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COMPARING THE SENSITIVITY AND SPECIFICITY OF CBCT AND MRI IN DETECTING OSTEOARTHRITIS OF THE TMJ: A SYSTEMATIC REVIEW

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science at Virginia Commonwealth University.

by

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List of Abbreviations

TMJ	Temporomandibular Joint
TMD	Temporomandibular Disorders
OA	Osteoarthritis
DJD	Degenerative Joint Disease
CBCT	Cone-beam Computed Tomography
MRI	Magnetic Resonance Imaging
CT	Computed Tomography
RDC/TMD	Research Diagnostic Criteria for Temporomandibular Disorders
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
PICO	Patient/Population, Intervention, Comparison, Outcome
MeSH	Medical Subject Headings

Abstract

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The aim of this systematic review was to compare the sensitivity and specificity of cone-beam computed tomography (CBCT) and magnetic resonance imaging (MRI) in detecting osteoarthritis (OA) of the temporomandibular joint (TMJ). This was done by using computed tomography (CT) and the research diagnostic criteria for temporomandibular disorders (RDC/TMD) as reference methods and using CBCT and MRI as index methods. A specific search strategy was developed and applied to these electronic databases: PubMed, Embase, DOSS, and Cochrane. The search results returned 802 articles, which were then narrowed down using the inclusion/exclusion criteria, to four final articles that were included in this review. Two of these articles used CBCT as

their index method, and the other two used MRI. The sensitivity and specificity for CBCT was calculated to be moderate. Regarding MRI, we were not able to retrieve the raw data necessary so sensitivity and specificity were unable to be calculated. It was concluded that while CBCT and MRI show promise in their use as a diagnostic tool in the diagnosis of OA of the TMJ, more studies are needed to fully evaluate their validity.

Introduction

The temporomandibular joint (TMJ) connects the mandible to the temporal bone of the skull and allows for the complex function of jaw movement. This is essential to a high quality of life and allows for functions such as mastication, communication, and yawning. Regarding joint movements, the TMJ allows for movements such as mandibular elevation, depression, protrusion, retrusion, and lateral deviation. The muscles involved that allow for these movements include the temporalis, masseter, and the lateral and medial pterygoid muscles. The TMJ is innervated by the mandibular and facial nerves[1]. Any problems affecting the TMJ can thus impact its functions negatively. Temporomandibular disorders (TMD) are defined as problems that affect the TMJ, the associated muscles, or any other hard or soft tissue components surrounding it[2]. Typical forms of TMD include arthralgia, myalgia, myofascial pain, disc displacement disorders, degenerative joint disease, subluxation, and headache attributed to TMD[3]. The combination of these problems can often result in a broad variety of disorders with a complex etiology, making it difficult to diagnose and treat properly. In order to help patients get the best care possible, it is essential to improve diagnostic ability of TMD.

One of the most common forms of TMD is osteoarthritis (OA), also known as degenerative joint disease (DJD). OA or DJD is characterized by the chronic degradation of the hard and soft tissues around a joint. This leads to symptoms such as pain and joint dysfunction[4]. OA is considered to be the most common joint disorder in the world, with the most commonly affected joints being the hands, hips, and knees[5]. It also tends to affect women more so than men, with the main cause believed to be hormonal factors[6].

Regarding OA of the TMJ, it is estimated to affect about 15% of the world's population and can be caused by various factors such as age, genetics, and trauma[7]. While its diagnosis may be more obvious in late-stage OA, its early stage is where the difficulty lies[8]. Treatment can include oral appliance therapy, pharmacotherapy, physical therapy, intraarticular injections, or surgery. Due to its broad factors of causation, shared symptoms with other TMD's, and its difficult diagnosis, it is critical that this topic is not overlooked to prevent patients from being undiagnosed or misdiagnosed.

Current diagnostic methodologies involve looking at the patient history and a physical exam[7]. In most instances, diagnostic imaging is used as an adjunct to confirming a clinical diagnosis. A panoramic radiograph is often used first for initial screening purposes. From there, a determination will be made to see if further imaging is required to confirm the diagnosis. Clinicians generally also use the research diagnostic criteria for temporomandibular disorders (RDC/TMD); a set of criteria created in 1992 to standardize processes for the diagnosis of TMD and assist clinicians in their diagnosis[3].

Various imaging modalities are used in the diagnosis of osteoarthritis. These range from the traditional modalities like panoramic imaging and computed tomography (CT), to newer modalities like magnetic resonance imaging (MRI) and cone-beam computed tomography (CBCT). A panoramic radiograph provides an overview of the dentition, jaws, and TMJs in one 2-D image. It is best used for general observation of structures, as its diagnostic value is limited due to superimposition of overlying bony structures and variable obliquity of the condyle[9]. Thus, it is often not enough to fully discern if OA is present[10]. However, it is readily available in most dental offices and is inexpensive.

Newer methods of diagnosis include using CBCT and MRI. In an effort to improve the diagnosis of OA of the TMJ and to prevent more misdiagnosed or undiagnosed patients, these are two imaging modalities that should not be overlooked. However, while there are studies that discuss their potential benefits, there are not many studies that provide definitive evidence as to which is the best modality in the detection of OA of the TMJ.

