study found significant associations between masticatory myalgia (muscle pain) and CBCT findings. Range of motion carried no significant associations with CBCT findings in the included studies. Based on the GRADEpro system, the certainty of evidence is low for said associations. **Conclusion:** The results suggest that TMD patients with TMJ arthralgia and joint noises may benefit from CBCT imaging. There would be less benefit in TMD patients exhibiting primarily myalgia or limited range of motion, and therefore these patients should not be prescribed routine CBCT radiographs unless indicated by other clinical findings. The heterogeneity of reporting in the included studies suggests that embracing universal clinical (DC/TMD) and radiographic diagnostic criteria for TMJ-DJD would benefit both research and clinical outcomes. *J Oral Facial Pain Headache 2021;35:332–345. doi: 10.11607/ofph.2953*

The temporomandibular joint (TMJ) allows for several activities integral to daily living, and so dysfunction related to the TMJ and its surrounding structures/musculature can significantly impact an individual's life.[1,2] Temporomandibular disorder (TMD) is an umbrella term used for structural and/or functional disorders that affect the TMJ and the surrounding structures.[3] The overall prevalence of TMDs in adults has been estimated to be approximately 31%.[4]

Degenerative joint disease (DJD), also known as osteoarthritis, is a TMD associated with the breakdown of fibrocartilage and articular surfaces within the joint.[5,6] This disorder is characterized by excessive force and use of the TMJ, which overwhelm the joint's reparative capabilities.[7,8] According to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD),[9] DJD can be screened based on a patient's history and clinical examination. Clinically, a tentative diagnosis of TMJ-DJD is obtained when joint noise, known as crepitus, is noted during function/movement. However, imaging is utilized to obtain a definitive diagnosis, as imaging can provide useful information in detecting signs related to TMD-DJD. CBCT imaging is recommended for these purposes, as it is superior to conventional radiographic methods in assessing osseous TMJ abnormalities despite the higher dose of radiation associated with it.[10] Proper selection criteria for each patient should be met, and imaging parameters that are indication-oriented and patient-specific should be used to keep the radiation dose as low as diagnostically acceptable.[11,12] As such, the role of an oral and maxillofacial radiologist with clinical expertise in the field is important for the proper prescription

and interpretation of CBCT images.[13] These images are presented in three orthogonal planes, making them extremely useful for viewing complex structures such as the TMJ while keeping the radiation dose below that of a conventional computed tomography (CT) scan.[10,14,15] Therefore, CBCT is becoming increasingly widespread for TMJ imaging due to its reliable and diagnostic accuracy for assessing hard tissue/bone.[16]

According to the DC/TMD, when a diagnosis of DJD needs to be confirmed, the patient must be positive for at least one of the following findings on CT imaging: subchondral cyst(s), erosion(s), generalized sclerosis, or osteophyte(s).[9] It should be noted that these radiographic findings are used only for the above purpose of confirming a diagnosis of DJD and are not used to identify the extent of the disease. Although not part of the DC/TMD, various other radiographic changes and clinical findings can be seen in patients diagnosed with DJD, including flattening of the articular surfaces. In addition to these radiographic findings, patients can have a variety of clinical signs and symptoms, including TMJ arthralgia/capsulitis, masticatory myalgia, decreased mouth opening, and joint noises (eg, crepitus).[7,8,17]

DJD represents one of the most common pathologies affecting the TMJs, and, as such, understanding the pathophysiology behind it is fundamental for diagnosis and potential treatments.[2] Therefore, understanding of the different clinical and radiographic associations of DJD is an essential step toward earlier diagnosis and optimal management of the disease process by TMJ clinicians. Furthermore, this information may provide insight for oral and maxillofacial radiologists about the clinical signs and symptoms that TMJ-DJD patients may display when presenting for advanced imaging. This systematic review aims to investigate the existing literature and determine whether clinical signs and symptoms of TMJ-DJD are associated with changes seen on CBCT imaging. To the authors' knowledge, this is the first systematic review aiming to investigate associations between multiple different clinical signs/symptoms and multiple CBCT findings in TMJ-DJD patients.

Materials and Methods

Protocol and Registration

This systematic review was conducted following the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) principles and criteria.[18] The protocol was registered in PROSPERO (the International Prospective Register of Systematic Reviews) under number CRD42020189096.

Eligibility Criteria

Study design. A systematic review of human studies was undertaken to evaluate the association between TMJ-DJD radiographic changes and any DJD signs/symptoms. The research question was explored using the PICOS acronym, as follows:

- Participants = patients with TMD symptoms and DJD
- Intervention/exposure = CBCT imaging
- Comparison/control (N/A)
- Outcomes = association between clinical signs/symptoms of TMDs and CBCT imaging in patients with TMJ-DJD
- Study design = observational studies assessing the association between TMD symptoms and radiographic findings

Inclusion criteria. Results included from the search were studies including TMJ CBCT results in patients with TMDs; more specifically, patients with TMJ-DJD. Furthermore, studies were only included if clinical signs and symptoms of these patients were reported. Patients were above the age of 16 years, and observational studies in Roman alphabet languages were included.