CBCT is an imaging technology that emits a cone-shaped source of ionizing radiation to produce multiple images, which are then stacked and reconstructed to obtain a 3D composite image[11]. This allows it to overcome many of the original limitations of the standard radiograph such as tissue overlapping and superimposition[12]. It can be used in various applications, including oral and maxillofacial surgery, endodontics, implant dentistry, orthodontics, periodontics, forensic dentistry, and TMJ imaging[13]. CBCT benefits in exceling in hard tissue visualization such as skeletal and dental tissues and is also cost-effective. However, CBCT uses radiation and artifacts involving image distortion can be an issue in images[14]. Compared to CT, CBCT machines are much smaller and affordable, allowing it to gain traction in the dental field around the late 1990's[11].

The application of MRI in dentistry has significantly increased in the recent years. MRI is an imaging technology that functions by generating a local magnetic field that aligns hydrogen nuclei to that field, then using radio frequencies to cause the nuclei to resonate. The movement of the particles back to their original state allows a detailed image to be produced[15]. MRI benefits in exceling in soft tissue visualization such as masticatory muscles, ligaments, and the cartilaginous disc of the TMJ, as well as not involving any radiation[14]. However, it is expensive and may be problematic for patients that have any metal-based implants or have claustrophobia. MRI machines are not currently found in dental offices due to their size and costs, making it not as readily available as CBCT machines. However, referring patients to an imaging center that has an MRI machine is an option if needed.

The typical imaging features of OA of the TMJ include articular surface flattening, sclerosis, cortical thickening and irregularity, osteophytes, subcortical lucencies (areas of low density), and ossified intra-articular bodies[9]. Therefore, the ability of an imaging modality to detect these features is crucial to have an accurate diagnosis of OA. The ideal choice would be an imaging modality that is able to detect the most features while having the highest accuracy.

There are also non-imaging methods to diagnose OA of the TMJ, such as arthroscopy. Arthroscopy is a minimally-invasive procedure that involves making a small incision at the joint and viewing it directly or through a camera for diagnosis. However, since newer non-invasive methods have been able to successfully manage OA of the TMJ, it is not seen as commonly today[8].

When comparing any two imaging modalities, a reference standard is needed to compare them. A reference method is important when comparing two different variables, as you need a standard or "true" value to have a baseline to compare to. We used computed tomography (CT) as one of our reference standards, as it is currently considered to be the gold standard for the diagnosis of DJD of the TMJ[16]. CT functions similarly to CBCT, involving multiple x-ray images being taken at different angles of a subject. However, it uses fan-beam x-rays, capturing multiple slices of the subject, resulting in a longer image acquisition process and thus higher radiation exposure[17].

The RDC/TMD criteria was also used as a reference method for the study, as it is a widely used diagnostic system used to assist in the classification of TMD, and has been demonstrated to be reliable. There is also a newer evidence-based version, termed the diagnostic criteria for temporomandibular disorders (DC/TMD), which was published in 2015. It is comprised of 2 assessment components: Axis I involves pain and joint assessment, while Axis II involves distress and pain disability[3]. Using these criteria has been recommended for use in clinical and research settings. The goal of DC/TMD is to standardize diagnostic criteria for classifying subtypes of TMD.

Sensitivity and specificity are the two main variables this study will focus on regarding the imaging modalities. Sensitivity is a measure of how often a test generates a positive result in those who actually have the condition, while specificity is a measure of how often a test generates a negative result in those who do not actually have the condition. In this study, we will use sensitivity and specificity to compare the two imaging modalities.

The aim of this study is to compare the sensitivity and specificity of CBCT and MRI in detecting osteoarthritis of the TMJ.

Methods

A systematic review is a type of review that follows a series of methodical steps to evaluate relevant current literature to answer a question or issue[18]. Its purpose is to summarize its findings to make evidence more accessible to other researchers and determine the current literature landscape of the topic. Our systematic review used a two-phase selection process following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. PRISMA is a guideline originally created in 2009 to improve the reporting of systematic reviews. It involves a checklist of items recommended to report in systematic reviews[19].

Focused question

Compare the sensitivity and specificity of CBCT and MRI in the diagnosis of OA of the TMJ.

Search strategy

First, we identified our research question using the PICO framework. PICO is a mnemonic device for population/problem, intervention/exposure, comparison, and outcome[20]. A PICO table was created, which involves a table that has the PICO criteria on one axis and our concepts and keywords for our question on the other. After working through the table, we identified our key concepts and were able to formulate a proper question for our search. We then developed our search strategy specifically for each database used in our search: PubMed, Embase, DOSS, and Cochrane. We did this by combining keywords, MeSH terms, and the appropriate search modifiers. Once the search query was finalized, we performed the search on all the databases and the results were compiled. A manual search of the reference lists of identified relevant articles was also performed, but no additional articles were found. A grey literature (literature published outside of traditional scientific journals) and hand search was not performed. The final electronic database search was conducted on December 01, 2020.

Management of references

References were managed through Mendeley, a reference manager software. Mendeley was used to document the articles that would be included in the paper. Any duplicate results were removed.

Inclusion/exclusion criteria

We made an inclusion/exclusion criteria to determine which articles would be most relevant to our study. The articles selected for this review contained and evaluated: (1) Osteoarthritis of the TMJ; (2) Involved the use of CBCT or MRI as the index method; (3) Used CT or RDC/TMD as a reference method; (4) Was an original in vivo clinical study; (5) Was conducted on live human participants; (6) Had a minimum of 10 participants; (7) Involved participants who are 18 and older; (8) Was published after the year 2000; (9) Was in English. The imaging features of the TMJ were also taken note of if available, such as condylar flattening, condylar erosion, osteophyte formation, joint effusion, sub-chondral cysts, and sclerosis of the condyle. These parameters were selected after we discussed and determined what factors would be important to our study.

We did not select articles for this review that only included articles that discussed only participants with trauma, infection, or a tumor of the TMJ, as well as any publications that were review papers, case reports, part of a conference summary, or posters.

Study selection

All articles were screened through a 2-stage process involving 2 independent reviewers (GRS and SAR). In the first stage of the screening, the title and abstract of each article were examined and evaluated against the inclusion/exclusion criteria. Articles that did not meet the criteria were not included in the study. After the initial title abstract review, a third independent reviewer (SB) was called in as a tiebreaker if there were any disagreement between the two reviewers. The same two reviewers participated in stage two of the screening process. The selected articles from stage one were independently reviewed and the full text was assessed. Final selection was based on determining if the articles met the criteria. The majority of the articles that did not pass the second stage of screen typically did not involve sensitivity and specificity of the compared imaging modalities, or did not use CT or RDC/TMD as the reference method.

Data extraction

The relevant information was collected from the included articles. This included the following data: study characteristics (authors, year of publication, study design), population characteristics (sample size, age of participants, sex) index method (CBCT, MRI), reference method (CT, RDC/TMD), and outcome characteristics. In the case of a couple articles, the required data was not able to be retrieved despite attempts in contacting the original authors.

Data synthesis & statistical analysis

Data were extracted and placed into Excel spreadsheets, where the appropriate summary statistics were calculated. The data were summarized with counts, percentages, or means and standard deviations, as appropriate. All analyses were performed by Excel or by SAS software (version 9.4, SAS Institute Inc., Cary NC). Meta-analysis was performed using the MetaDAS macro in SAS software[21]. Meta-analysis, in this case, combines the estimates of sensitivity and specificity across studies using a random-effects model to yield a single overall estimate.

Results

Study selection

The final database search yielded a total of 802 results after duplicates were removed. After the initial review of the title and abstracts, 780 articles were excluded, leaving 22 potential articles remaining. A full-text evaluation was then performed, which resulted in 18 more articles that were excluded. The references of these articles were also considered, but none met the required criteria. The remaining 4 articles were the articles that were included in this review. A flowchart summarizing the selection process is seen in Figure 1.

Study characteristics

The total sample size of all the studies was 1,563 subjects. The publishing range of the selected studies was between 2009 and 2018, with 2 of them being from the USA, 1 from Brazil, and 1 from the UAE. 2 studies used CT as their reference method, while the other 2 used RDC/TMD. CBCT was used in 2 studies as their index method, while MRI was used in 2 studies. Sample sizes ranged from 45 to 724. Due to one of the studies not providing demographic information, 839 participants were considered. From that population, 81% were females. From the original sample size, we also only considered patients that were classified with OA or osteoarthrosis of the TMJ. Control groups were included as well. The study characteristics of the selected articles are summarized in Table 1.

Results of individual studies

All of the selected studies used either CBCT or MRI to confirm a diagnostic test, using CT or RDC/TMD as the reference method. Some articles also discussed other results that were not relevant to our study, but we will focus on only the relevant parts in this study.

Ahmad et al.[22] aimed to develop comprehensive image analysis criteria for the RDC/TMD validation project. 724 study participants (1435 joints) were enrolled and assessed with CT and MR imaging. When referenced to CT imaging, it was concluded that MRI had poor to marginal sensitivity (59.4%, 95%CI=53.7 to 64.9%), but excellent specificity (98.0, 95%CI=97.0 to 98.8) in diagnosing OA of the TMJ.

Kaimal et al.[16] aimed to determine the diagnostic accuracy of MRI for detecting DJD of TMJ, using CT as a reference method. 705 subjects (1410 joints) were evaluated by CT and MR imaging. Imaging criteria was established that included subcortical cysts, erosion, osteophytes, and sclerosis. When compared against their target values for sensitivity and specificity, it was concluded that MRIs had below-target sensitivity but above-target specificity in detecting all the reference CT imaging criteria. Their results are summarized in Table 2. In this case, sensitivity is a measure of how often a MRI generates a positive sign of those with DJD in those who actually have the condition, while specificity is a measure of how often an MRI generates a negative sign of DJD in those who do not actually have the condition. Sensitivity ranged from 32% to 71%, depending upon the sign and specificity was at least 98% across all signs.

Dias et al.[23] aimed to evaluate the presence of degenerative bone changes of the TMJ in individuals with sleep bruxism (teeth grinding). 45 subjects were evaluated using

CBCT and RDC/TMD as the reference method (see Table 3). 19 subjects were classified with OA and 18 with osteoarthrosis in at least 1 of the joints. In the 19 subjects identified with OA by the reference method (RDC/TMD) only 10 were positive on the CBCT image, yielding a sensitivity of 53% (CI = 30 to 75%). In the 28 subjects without OA, 26 were negative on CBCT, yielding a specificity of 93% (CI = 83% to 100%). Dias et al. also observed that there was a high prevalence of degenerative changes with individuals who had OA of the TMJ.