Exclusion criteria. The following criteria were used for exclusion: reviews, letters, conference abstracts, personal opinions, book chapters, in vitro or in vivo animal studies, protocols, case reports, case series, and studies with in vitro phantom or in vivo animal models. Studies without relevant CBCT findings were excluded, as were studies with patients under the age of 16. Studies without specific TMD signs/symptoms and/or radiographic findings were excluded for not having relevant information. If there were incomplete data in any paper, that paper was excluded. Non–Roman alphabet language studies were excluded, as were papers that could not be acquired even after contacting the authors. Finally, studies with patients with nonosteoarthritic issues, including congenital changes, were not included in an attempt to achieve homogeneity in the patient population.

Search strategy. An electronic search for relevant studies was conducted on February 26, 2021, in the following databases: Medline, PubMed, Embase, Scopus, and Web of Science. Google Scholar was used to perform a gray literature search. Appropriate search terms (word combinations and truncations) were organized for each database (Appendix 1). The references were organized, and duplicates were removed using the reference manager software Covidence (Covidence systematic review software, Veritas Health Innovation; available at www.covidence.org).

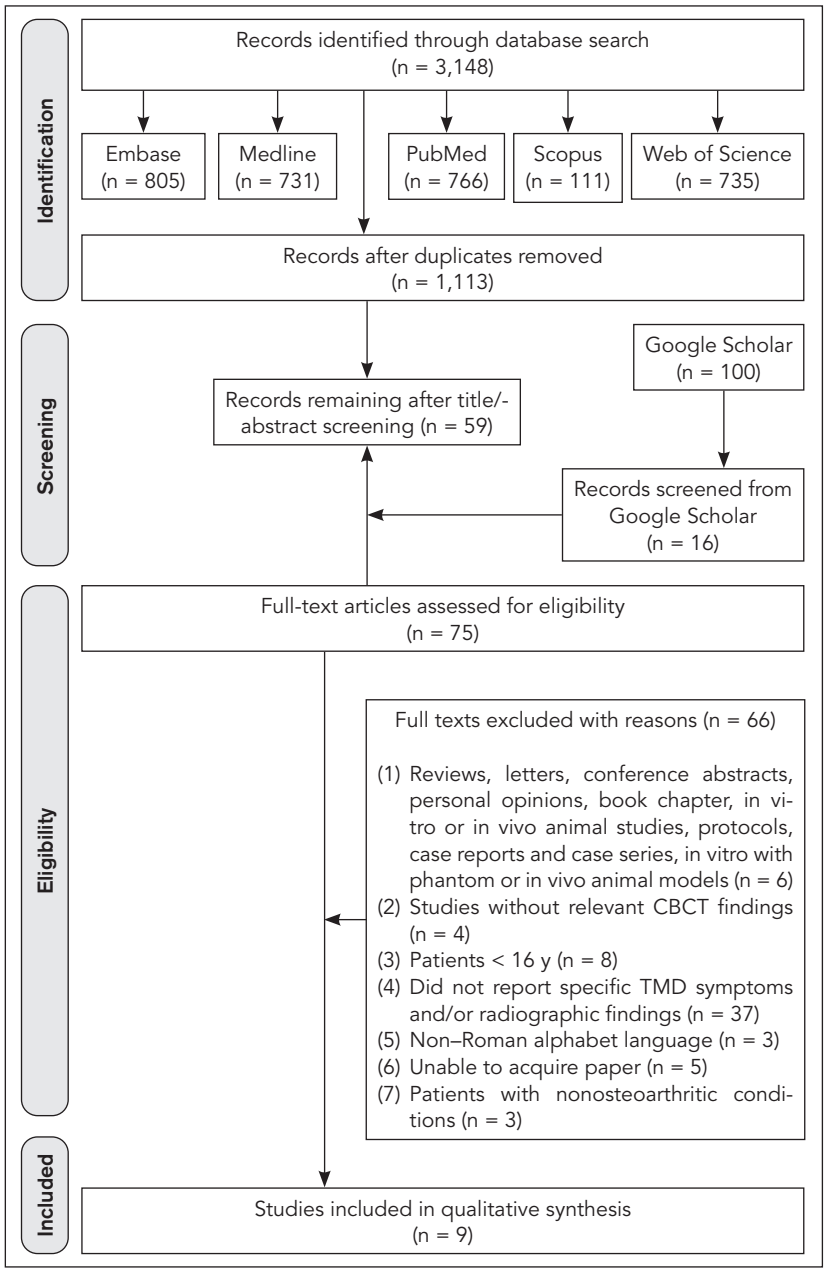

Fig 1 PRISMA flowchart of literature search and selection criteria.

Study selection. Two reviewers (R.F. and M.W.) conducted a two-phase review process for selection of the final articles to be included. In the first phase, all titles and abstracts were screened according to the eligibility criteria. In the second phase, full texts of the articles deemed appropriate from the first phase were retrieved and analyzed by the same reviewers using the same eligibility criteria. If there was a conflict at either phase, a third reviewer (F.T.A.) resolved the issue, and the final decision was made upon discussion.

Data collection process. The following data were collected by one author (M.W.): study characteristics (including author, year of publication, and country the study was conducted in), characteristics of the study population, sample size, age range, clinical signs and symptoms, CBCT findings, and any other relevant outcomes from the studies. The data collected can be found in Table 1 and were reviewed by the other two authors (R.F. and F.T.A.).

Risk of bias assessment and applicability. Upon completion of study selection, risk of bias assessment was conducted according to the Joanna Briggs Institute Checklist for Systematic Reviews and Research Syntheses tool.[19] Risk of bias assessment for cross-sectional studies and case-control studies was applied. Two reviewers (R.F. and M.W.) assessed each study independently. For each study, each of the categories in the risk of bias assessments was classified as "yes," "no," "unclear," or "not applicable." Risk of bias was considered high when a study was scored "yes" on up to 49% of the categories, moderate when this score was between 50% and 69%, and low when this score was at least 70%. In case of a disagreement between the two reviewers, disagreements were resolved with input from the third reviewer (F.T.A).

To assess risk of bias across the different studies, clinical (by comparing variability among the participant characteristics and outcomes studied), methodologic (by comparing the variability in study design and risk of bias), and statistical analysis heterogeneities were considered.

Summary measures and approach to synthesis. The primary outcome of interest in this study was the association between clinical signs/symptoms and CBCT findings in TMJ-DJD. Due to substantial methodologic and clinical heterogeneity among the included studies when evaluating and describing the clinical symptoms and CBCT findings of TMJ-DJD, a quantitative analysis was prevented. An assessment of the overall certainty of evidence was conducted using the GRADEpro criteria (Grading of Recommendations Assessment, Development, and Evaluation).

Results

Study Selection

The electronic database search yielded a total of 3,148 results, of which 1,113 were duplicates. After screening of titles and abstracts, 59 full-text articles were assessed for eligibility. The titles and abstracts of an additional 100 articles from the gray literature search were screened, and 16 full-text articles resulting from this gray literature search were also assessed for eligibility. In total, 75 full-text studies were screened in phase 2. Finally, according to the inclusion and exclusion criteria, 9 articles were selected for inclusion. Figure 1 demonstrates this process. Excluded studies and reasons for exclusion are shown in Appendix 2.

Study Characteristics

Across the 9 included studies, there were 697 total subjects, with 528 women and 169 men. Sample sizes ranged from 30 to 198, and the mean ages ranged from 27.6 to 71.3 years. The included studies were observational studies conducted in different countries, including Saudi Arabia, Norway, Thailand, Brazil, Austria, Iran, South Korea, and the United States.

Each of the included studies comprised CBCT scans of the TMJ with specific findings, such as erosion, sclerosis, osteophytes, articular eminence flattening, and cysts, and each of the included studies reported clinical signs and symptoms relating to DJD, such as joint pain, muscle pain, maximum mouth opening, crepitus, and other joint noises. Abrahamsson et al[20] is the only exception in which specific radiographic findings were not disclosed and were instead classified as radiographic findings according to Ahmad et al.[21] The categories described by Ahmad et al for DJD patients include the presence of subcortical cysts, surface erosions, osteophytes, and generalized sclerosis.[21] Furthermore, Palconet et al[6] used the Ahmad et al[21] classification and the Koyama et al[22] criteria for reporting of the results and associations. The main findings of the studies are presented in Table 1.

Risk of Bias

The risk of bias assessment following the Joanna Briggs Institute Checklist for Systematic Reviews and Research Syntheses tool can be found in Appendix 3. A score out of 8 was given, and the proportion of questions answered "yes" was used to determine the risk of bias. Eight studies[1,5–7,23–26] scored a low risk of bias, and one study[20] scored a moderate risk of bias.

Synthesis of Results

Due to substantial methodologic and clinical heterogeneity among the studies, a quantitative combination of data through a meta-analysis was prevented; therefore, a qualitative analysis of the information collected was conducted instead.

Results of Individual Studies

TMJ arthralgia x CBCT findings. TMJ pain was positively associated with CBCT findings in four studies.[1,20,24,25] Joint pain (TMJ arthralgia) on clinical examination was found to be associated with two different radiographic findings, including loss of cortication ($P = .046$)[1] and condylar erosion ($P < .001$).[24] Furthermore, Emshoff et al graded the severity of TMJ condylar erosion (with grade 0 being a lack of erosion and grade III being extensive erosion) and found a strong and statistically significant association between patients with condylar erosion grade II and TMJ arthralgia ($P = .023$), as well as a significant increase in the risk of TMJ arthralgia associated with condylar erosion grade III ($P < .001$).[24] Also found was a statistically significant positive association between self-reported pain on mouth opening and osteoarthritic patients, where osteoarthritic patients were classified as having deformations of the TMJ due to subcortical cysts, surface erosion, osteophytes, or generalized sclerosis ($P < .05$).[20] Other study findings included a weak association between bony condylar changes and self-reported pain,[6] while others suggested no associations between TMJ arthralgia and DJD findings.[5,7,23]