Talaat et al.[24] aimed to compare bony changes of TMD using CBCT, using RDC/TMD as the reference method (see Table 4). 89 subjects were enrolled in the study and assessed using CBCT and classified based on their RDC/TMD diagnosis. 20 subjects were classified with OA according to RDC/TMD. In the 40 joints identified with OA by the reference method (RDC/TMD) 36 were positive on the CBCT image, yielding a sensitivity of 90% (CI = 81 to 99%). In the 86 joints in subjects without OA, 55 were negative on CBCT, yielding a specificity of 64% (CI = 54% to 74%). Talaat et al. concluded that assessment by CBCT showed a statistically significant difference between non-TMD and TMD joints. It was concluded that CBCT findings are significantly associated with the RDC/TMD clinical diagnosis of TMD.

Quantitative analysis

The results from the two CBCT studies were combined using meta-analysis software. The result is summarized in forest plots—a method for displaying the results of several papers into one image. The combined sensitivity across the Dias et al. and Talaat et al. studies was 76% (95% CI = 40% to 94%, Figure 2) and specificity was 84% (CI = 52% to 96%, Figure 3). In the forest plots the horizontal axis is the estimate of interest, here either the sensitivity or the specificity. The individual studies are ordered along the vertical axis, and the meta-analysis summary of all the studies appears at the bottom. The results appear in text—on the left side of the figure—and as lines—on the right side of the figure. The point estimate appears in the center of the line and the range estimate (the 95% confidence interval) appears as a line. The combined results—"Total" in the figure—appears as a line of greater thickness.

For example, the line for the combined estimate of sensitivity extends from a lower bound of 40% to an upper bound of 94% and is centered on the combined estimate of 76%. Informally, this combined estimate is formed by the meta-analysis "averaging" of the two study's individual values—53% and 90% in this case. Note that these disparate study findings result in a relatively wide confidence interval on the combined (total) estimate.

Discussion

There is a growing trend in the field of dentistry on the use of CBCT and MRI for diagnostic purposes; however, there is no consensus on the use of CBCT or MRI as diagnostic tools for TMJ DJD. The present systematic review attempted at analyzing all the in vivo studies conducted in the literature to assess evidence for the sensitivity and specificity of CBCT and MRI imaging in the detection of OA of TMJ. Both the above-mentioned imaging modalities were compared to reference diagnostic methods such as CT and RDC/TMD criteria, which have been used as a standard in previous studies. We found 4 articles that met the required criteria and were selected to be included in this study.

CBCT has found use in various fields of dentistry, such as maxillofacial, sinonasal, and TMJ bone imaging, with its most widespread application being in diagnostic imaging[25]. It is also used in dental implant applications, being useful for presurgical diagnosis and planning[26]. MRI has found use in the dental field mostly involving imaging involving the TMJ, soft tissues, tumors, salivary glands, and maxillary sinuses[27].

Previous studies discussed the various benefits of CBCT and MRI gives over conventional imaging techniques in TMD diagnosis, but evidence supporting these claims have been inconclusive. Ahmad et al.[22] discusses that while CBCT has clear benefits and may surpass CT, further studies are needed to fully determine its efficacy. Kaimal et al.[16] also discusses how MRI has promising applications, but ultimately still needs CT to confirm diagnoses of DJD. It is evident that there is varying evidence and opinions on the usefulness of CBCT and MRI in TMD diagnosis, but this demonstrates that more studies are needed before making a conclusive argument.

While diagnostic imaging does have its benefits, it should not be used just because the technology is available. TMD imaging alone without any form of standardization in interpretation can lead to varying results[28]. A cost-benefit analysis should be considered first, as performing imaging analysis can be costly, involve taking more time if a patient needs to be referred somewhere, and can involve radiation. These are factors that should be considered before deciding to use diagnostic imaging. In addition to this, Petersson[29] states there it is generally unclear when patients with TMD should undergo examination with imaging methods. However, Talmaceanu et al.[30] discusses that imaging techniques are an essential step in the diagnosis of TMD due to its complex anatomy and pathology. It is evident that there are conflicting opinions on whether radiographic imaging should be a considered standard in diagnosis of OA of the TMJ.

Although CBCT and MRI have been emerging with great potential in the dental field, there are still some constraints to surpass until they can gain widespread use. MRI's biggest constraints involve the size of the machine, cost, and patients who may have claustrophobia. It currently would not be feasible to have an MRI machine in every dental office. Therefore, until it becomes more practical to be used in dental offices, its exploration and applications will remain limited. On the other hand, CBCT has been gaining some traction with its incorporation in dental offices. It is much smaller and can be incorporated into a multimodal system that allows panoramic and CBCT imaging[26], therefore is much more feasible to be included in dental offices. However, it does expose the patient to radiation and therefore should not be used needlessly.

CT is considered the gold standard for diagnosing OA of the TMJ[16]. For this reason, it was used as a reference method. CT uses a narrow fan-shaped X-ray beam and multiple exposures around an object to reveal its internal structures[31]. This allows the observer to view morphology in 3-D as opposed to a conventional radiograph which is in 2-D. While CT seems to be the most reliable method to diagnose OA of the TMJ, its main drawback is cost and radiation, which is a sizable amount higher than a regular radiograph. While CBCT radiation is lower than CT, its radiation can vary widely, from the equivalent of 2 to 200 panoramic radiographs[26]. Therefore, a plan should be set in place to find a suitable replacement that is more cost-efficient and involves less radiation, yet still being a reliable tool for diagnostic imaging. The RDC/TMD was also considered as a reference method in this study due to its wide acceptance and long-standing use as a tool in the diagnosis of common forms of TMD. It is considered by some in the dental community to also be a gold standard for its use as a validity diagnostic classification tool[32]. Having these two widely accepted approaches as reference methods allows for a more valid comparison of imaging modalities.