Masticatory muscle pain x CBCT findings. Masticatory muscle pain was noted in association with radiographic changes in one study. A positive statistically significant association was found between masticatory muscle pain on palpation and condylar osteophytes ($P = .039$).[25] Two studies found no significant associations between CBCT findings and muscle pain.[6,20]

Joint noises x CBCT findings. Joint noises and radiographic findings were positively associated in three studies,[7,20,25] while negative associations were found in one study.[1] Significant positive associations between TMJ crepitus detected upon clinical examination and subchondral sclerosis ($P = .00$), subchondral cysts ($P = .04$), and erosion ($P = .00$) were found.[7] Two studies found significant positive associations between crepitus and osteophyte formation ($P = .01$, $P = .010$).[7,25] Self-reported clicking ($P < .05$), self-reported crepitus ($P < .05$), and crepitus detected upon clinical examination ($P < .05$) were associated with osteoarthritic patients, where osteoarthritic patients were defined as those with deformations of the TMJ due to subcortical cysts, surface erosion, osteophytes, or generalized sclerosis.[20] There were significant negative associations between TMJ clicking and articular eminence flattening ($P = .009$), wide joint space ($P = .048$), erosion ($P = .046$), and sclerosis ($P = .042$)

Table 1 Summary of Descriptive Characteristics of Included Articles

Study characteristics		Sample characteristics			Intervention characteristics		Outcomes (correlations, r^2)
Study, y	Country	Population studied	Sample size, N	Age range or mean age (y)	Clinical signs/ symptoms	CBCT findings	Main results
Abdel-Alim et al,[1] 2020	Saudi Arabia	Patients who presented to OS department with TMJ symptoms	F = 46 M = 14	F = 26.8 M = 30.1 Overall = 27.6	TMJ pain, joint sounds, limited mouth opening	Loss of cortication, condylar/AE flattening, narrow/wide joint space, erosion, osteophytes, sclerosis, subchondral erosion, joint mice	Significant correlation between loss of cortication and pain (P = .046). TMJ clicking was negatively correlated with AE flattening (P = .009), wide joint space (P = .048), erosion (P = .046), and sclerosis (P = .042). Remaining correlations were not statistically significant.
Abrahamsson et al,[20] 2017	Norway	Patients from a rheumatology clinic at Diakinhjemmet Hospital	F = 48 M = 6	Mean = 71.3	Self-reported pain at rest/mouth opening/chewing, self-reported jaw locking and noises, masseter/temporalis muscle pain on palpation, TMJ pain on palpation, TMJ noises, unassisted MMO	Specific CBCT findings are not reported; patients were classified as OA, non-OA, or indeterminate for OA	Statistically significant difference in self-reported pain on mouth opening (P < .05). Statistically significant difference in self-reported experience of clicking (P < .05). Statistically significant difference in self-reported experience of crepitus (P < .05). Significant association on clinical examination between crepitus and TMJ OA (P < .05). No statistically significant difference in mouth opening.
Arayasantiparb et al,[7] 2020	Thailand	Patients who underwent TMJ CBCT examination	F = 67 M = 6	Mean (SEM) = 38.95 (1.76)	Joint noise, joint pain, ROM	Generalized subchondral sclerosis, osteophytes, condylar erosion, subchondral cysts, condylar flattening	Statistically significant association between crepitation and generalized subchondral sclerosis (P = .00), subchondral cysts (P = .04), erosion (P = .00), and osteophyte formation (P = .01). Remaining correlations were not statistically significant.
da-Silva et al,[23] 2020	Brazil	Patients at the radiology department at the School of Dentistry	F = 34 M = 4	Mean = 48.8 ± 9.2	Joint pain on lateral and intra-auricular palpation, joint pain on excursive and opening movements	Condylar and articular eminence flattening, erosion, osteophytes, sclerosis	There was no significant correlation between the presence of symptoms and image-based changes (P = .5374).
Emshoff et al,[24] 2016	Austria	Chronic TMJ arthralgia patients and patients without pain undergoing CBCT	Chronic arthralgia: F = 92 M = 7 Without arthralgia: F = 56 M = 43	Chronic arthralgia: Mean = 37 Without arthralgia: Mean = 37.4 Mean = 37.2	Arthralgia	Condylar erosion	Significant association between TMJ arthralgia and condylar erosion (P < .001). Significant association between TMJ with condylar erosion grade II and TMJ arthralgia (P = .023). Significant increase in the risk of TMJ arthralgia occurred with condylar erosion grade III (P < .001).

(continued)

Table 1 Summary of Descriptive Characteristics of Included Articles *(continued)*

Study characteristics		Sample characteristics			Intervention characteristics		Outcomes (correlations, r^2)
Study, y	Country	Population studied	Sample size, N	Age range or mean age (y)	Clinical signs/ symptoms	CBCT findings	Main results
Imanimoghaddam et al,[25] 2017	Iran	Patients with TMD symptoms attending Iranian dental school	F = 22 M = 19	Mean = 42.5 ± 27.5	MMO, myofascial pain during rest and function, pain on palpation of the masticatory muscles/regions, TMJ pain and sounds	Condylar erosion, sclerosis, osteophytes, resorption, flattening, AJS, PJS	Significant association between condylar osteophytes and masticatory muscle pain (*P* = .039). Significant association between crepitus and condylar osteophytes (*P* = .010). Remaining correlations were not statistically significant.
Lee et al,[26] 2019	South Korea	Patients with aTMD and cTMD diagnosed with TMJ pain condition arthralgia	aTMD: F = 28 M = 22 cTMD: F = 27 M = 23	Mean ± SD = 33.09 ± 13.92	MMO, range of protrusion and lateral excursion, self-reported duration of pain in the masticatory muscles and TMJ, self-reported pain intensity	Condylar flattening, erosion, osteophytes, sclerosis, subchondral cysts, AJS, PJS	Presence of bony changes not related to decreased AJS. Decreased AJS negatively correlated with TMJ DI in cTMD patients (*P* < .01). Decreased PJS associated with increased PI (*P* = .039) and CMI (*P* = .032). VAS values (subjective discomfort) not related to AJS/PJS changes but significantly and positively correlated with PI (*P* < .01), DI (*P* < .01), and CMI (*P* < .01). Proportion of CBCT bony changes did not differ significantly between groups.
Lee et al,[5] 2017	USA	Patients at University of Washington School of Dentistry	Control: F = 34 M = 9 Unilateral OA: F = 48 M = 12	Control: Mean = 54 Unilateral OA: Mean = 60	Crepitus, ROM, self-reported joint pain	Condylar osteophytes, erosion, sclerosis, flattening, subcortical cysts, condylar angle; AE erosion, flattening, and sclerosis	In OA joints, AE flattening (*P* = .02)/erosion (*P* = .04) was associated with a significantly greater condylar angle. No significant difference in condylar angle in patients with/without subjective pain, limited ROM, or presence of joint sounds.
Palconet et al,[6] 2012	USA	TMJ OA patients	F = 26 M = 4	Mean = 41	Self-reported pain, MMO, TMJ and muscle pain on palpation and function, crepitus	Condylar flattening, erosion, osteophytes; glenoid fossa flattening, erosion, sclerosis	Poor correlation between maximum condyle bony change and verbal pain rating. Remaining correlations were not statistically significant.

AE = articular eminence; AJS = anterior joint space; aTMD = acute TMD; CMI = craniomandibular index; cTMD = chronic TMD; DI = dysfunction index; MMO = maximum mouth opening; OA = osteoarthritis; PI = palpation index; PJS = posterior joint space; RDC = research diagnostic criteria; ROM = range of movement; OS = oral surgery; TMD = temporomandibular disorders; TMJ = temporomandibular joint.

according to one study.[1] Others found no significant associations between joint noises and CBCT findings.[5,6]

Range of motion and CBCT findings. Range of motion and CBCT findings were examined in six studies, but no statistically significant findings were noted.[1,5–7,20,25] The CBCT findings explored by the six

studies were loss of cortication, condylar flattening, articular eminence flattening, joint space alterations, erosions, osteophytes, sclerosis, resorption, and subchondral/subcortical cysts.

Risk of bias across studies. Although all studies were observational, heterogeneity between them was found. The concern identified was related to the variability of the criteria used to define DJD clinical assessment and the criteria for interpretation of CBCT findings, leading to a publication bias.

Level of evidence. Overall, the quality of evidence from the outcomes evaluated by the GRADE system was assessed as low (Appendix 4), suggesting low confidence in the estimated effect from the outcomes evaluated. Heterogeneity was the main factor responsible for the limited quality of the evidence.

Discussion

This systematic review aimed to determine associations between clinical signs/symptoms and CBCT bone changes of TMD patients with DJD. These findings can be used to help dictate clinical decision-making and to determine the best indications for advanced imaging in TMD patients. The main findings of this review were that the associations between clinical and radiographic findings exist for certain clinical parameters and that using these parameters for a basis of prescribing CBCT imaging can benefit patients and clinicians. There were significantly more women in this study population, consistent with the demographics for TMDs.

TMJ pain (arthralgia) and joint noises carried the strongest associations with CBCT findings,[1,7,20,24,25] while range of movement had no associations with radiographic findings.[1,5–7,20,25] Furthermore, one study demonstrated that radiographic changes—specifically changes in the anterior joint space—in TMD patients were associated with patient dysfunction (a combination of pain and limitation in TMJ range of movement), which is a vital clinically applicable finding.[26]

Of the eight studies examining TMJ pain, four found statistical associations between pain and CBCT bone changes.[1,20,24,25] TMJ erosive changes, including condylar erosion or loss of cortication, were the bone changes showing the strongest association with TMJ arthralgia. Some evidence suggests that the more severe the erosive process, the more intense the arthralgia. It should be noted that four studies found no associations.[5,7,20,23] Therefore, with further research on the topic, the early detection of CBCT erosive destruction may prove to be an important finding in managing TMJ pain in DJD patients.