A diagnostic test such as diagnostic imaging should be used with a valid purpose and have a reliable way to ensure that the disease or condition it is testing for is true. In this case, diagnostic imaging is considered to help clinicians diagnose a disease, specifically OA of the TMJ. With this in mind, several factors should be considered to ensure a valid diagnosis. A gold standard being used as a reference method is essential. As mentioned before, CT and RDC/TMD meets those criteria for our study. Validity can be defined as the extent to which a test measures what it is supposed to measure; e.g., accuracy. Specifically, validity is measured by sensitivity and specificity[33]. Sensitivity can be defined by the ability of a diagnostic test to determine if a diseased individual tests positive. Specificity on the other hand is the ability of a diagnostic test to determine if an non-diseased individual tests negative[34]. With our main goal to be to compare the sensitivity and specificity of CBCT and MRI in diagnosing OA of the TMJ, these parameters in essence determine the validity of each imaging modality and therefore were considered in this study.

Kaimal et al.[16] aimed to determine the diagnostic accuracy of panoramic radiography and MRI in detection of signs of TMJ DJD, using CT as a reference standard. DJD was defined as having at least one of the 4 signs: a subcortical cyst, surface erosion, osteophyte formation, or generalized sclerosis. The sensitivity and specificity values for MRIs, respectively, were found to be: subcortical cysts, 32% and 100%; erosion, 35% and 99%; osteophytes, 71% and 98%; sclerosis, 50% and 100% (Table 2). Using their target values for sensitivity and specificity of ≥70% and ≥95%, MRIs had below-target specificity and above-target sensitivity in all features except in osteophyte detection, where sensitivity was adequate. It was recommended that CT still be used for diagnosis to avoid false-negatives that may occur with MRI. This points towards that MRI is not quite ready to replace CT as the gold standard, however, more research is necessary. Despite attempts to contact the authors, raw data could not be obtained to perform data analysis.

Ahmad et al.[22] aimed to develop comprehensive TMJ diagnostic criteria for image analysis involving panoramic radiography and MRI, using CT as the reference standard. In regards to OA diagnosis, reliability of MRI was fair, with positive percent agreement (the percentage of patients with a positive test that actually have the disease[33]) being 59%. MRIs had marginal sensitivity but excellent specificity. Image analysis criteria was able to be developed for the assessment of OA using CT, but MRI was only considered for evaluating disc position and effusion, in which it was good to excellent. This demonstrates that more studies need to be conducted to determine the efficacy of MRI in diagnosing OA of the TMJ. This is in agreement with Kaimal et al.[16], which also did not have enough evidence about the efficacy of MRI usage in this aspect. Different imaging machines were used for each study, which may lead to a more varied result. Both studies involved 3 board-certified radiologist who reviewed images independently and blind to patient's history. One difference to note is that Ahmad et al.[22] considered more osseous components than Kaimal et al.[16], including: hyperplasia, flattening of the articular surface/eminence, subcortical sclerosis or cyst, surface erosion, osteophytes, generalized sclerosis, loose joint bodies, and deviation in form. Condylar position and ankylosis, as well as condylar edema, were also taken into account. This may account for some heterogeneity between the two studies.

Dias et al.[23] classified TMD of their participants using RDC/TMD and used CBCT as their index method. Image analysis criteria was based on the criteria described by Ahmad et al.[22], specifically: planning, erosion, osteophytes, and sclerosis. Images were evaluated by an experienced radiologist. The sensitivity and specificity of CBCT for diagnosing OA of the TMJ according to these criteria was calculated to be 52.63% and 92.86%, respectively (Table 3). This illustrates that CBCT has excellent specificity but adequate sensitivity in the diagnosis of OA of the TMJ.

Talaat et al.[24] classified OA of the TMJ of their participants according to the RDC/TMD for TMD's Group IIb, IIc, and III. Diagnosis of TMD was also confirmed by reviewing patient history and symptoms, a clinical examination, and radiographic examination, including MRI imaging. The sensitivity and specificity were calculated to be 90% and 64%, respectively (Table 4). Interestingly, in contrast to Dias et al.[23] results, excellent sensitivity was observed, but with just adequate specificity. This heterogeneity can possibly be explained due to the two studies having different imaging machines, different image examining methods, or differences in participant positioning/presence of artifacts. This could also be possible due to using Talaat et al.[24] using MRI to confirm findings, while Dias et al.[23] did not use such as method.

While there is a general consensus agreeing upon CT and RDC/TMD as viable reference standards for the diagnosis of OA of the TMJ, there are some who argue otherwise. Many researchers agree that CT is the gold standard for OA of the TMJ diagnosis, while others have varying opinions about the subject. Dias et al.[23] states that RDC/TMD is the gold standard for TMD diagnosis, however, Ahmad et al.[22] argues RDC/TMD for image applications is limited. Boeddinghaus et al.[25] also states that MRI is the reference standard for TMJ imaging and that CBCT is not a good substitute for MRI. With all these varied statements from different articles, it is clear that there is no fully unified consensus of what the gold standard is for diagnosis or what imaging modality is best for diagnosis of OA of the TMJ. Diagnosis should be based on a clear and methodological criterion that can be applied for any case. This information only highlights the need for more information in this subject, with the main goal to be to improve diagnostics to better help patients who may be suffering from OA of the TMJ. Having varying methodologies and using different imaging modalities may lead to incorrect diagnoses, which may lead to undiagnosed patients who may not be able to get the help that they need. This is further seen in the clinical aspect as well, as many dentists also feel ambiguous when it comes to diagnosing TMD, with only 25-50% of dentists that feel positive about it[32]. Therefore, it is of utmost importance that more light is shed on finding the most reliable method to diagnose OA of the TMJ properly.

Implications

CBCT demonstrated moderate pooled sensitivity and specificity for diagnosis of OA of the TMJ, i.e., 76% and 84%, respectively. Variable CBCT data does not allow a clear conclusion of its sensitivity and specificity to be drawn. However, more studies in this area may be able to expand upon this data and allow for a more conclusive result.

Regarding the validity of MRI in the diagnosis of OA of the TMJ, as we were not able to gather the information needed for MRI data analysis, we were unfortunately unable to determine its sensitivity and specificity. However, past studies have shown potential and further studies could potentially showcase further how it could benefit in diagnosis of OA of the TMJ.

Limitations

It can be observed that the literature is generally lacking, specifically in comparing sensitivity and specificity values for imaging modalities, and therefore, our data was limited. The available literature was mostly heterogeneous, which may be due to various factors such as machines used, number of examiners used, protocol followed, and interobserver agreement differences. Having this heterogeneity may influence data analysis negatively as having low consistency in data will lead to a result that is not consistent with other studies.

Recommendations

Future studies are recommended to consider other reference methods than CT or RDC/TMD, if another reliable method is available. Exploring other ways to measure the validity of an imaging modality other than sensitivity and specificity may also be of benefit.

Implications for practice

As the systematic review addressed a focused question on sensitivity and specificity, combined with the fact that existing literature is scarce and significantly heterogeneous, the results of our study should not be used to recommend one modality over another. Further, well-designed and controlled studies are required on this understudied topic, which has huge clinical implications, given the rise in in TMJ disorders.

Implications for research

As mentioned previously, there is a tremendous need for more research investigating the two modalities directly as well as with other reference standards for diagnosing OA of TMJ. There are only select studies, which have investigated MRI for diagnosing OA of TMJ. This might be attributed to the limited feasibility of using MRI in dental settings as a result of size of equipment along with financial considerations. However, given the trend towards minimally invasive diagnostics and avoidance of harmful radiation from CT and CBCT, research on MRI as a TMJ diagnostic modality holds great potential.

Amongst the studies included in this systematic review, there is a lack of standardization in outcomes and outcome measures, which makes direct comparisons difficult and external validity of the results questionable. This could be addressed in future research by predefining and adopting a core outcome set for diagnosing OA of TMJ.

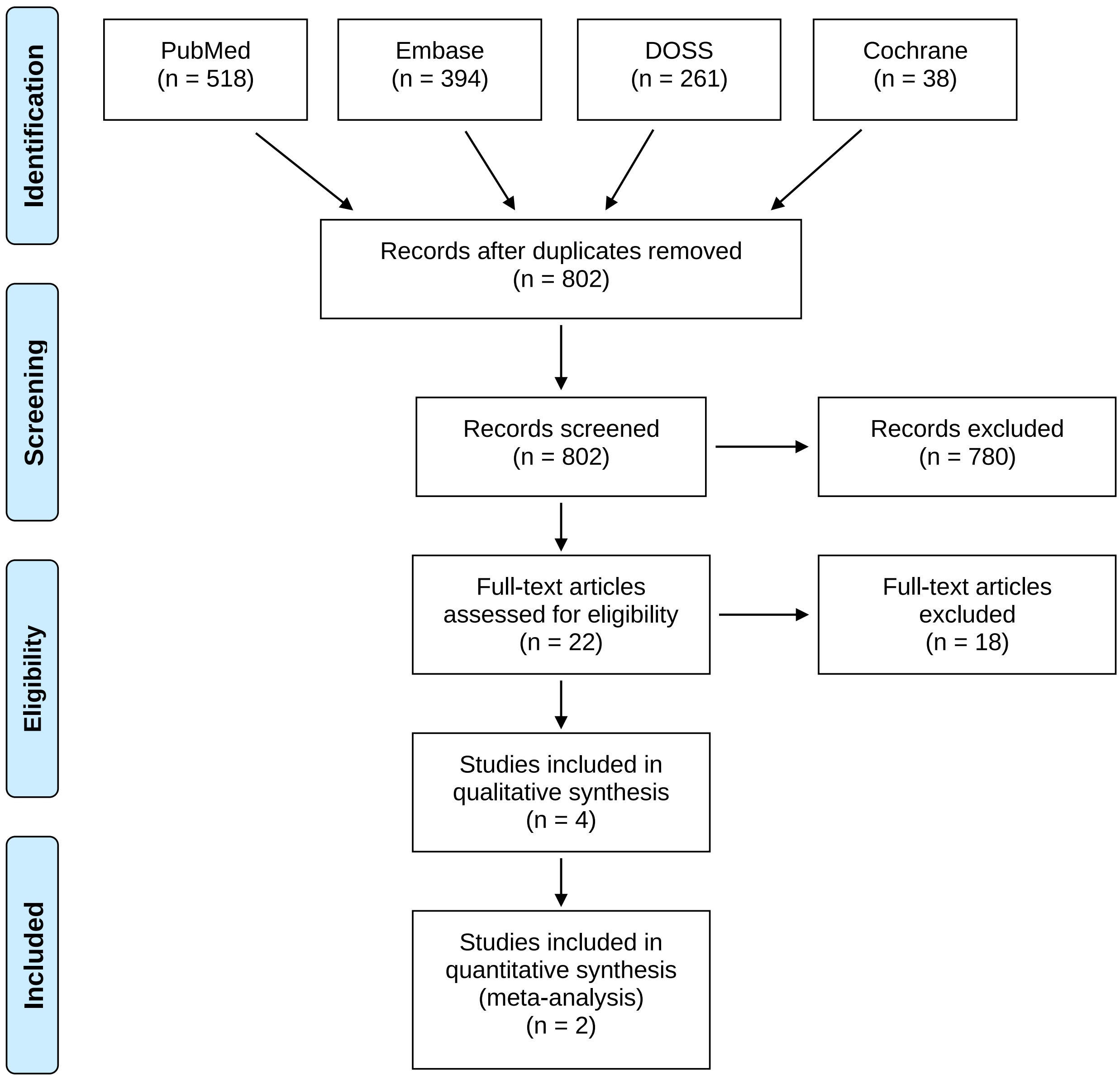
It is also important to mention the healthcare settings where the studies are being performed as these can affect the applicability of the results and its translation into clinical practice. E.g., Studies on more commonly available diagnostic modality CBCT might be performed in a primary dental care setting whereas research on MRI might be performed in a hospital-based setting, which does not have translational relevance from a clinical practice point of view.

There are several other confounding moderators, which need to be taken in account and should be reported in future research on TMJ disease. These include patient factors (such as age, gender, dental history, medical history), operator factors (number of investigators, experience and calibration), and technical factors (e.g. KvP, ma, FoV, and voxel size for CBCT scan, viewing conditions for the images). Having these factors reported in future studies will help other researchers and clinicians to understand the outcomes better and will also improve the applicability and generalizability of the results.

Conclusion

Diagnosis of OA of the TMJ is often difficult and determining if CBCT or MRI are beneficial in diagnosis may help alleviate the issue. CBCT sensitivity and specificity for the diagnosis of OA of the TMJ was determined for our studies to be moderate for both parameters. MRI sensitivity and specificity were not able to be pooled due to a lack of access to raw data. It can be concluded that while CBCT and MRI show promise in being used to diagnose OA of the TMJ, more well-designed studies are needed to substantiate their validity.

Figure 1: Flowchart of articles



Note that in order to be eligible for this systematic review, an article needed to: evaluate osteoarthritis in live adult human participants, have at least 10 participants, use either CBCT or MRI as the index method, use either CT or RDC/TMD as the reference method, provide estimates of sensitivity and specificity, be published in English, and be published after 2000.

Table 1: Description of selected studies

Author, year, and country	Type of study	Sample (n)	Age in years (mean or range)	Gender	Reference standard	Index method	Number of examiners	Index method parameters	Results	Conclusion
Ahmad et al, 2009, USA	Multicenter, cross-sectional	724 participants (1,448 joints)	N/A	N/A	CT - multidetector CT, 1mm slices.	MRI	3 board-certified radiologists; blinded to clinical histories or diagnoses of participants	Closed-mouth images - proton density and T2 algorithm. Open-mouth images - only PD images. PD images had TR 2,000 and TE 17. T2 images had TR 2000 and TE 102.	When OA was detected on CT, 59% of MR images displayed a positive finding of OA. When OA was not detected on CT, 98% of MR images were also negative for OA.	Using CT as the reference standard for diagnosis OA, MRI has marginal sensitivity but excellent specificity.
Kaimal et al, 2018, USA	Multicenter, cross-sectional	705 subjects (1,410 joints)	39.4 (±15)	Males: 124 Females: 581	CT - LightSpeed VCT, Aquilion CT (Toshiba)	MRI	3 board-certified radiologists; blinded to clinical histories or diagnoses of participants	Vision 1.5T and Avanto 1.5 MRI scanners (Siemens). Signa 1.5T MRI scanner (GE Healthcare Life Sciences). Symphony 1.5T MRI scanner (Siemens).	MRIs had a poor sensitivity for subcortical cysts (32.1%) and erosion (35.9%), marginal sensitivity for generalized sclerosis (50.0%), and excellent sensitivity for osteophyte formation (70.7%). Specificity was excellent for all 4 signs of DJD.	MRIs of the TMJ have excellent specificity but inadequate sensitivity for the detection of subcortical cysts, surface erosion, and generalized sclerosis.
Dias et al, 2015, Brazil	Multicenter, cross-sectional	45 subjects	43.0 (±6.2)	Females: 45	RDC/TMD	CBCT	1 experienced radiologist, blinded to patient's clinical data	iCat Next Generation system (Imaging Sciences International) - ET: 26.9s; FoV: 8cm; Voxel: 0.25mm	Through the RDC/TMD and CBCT images, it was found that 97.7% had at least 1 Group III diagnosis	High prevalence of degenerative changes in individuals with OA of the TMJ
Talaat et al, 2015, UAE	Multicenter, cross-sectional	89 subjects	34.0 (±21.0)	Males: 33 Females: 56	RDC/TMD	CBCT	2 - 1 oral radiologist and 1 oral and maxillofacial surgeon	GALILEOS 3-D X-ray systems (SIRONA dental systems). ET: 3 seconds; Voxel: 150μm; ST: 1.0mm	Assessment of CBCT showed a statistically significant difference between TMD and non-TMD joints.	CBCT findings are significantly associated with the clinical diagnosis of TMD.

Key

CBCT: Cone-Beam Computed Tomography	PD: Proton Density	TE: Echo Time
MRI: Magnetic Resonance Imaging	TR: Repetition Time	ET: Exposure Time
CT: Computed Tomography	OA: Osteoarthritis	FoV: Field of View
RDC/TMD: Research Diagnostic Criteria for Temporomandibular Disorders	VCT: Volumetric Computed Tomography	ST: Slice Thickness

Table 2: Kaimal et al. results: Diagnostic accuracy of MRI compared to CT for DJD

Signs of DJD	**Sensitivity** (%)	**95% CI**	**Specificity** (%)	**95% CI**
Subcortical cysts (n = 56)	32.1	17.6-51.1	99.9	99.0-100.0
Surface erosion (n = 256)	35.9	28.1-44.6	99.0	97.7-99.5
Osteophyte formation (n = 184)	70.7	60.6-79.0	97.9	96.4-98.8
Generalized sclerosis (n = 24)	50.0	24.4-75 .6	99.7	98.9-99.9

Note: From Table 3 of Kaimal et al.

Table 3: Dias et al. results: Diagnostic accuracy of CBCT compared to RDC/TMD

	RDC/TMD		
CBCT	+	–	Total
+	10	2	12
–	9	26	35
Total	19	28	47

	Estimate	95% CI	
Sensitivity=	53%	30%	75%
Specificity=	93%	83%	100%

Notes: Values were extracted from Table 2 of the Hilgenberg-Sydney summary[35] of the Dias et al. results.

Table 4: Talaat et al. results: Diagnostic accuracy of CBCT compared to RDC/TMD

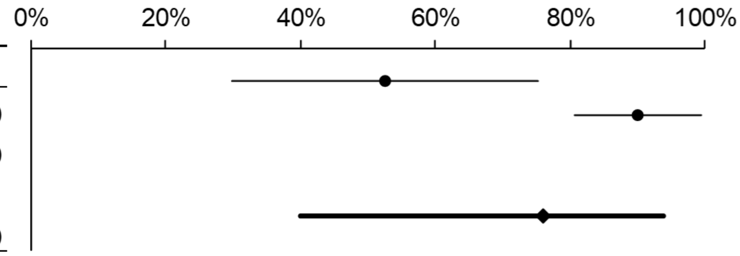
	RDC/TMD		
CBCT	+	−	Total
+	36	31	67
−	4	55	59
Total	40	86	126

	Estimate	95% CI	
Sensitivity=	90%	81%	99%
Specificity=	64%	54%	74%

Notes: Values were extracted from Table 2 of the Hilgenberg-Sydney summary[35] of the Talaat et al. results.

Figure 2: Forest plot for sensitivity of CBCT diagnosing RDC/TMD

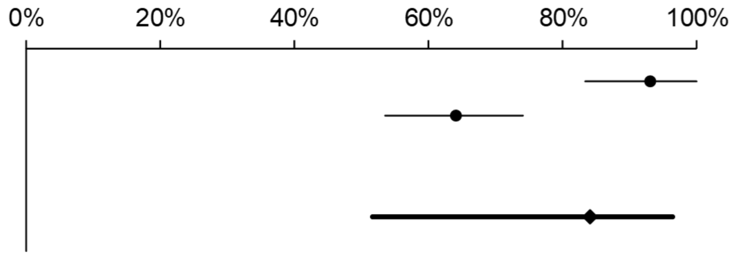
	Sensitivity		
Source	N	Estimate	95% CI
Dias 2015	47	0.53	(0.30 to 0.75)
Talaat 2015	126	0.90	(0.81 to 0.99)
Total	173	0.76	(0.40 to 0.94)



Legend: The horizontal axis shows sensitivity, as a percentage. The individual studies are ordered along the vertical axis, and the meta-analysis summary of all the studies appears at the bottom. The results appear in text—on the left side of the figure—and as lines—on the right side of the figure. The point estimate appears in the center of the line and the range estimate (the 95% confidence interval) appears as a line. The combined results—"Total" in the figure—appears as a line of greater thickness.

Figure 3: Forest plot for specificity of CBCT diagnosing RDC/TMD

Source	N	Estimate	95% CI
	Specificity		
Dias 2015	47	0.93	(0.83 to 1.00)
Talaat 2015	126	0.64	(0.54 to 0.74)
Total	173	0.84	(0.52 to 0.96)



Legend: The horizontal axis shows specificity, as a percentage. The individual studies are ordered along the vertical axis, and the meta-analysis summary of all the studies appears at the bottom. The results appear in text—on the left side of the figure—and as lines—on the right side of the figure. The point estimate appears in the center of the line and the range estimate (the 95% confidence interval) appears as a line. The combined results—"Total" in the figure—appears as a line of greater thickness.

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Vita

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