Joint noises were examined in six studies, half of which found positive associations with CBCT findings.[7,20,25] It should also be noted that the remaining three studies found no significant positive associations.[1,5,6] Therefore, patients presenting with joint noises may benefit from CBCT imaging, although further studies would be required to confirm these potential associations. Unfortunately, joint noises were broadly categorized with little description of the noises, and some studies interchangeably defined clicking and crepitus.[7,20,25] These inconsistencies limited the present analysis. As the current DC/TMD recognizes crepitus as the only diagnostic clinical sign/symptom of DJD,[9] assessing for crepitus is of the utmost importance for reaching an appropriate diagnosis. These findings suggest the need for standardization and calibration in the assessment of TMJ noises in clinical research to categorize these signs and symptoms more accurately, providing important supplemental information for diagnosis.[23] Ensuring clinicians can differentiate between TMJ clicking associated with disc displacement and crepitus associated with DJD is important when prescribing CBCT imaging. These limitations also suggest the need for additional research on the topic.

Masticatory muscle pain was correlated with CBCT findings, particularly condylar osteophytes, in only one study,[25] whereas two studies found no significant associations between myalgia and CBCT findings.[6,20] Associations between range of motion alterations and DJD findings were not found in six different studies.[1,5–7,20,25]

The present findings suggest that advanced CBCT imaging should perhaps be selectively acquired in patients exhibiting TMJ arthralgia and joint noises, particularly crepitus, when patients present with TMD symptoms. Patients exclusively exhibiting muscle pain or reduced range of motion may benefit less from this image modality. Though the overall quality of evidence was assessed as low, the largest sample size and number of associations were associated with arthralgia, followed by joint noises; therefore, the potential benefit that patients may obtain from CBCT is suggested to be higher for these conditions.

The studies in this review only examined patients who experienced painful symptoms. According to the DC/TMD, this criterion is somewhat limiting, as pain is not a diagnostic sign or symptom of DJD.[9] Therefore, of the entire patient DJD patient population, only a subset was assessed. As seen in other studies, there may be many CBCT-confirmed, asymptomatic DJD patients.[27] Broader studies examining all patients diagnosed by CBCT as having DJD, and not only patients suffering from TMD pain, would give more insight into this association.

Some limitations of the included studies should be considered, such as the lack of specific radio-

graphic findings and the absence of well-defined image analysis criteria. Another limitation is the variability in classification of clinical signs and symptoms. The classification of pain severity and type was heterogenous and varied between studies, and classification of joint noises also varied in descriptions between studies. Orofacial pain, a subjective finding that can be influenced by an individual's cognitive response, was assessed differently depending on the study.[28] Information about whether pain was clinically determined during examination or self-reported during history-taking was not included in one study.[1] Those studies in which only self-reported pain was assessed demonstrate the need for more extensive studies to utilize an objective, standardized clinical examination to confirm the nature and location of the pain. Utilizing a standardized approach across all TMD research would improve the homogeneity of the data and make comparisons appropriate. The adoption of the DC/TMD criteria put forth by Schiffman et al would ameliorate this problem, allowing more objective and consistent patient evaluation for clinical and research purposes.[9]

Although the heterogeneity of the results was such that a meta-analysis was not performed, the presence of associations between some TMD symptoms and DJD CBCT findings suggest that further research should be done to increase said analyses' strength. The variability in descriptions of signs and symptoms should be reduced by standardization and calibration; as noted, adoption of the DC/TMD criteria has not been universal. Future studies on this topic should also include nonpainful TMD-DJD patient populations. Regarding CBCT degenerative bone changes, an inclusive, standardized approach for proper TMJ-DJD imaging evaluation should be more universally applied to improve the clinical assessment of patients who present for oral medicine and oral and maxillofacial radiologic examination, thereby facilitating the optimal treatment of these patients.

Conclusions

The results of the included studies suggest that TMD patients exhibiting TMJ arthralgia and joint noises (crepitus) may benefit from CBCT imaging. TMD patients primarily suffering from muscle pain or limitation in mouth opening should not be routinely prescribed CBCT imaging unless dictated by other clinical indications, as they may not benefit from said imaging. Further studies should be conducted to confirm the possible benefits of CBCT imaging in these patients. Embracing universal clinical (DC/TMD) and radiographic diagnostic criteria for TMJ-DJD will benefit clinical and research outcomes and advance understanding of this common disease process.

Key Findings

- In patients suffering from TMDs, CBCT imaging should be selectively prescribed in patients suffering from arthralgia or exhibiting joint noises, particularly crepitus.
- Masticatory myalgia as a stand-alone feature does not require CBCT imaging.

Acknowledgments

Financial support was received from the School of Dentistry, University of Alberta, Edmonton, Alberta Canada through the Summer Student Research Grant. The authors report no conflicts of interest.

Author contributions: All three authors contributed equally to planning of the study and analysis of the data. M.W.: primary author, reviewed all articles for inclusion in the review; R.F.: reviewed all articles for inclusion in the review, review and editing of the manuscript; F.T.A.: third reviewer for addressing any conflicts, review and editing of the manuscript.

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Appendix 1 Search Strategies with Appropriate Keywords and MeSH Terms

Database	Search strategy
Medline	Temporomandibular joint or temporomandibular joint disorders or temporomandibular joint disc or TMJ or TMD or TMJD AND cone beam computed tomography or CBCT or digital volumetric tomography or volumetric computed tomography or cone beam computer assisted tomography
PubMed	Temporomandibular Joint Disorders or Temporomandibular Joint or Temporomandibular Joint Disc or Temporomandibular or temporo-mandibular or craniomandibular or cranio-mandibular or TMJ or TMD or TMJD or osteoarthritis AND CBCT or cone beam computed tomography or cone beam CT
Embase	Temporomandibular joint or temporomandibular joint disorders or temporomandibular joint disc or TMJ or TMD or TMJD and cone beam computed tomography or CBCT or digital volumetric tomography or volumetric computed tomography or cone beam computer assisted tomography
Scopus	Temporomandibular Joint Disorders or Temporomandibular Joint or Temporomandibular Joint Disc or Temporomandibular or temporo-mandibular or craniomandibular or cranio-mandibular or Costen syndrome or TMJ or TMD or TMJD or osteoarthritis AND CBCT or cone beam computed tomography or cone beam CT
Web of Science	Temporomandibular Joint Disorders or Temporomandibular Joint or Temporomandibular Joint Disc or Temporomandibular or temporo-mandibular or craniomandibular or cranio-mandibular or Costen syndrome or TMJ or TMD or TMJD or Temporomandibular disorder or TMJ osteoarthritis AND CBCT or cone beam computed tomography or cone beam CT
Google Scholar	TMJ AND CBCT

Appendix 2 Excluded Articles and Reasons for Exclusion

Study, y	Reason for exclusion
Aboalnaga et al,[1] 2019; Bakke et al,[12] 2014; de Holanda et al,[21] 2018; Li et al,[48] 2015	No relevant CBCT findings
Agirman and Çakur,[2] 2019; Al-Ekrish et al,[3] 2015; Al-Ekrish et al,[4] 2017; Al-Rawi et al,[5] 2017; Alexiou et al,[6] 2009; Alkhader et al,[7] 2012; Alkhader et al,[8] 2010; Alves et al,[9] 2014; Alves et al,[10] 2013; Borahan et al,[14] 2016; Çağlayan et al,[15] 2014; Çakur and Bayrakdar,[16] 2016; Cevidanes et al,[17] 2014; Choudhary et al,[18] 2020; Derwich et al,[22] 2020; Dumbuya et al,[24] 2020; Gomes et al,[29] 2015; Im et al,[33] 2018; Imanimoghaddam et al,[34] 2018; Jeon et al,[37] 2020; Kayipmaz et al,[38] 2019; Khojastepour et al,[39] 2019; Khojastepour et al,[40] 2017; Cömert Kiliç S et al,[41] 2015; Koç,[42] 2020; Kristensen et al,[44] 2017; Lei et al,[45] 2017; Lelis et al,[46] 2015; Li et al,[47] 2015; Liang et al,[49] 2017; Nah,[51] 2012; Paknahad et al,[52] 2016; Paknahad and Shahidi,[53] 2015; Paknahad et al,[54] 2015; Resnick et al,[56] 2017; Shahab et al,[58] 2017; Shahidi et al,[59] 2018; Shahidi et al,[60] 2013; Su et al,[62] 2014; Talaat et al,[63] 2016; Tran-Duy et al,[64] 2020; Yasa and Akgul,[66] 2018	No specific TMD symptoms and/or radiographic findings
Bae et al,[11] 2017; Ferraz et al,[25] 2012; Iordache et al,[35] 2017	Patients < 16 y
Barghan et al,[13] 2012; de Boer et al,[20] 2014; Derwich et al,[23] 2020; Jayachandran and Khobre,[36] 2016; Kothari et al,[43] 2016; Santos et al,[57] 2019	Review, letter, conference abstract, personal opinion, book chapter, in vitro or in vivo animal study, protocol, case report, case series, in vitro study with phantom or in vivo animal models
Cordeiro et al,[19] 2016; Glerup et al,[28] 2020; Rehan et al,[55] 2018	Patients with nonosteoarthritic conditions
Frazier and Spencer,[26] 2019; Idan and Al-Aswad,[32] 2019; Moon-Soo et al,[50] 2019; Stoustrup et al,[61] 2016; Wiese et al,[65] 2008	Unable to acquire paper
Fu et al,[27] 2007; Han et al,[30] 2017; Han et al,[31] 2016	Non–Roman alphabet language

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Appendix 3a Risk of Bias in Individual Studies According to the Joanna Briggs Institute Checklist for Cross-Sectional Studies

Item	Abdel-Alim et al,[1] 2020	Abrahamsson et al,[20] 2017	Arayasantiparb et al,[7] 2020	da-Silva et al,[23] 2020	Imanimoghaddam et al,[25] 2017	Lee et al,[26] 2019	Palconet et al,[6] 2012
1. Were the criteria for inclusion in the sample clearly defined?	Y	U	Y	Y	Y	Y	Y
2. Were the study subjects and the setting described in detail?	Y	Y	Y	Y	Y	Y	Y
3. Was the exposure measured in a valid and reliable way?	Y	Y	Y	Y	Y	Y	Y
4. Were objective, standard criteria used for measurement of the condition?	Y	Y	Y	Y	Y	Y	Y
5. Were confounding factors identified?	NA	NA	NA	NA	NA	NA	NA
6. Were strategies to deal with confounding factors stated?	NA	NA	NA	NA	NA	NA	NA
7. Were the outcomes measured in a valid and reliable way?	Y	Y	Y	Y	Y	Y	Y
8. Was appropriate statistical analysis used?	Y	Y	Y	Y	Y	Y	Y
Overall risk of bias (Low/moderate/high)	Low	Moderate	Low	Low	Low	Low	Low

Y = yes; N = no; U = unclear; NA = not available.

Appendix 3b Risk of Bias in Individual Studies According to the Joanna Briggs Institute Checklist for Case-Control Studies

Item	Emshoff et al,[24] 2016	Lee et al,[5] 2017
1. Were the groups comparable other than the presence of disease in cases or the absence of disease in controls?	Y	Y
2. Were cases and controls matched appropriately?	Y	Y
3. Were the same criteria used for identification of cases and controls?	Y	Y
4. Was exposure measured in a standard, valid, and reliable way?	Y	Y
5. Was exposure measured in the same way for cases and controls?	Y	Y
6. Were confounding factors identified?	NA	NA
7. Were strategies to deal with confounding factors stated?	NA	NA
8. Were outcomes assessed in a standard, valid, and reliable way for cases and controls?	Y	Y
9. Was the exposure period of interest long enough to be meaningful?	Y	Y
10. Was appropriate statistical analysis used?	Y	Y
Overall risk of bias (Low/moderate/high)	Low	Low

Y = yes; N = no; U = unclear; NA = not available.

Appendix 4 GRADE Summary of Findings Table

Outcomes	No. of participants (studies)	Certainty of the evidence (GRADE)	Impact
TMJ arthralgia	597 (8 observational studies)	⊕⊕◯◯ LOW	Abdel-Alim et al[1] (2020): TMJ arthralgia & loss of cortication ($P = .046$). Abrahamsson et al[20] (2017): Self-reported pain and subcortical cysts, surface erosion, osteophytes, general sclerosis ($P < .05$). TMJ pain on palpation showed no significant correlations. Arayasantiparb et al[7] (2020): No significant correlations. da Silva et al[23] (2020): No significant correlations. Emshoff et al[24] (2016): TMJ arthralgia and condylar erosion ($P < .001$). Imanimoghaddam et al[25] (2017): No significant correlations. Lee et al[26] (2019): No significant correlations. Palconet et al[6] (2012): Weak, statistically insignificant correlations between self-reported pain and condylar bony changes.
Masticatory muscle pain (myalgia)	125 (3 observational studies)	⊕⊕◯◯ LOW	Abrahamsson et al[20] (2017): Masticatory muscle pain on palpation showed no significant correlations. Imanimoghaddam et al[25] (2017): Masticatory muscle pain and condylar osteophytes ($P = .039$). Palconet et al[6] (2012): No significant correlations.
TMJ noises	361 (6 observational studies)	⊕⊕◯◯ LOW	Abdel-Alim et al[1] (2020): Negative correlation between TMJ clicking and flattening ($P = .009$), wide joint space ($P = .048$), erosion ($P = .046$), sclerosis ($P = .042$). Abrahamsson et al[20] (2017): Self-reported clicking and crepitus and subcortical cysts, surface erosion, osteophytes, general sclerosis ($P < .05$). Arayasantiparb et al[7] (2020): TMJ crepitus and generalized subchondral sclerosis ($P = .00$), subchondral cysts ($P = .04$), erosion ($P = .00$), osteophyte formation ($P = .01$). Imanimoghaddam et al[25] (2017): TMJ crepitus and osteophyte formation ($P = .010$). Lee et al[26] (2019: No significant correlations. Palconet et al[6] (2012): No significant correlations.
Range of motion	361 (6 observational studies)	⊕⊕◯◯ LOW	Abdel-Alim et al[1] (2020): No significant correlations. Abrahamsson et al[20](2017): No significant correlations. Arayasantiparb et al[7] (2020): No significant correlations. Imanimoghaddam et al[25] (2017): No significant correlations. Lee et al[26] (2019): No significant correlations. Palconet et al[6] (2012): No significant correlations.
TMJ dysfunction indices	100 (1 observational study)	⊕⊕◯◯ LOW	Lee et al[26] (2019): Negative correlation between TMJ DI and decreased left anterior joint space ($P < .01$); TMJ PI and decreased right posterior joint space ($P = .039$); TMJ CMI and decreased right posterior joint space ($P = .032$).

*The risk in the intervention group (and its 95% CI) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI). CMI = craniomandibular index.

GRADE Working Group grades of evidence:

High certainty: We are very confident that the true effect lies close to that of the estimate of the effect.

Moderate certainty: We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different.

Low certainty: Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect.

Very low certainty: We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect.