

ACCURACY OF CBCT IN MANDIBULAR CONDYLE VOLUMETRIC AND SURFACE MEASUREMENT: LITERATURE REVIEW

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Abstract: The purpose of this review is to evaluate the accuracy and reliability of cone beam computed tomography (CBCT) in the measurement and diagnosis of mandibular condyle morphology, in comparison to other diagnostic devices. The design and method In order to achieve our study, we searched several databases, including Google Scholar, PubMed, and Scopus. We only considered studies published between 2005 and 2023. Our review was focused on clinical trials, meta-analysis, article reviews, and randomized controlled trials. The exclusion criteria included patients with certain medical conditions, jaw abnormalities, jaw fractures, and animal experiments. The studies we analyzed had to address one specific question: What is the diagnostic accuracy of Cone Beam Computed Tomography (CBCT) compared to conventional tomography? conclusion: CBCT has become a cost- and dose-effective alternative to CT for examining the condyle and also TMJs. This imaging method is better than conventional radiographic methods and MRI in assessing osseous TMJ abnormalities, despite being more sensitive to motion artifacts. In addition, CBCT-MRI fused images can significantly improve the reliability of observers in determining anterior disc displacement and bone changes of the TMJ. This technology can also be utilized to improve diagnostic efficacy, especially for inexperienced residents.

Keywords: cone beam computed tomography, imaging, magnetic resonance imaging, temporomandibular joint, ultrasonography.



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INTRODUCTION

Radiographic imaging plays a crucial role in diagnosing temporomandibular joint (TMJ) disorders. The most common imaging modalities used for TMJ assessment are computed tomography (CT) and magnetic resonance imaging (MRI). [1,2] In the late 1990s, Cone Beam Computed Tomography (CBCT) was introduced as a more cost-effective imaging technique that produces high-resolution images with lower radiation doses. Since then, CBCT has become a reliable imaging modality for detecting osseous changes in the TMJ. [3,4] Studies have shown that CBCT is as accurate as CT in detecting surface osseous changes, with similar reliability levels. However, CBCT's more flexible reformatting capabilities provide higher reliability than CT. [5,6,7,8]

Radiologists must be aware that the accuracy of CBCT depends on various factors, such as the imaging protocol, field of view, and voxel size [8,9,10,11]. The accuracy and discernibility of CBCT on bone morphology and bony defects are excellent, making it an indispensable imaging modality for TMJ assessment [12].

In its short lifespan of about 20 years, CBCT has surpassed other imaging modalities such as conventional, panoramic, and cephalometric radiography and competes with conventional CT in accuracy.

Condyle and TMJ joint assessmentThe mandible is the largest and strongest bone in the face, supporting the lower teeth. It has a curved body and two vertical ramus with a horseshoe-like shape. A slight ridge marks the joining point of the two pieces that make up the bone.

The ramus is quadrilateral in shape with two surfaces, two processes, and four boundaries. The lateral surface has oblique ridges, and the masseter muscle can attach to it along its entire length.

More significantly, The Coronoid Process is a thin, triangular prominence that varies in shape and size. The Condylod Process is thicker than the coronoid and consists of the condyle and the neck. The condyle provides the articular surface for contact with the articular disk of the TMJ joint [14].

2.2 ANATOMY OF TMJ

The temporomandibular joint (TMJ) is a type of synovial joint that allows both backward and forward translation as well as gliding motion [8]. The TMJ joint has a disk, fibrous capsule, synovial fluid, synovial membrane, and ligaments. Its articular surfaces are covered by fibrocartilage instead of hyaline cartilage. The inferior surface is formed by the mandibular condyle and the superior surface is formed by the glenoid fossa and articular eminence of the temporal bone [15].

2.3 Embryology and development of TMJ

The TMJ appears during fetal development in the craniofacial region around the 8th week of gestation. It is considerably underdeveloped at birth, making it vulnerable to perinatal and postnatal insults. During early childhood, the joint develops further as the jaw is utilized for sucking motions and chewing [6].

2.4 Articular disk

The articular disk is a round or oval, avascular fibro-cartilage between the condyle and glenoid fossa. It has two bands, anterior and posterior, which are longer in mediolateral dimension than in anteroposterior dimension. The disk is firmly attached to the medial and lateral poles of the condyle, allowing simultaneous movements of the disk and the condyle.

2.5 Articulation of the Mandible

The temporomandibular joint or TMJ is a ginglymo-arthrodiar joint that comprises the front section of the mandibular fossa in the temporal bone, the articular tubercle above it, and the mandible's condyle below it. This joint is supported by several ligaments, including the Capsular, Sphenomandibular, and Temporomandibular ligaments, as well as the Articular Disk, which is a thin, oval plate located between the mandibular fossa and the condyle of the mandible. The Articular Disk is designed to fit the shape of the mandibular fossa and articular tubercle, with its top surface being concavo-convex and the bottom surface being concave, which comes in contact with the condyle. The disk is thicker at its edges, especially behind, than at its center, and its fibers are arranged in concentric circles, with a more noticeable pattern at the outer rim than in the middle. The Articular Disk divides the joint into two cavities, each with a synovial membrane [16].

2.6 Development of the mandible

During embryological development, the first branchial arch forms into the maxillary and mandibular processes. The maxillary process becomes the maxilla and palate, while the mandibular process becomes the lower jaw. Meckel's cartilage in the mandibular process regresses to form the incus and malleus of the middle ear. The mandible forms through perichondral ossification, using Meckel's cartilage as a "template" [16].

The condyle forms as a separate conical Chondrus during week 8 of development and eventually attaches to the mandible. It becomes ossified through perichondral ossification, except for a small part which forms the Temporomandibular joint. The articular disk develops from mesenchymal stem cells around week 12, and Meckel's cartilage stops developing and disappears as the TMJ begins to function.[17]. Before puberty, the growth of the mandible continues at a relatively steady rate. On average, the lower jaw increases about 1-2 mm per year, with resorption areas in the anterior part of the ramus and apposition areas in the posterior part. Bone apposition can also be seen in the symphysis area, especially in boys [16]. The development of the lower jaw follows the development of the condyle, which is actually up and backwards, and progresses from up and backward towards down and forward [18].

2.7 Imaging Techniques:

The goal of TMJ imaging should be to obtain new information that would influence patient care. After history and physical examination, choosing the imaging modality is challenging, whether bony compartment or soft tissue is targeted. The radiation dose and the cost of the examination should also influence the decision [18].

2.7.1 Conventional radiography:

Conventional radiology was the preferred modality because it was inexpensive, simple to use, low radiation, and could show results for various tissues. However, in contrast to new modality imaging, it cannot identify the soft tissue compartment of the TMJ [19,20]. Transcranial radiography was chosen over magnetic resonance imaging (MRI) as the primary radiological examination due to its ease of use and low cost [21,22].

2.7.2. Panoramic radiography:

In a single view, panoramic radiography can produce an image of the nasal cavities, maxillary sinuses, jaws, and both TMJs. Apart from its diagnostic capabilities, this method is simple, affordable, and involves minimal

radiation exposure. It assesses the mandibular condyle, articular eminence, and articular fossa of both TMJs. Certain panoramic radiography devices have unique TMJ imaging programs, which consist of four lateral TMJ projections for each TMJ on one image in both closed and open jaw positions [23,24]. Since panoramic radiography gives a 2D image, it does not record information about articular eminence and mandibular fossa in the sagittal plane. Due to magnification, Panoramic radiography cannot give a precise morphologic and volumetric analysis of the condyle and articular eminence [21,25].

2.7.3. MRI:

In addition to producing 3D construction images that can replace a multislice CT and CBCT, magnetic resonance imaging (MRI) is the best non-invasive imaging. It allows for the visualization of soft tissue in the TMJ in multiplanar views. MRI can also provide a detailed description of articulating disc morphology and assess joint spaces for joint effusion, and disc displacement. MRI uses in TMJ imaging are hindered by the time-consuming nature of the procedure and the incapacity to assess and diagnose condylar pathology [21].

2.7.4 Ultrasonography:

Cost-effectiveness, safety and easiness made the US the 1st line imaging modality in TMJ evaluation. It can easily detect joint effusion since the probe is a tactile instrument. Image-guided injections for therapeutic and diagnostic purposes are better used in the US. Finally, the US is an operator-dependent modality that needs an experienced one [26,27].

2.7.5 Arthrography:

Before the invention of MRI and its uses in the evaluation of TMJ, Arthrography was the modality of choice in examining articular disk dysfunction, perforation and adhesion by injecting a contrast media in the joint space under fluoroscopic guidance. Nowadays, it is of no use saying that it is an invasive modality when compared with MRI. In addition, it may cause allergy to contrast agents and infection [28].

2.7.6 Arthroscopy:

TMJ arthroscopy is a noninvasive, reliable, and sensitive method for diagnosing and treating TMJ. However, it can lead to complications such as bleeding, disk perforation, and infection. It is contraindicated in joint ankylosis, excessive disk resorption, and tumors. Arthroscopy is a good alternative to surgery when needed. [23,29].

2.7.7 Computed tomography (CT):

The TMJ is a complex structure containing bony and soft tissue compartments. CT imaging is preferred to evaluate both compartments and diagnose fractures, degenerative changes, infections, and other anomalies. Digital technologies in CT improve diagnosis and treatment planning by providing multiplanar and 3D images. Arthrography can be combined with CT for enhanced diagnosis. Unfortunately, CT may not be able to detect a small perforation of the articular disk, so when the disk is the main target, MRI is preferred [23,26,29].

2.7.8. Cone Beam Computed Tomography (CBCT):

CBCT is a modern imaging system that produces accurate 3D images using tomographic screening technology. It can detect osseous TMJ abnormalities with high sensitivity and specificity. Many studies have reported its effectiveness in detecting anomalies in different anatomical regions of the maxilla and mandible bones [29,30].

2.7.8.1 How does CBCT 3D cephalometry works?

When comparing CBCT with conventional CT, the most significant difference is the beam shape. Helical CT uses a wide fan-shaped beam, and the source and detectors rotate around the patient in a helical manner to cover the area to be examined. The image is displayed on the monitor as separate slices, stacked to form a 3D image. On the other hand, CBCT uses a cone-shaped 3D x-ray beam. A single rotation of the gantry around the patient is enough to scan the entire area of interest and reconstruct a 3D image in addition to 2D slices in the 3 planes. CBCT is faster and requires less radiation [31].

In a study comparing fan-beam CT (FBCT) and CBCT, Lechuga and Weidlich found that FBCT has a greater ability to discriminate low-contrast objects, while CBCT has a greater ability to distinguish small spatial variations [32].

High-resolution CBCT scans are essential for precise diagnosis. FOV and voxel size impact spatial resolution. Smaller voxel size and narrow FOV detect fine details with minimal distortion. While it can identify osseous changes, CBCT cannot assess articular disk alterations. MRI is preferred for this. Combining both methods provides a comprehensive evaluation of TMJ health [33].

2.7.8.2 The advantages of CBCT 3D cephalometry:

CBCT 3D cephalometry offers several benefits over multislice CT, including reduced radiation exposure (up to 98%), rapid scan time (5-40 seconds), high-resolution images, different FOV, easy and comfortable procedure, and cost-effectiveness [31,34].

2.7.8.3 The limitation of CBCT 3D cephalometry:

Despite its advancements, CBCT imaging still has limitations, including artifacts, low soft tissue resolution,

and image noise caused by scattered radiation.

THE DESIGN AND METHOD

In order to achieve our review, we searched several databases including Google Scholar, PubMed, and Scopus. We only considered studies written in English language that were published between 2005 and 2023. The search terms "Cbct accuracy and condyle morphology" or "Condyle surface measurement" were used. Our review was focused on clinical trial, meta-analysis, randomized controlled trial, article review, and case report articles. The exclusion criteria included patients with certain medical conditions, jaw abnormalities, and jaw fractures, as well as animal experiments. The studies that we analyzed had to address one specific question: what is the diagnostic accuracy of Cone Beam Computed Tomography (CBCT) when compared to conventional tomography in detecting temporomandibular joint (TMJ) and mandibular condyle?

DISCUSSION

In 2006, a study was demonstrated that cone beam computed tomography (CBCT) had a sensitivity of 0.80 in detecting erosions/osteophytes with macroscopic observation as the gold standard. In the same study, CBCT was compared to multislice or multidetector CT, also known as CT. Although the latter had a slightly inferior sensitivity (0.70), no significant differences were found between the two modalities [4].

In a larger series of dry human skulls comparing CBCT to conventional (spiral) tomography in 2007, a significantly lower sensitivity was found for depicting cortical defects and osteophytes, but there were no significant differences observed between the two modalities. Another dry skull study in the same year showed that CBCT provided superior reliability and greater accuracy than conventional (linear) tomography and panoramic radiography in depicting condylar cortical erosions [9].

A more recent study on a dry human skull material confirmed Honda et al.'s observation that there were no significant differences between CBCT and CT scans in detecting surface osseous changes. However, the study found lower sensitivities, which is consistent with Hintze et al.'s findings. The accuracy of CBCT in detecting bone defects relies on the size of the defects, which was demonstrated by Marques et al. and confirmed by Patel et al. in their studies of simulated condylar lesions. The detection of extremely small defects, i.e., less than 2mm, was challenging, although the overall sensitivity for detecting condylar osseous defects was relatively high between 72.9% to 87.5%.⁵⁶ These findings were consistent with those reported by Marques et al. but significantly higher than those reported by Hintze et al., who only investigated morphological changes such as condylar flattening and osteophytes. Therefore, it is suggested that erosion of the condylar surface is easier to detect from CBCT images than other morphological changes [5,8,9].

Different imaging protocols can affect the accuracy of diagnosing erosive changes in the TMJ [11,12]. While some studies have shown an impact, others have not [23,35]. A study found no significant difference between large view and standard view protocols in detecting defects on the surface of the condyles. Both protocols were reliable, but the large view protocol had an effective radiation dose of only about one-sixth of the standard view protocol, making it the recommended choice for assessing the condition of TMJ [12].

An interesting study compared conventional tomography, CT, and CBCT with microCT and microscopic observations. It concluded that CBCT most accurately defined erosive changes of the bone cortex of the condyle. The high detectability of CBCT images on bone morphology of mandibular condyles was confirmed [36].

Advanced technology, specifically CBCT-based surface models, have allowed for a more complete assessment of both qualitative and quantitative morphological changes in the temporomandibular joint (TMJ) [37]. An innovative method, known as 3D shape correspondence analysis (SPHARM-PDM), can accurately locate and quantify alterations between healthy and pathological structures. This method helps to minimize the impact of examiner experience, reduce intra- and inter-rater errors, standardize findings, and contribute to the development of new imaging markers for identifying risk factors during the diagnosis of TMJ osteoarthritis [38]. A clinical study conducted in 2015 was the first to quantitatively compare the 3D mandibular condyle surfaces constructed from CBCT and MSCT scans. These 3D surface models provide additional diagnostic information regarding the size, shape, and exact location of bone abnormalities on the affected joint, making them a valuable tool in the diagnostic process [35].

Several studies have investigated the accuracy of Cone Beam Computed Tomography (CBCT) scans on either the maxillary bones or the mandibular condyles. However, these studies have mainly used dry human skulls and thus, the soft tissue component's impact has been overlooked. The absence of soft tissues in such studies, replaced with air, enhances contrast and accuracy. When soft tissues are present, their attenuation coefficients can deteriorate the image quality. Therefore, the information provided by these studies is limited [39,40,41].

García et al. (2017) found that CBCT is a reliable method for measuring mandibular condyles with soft tissue present. The study used six cadaver heads and found a coefficient of variation of less than 3% and a concordance correlation coefficient greater than 0.90. The three linear measurements and volume obtained were highly

accurate. The study concluded that CBCT is a valid tool for clinical diagnosis. [36].

A study executed by Wang et al. in 2022 aimed to evaluate the effectiveness of CBCT-MRI fused images in diagnosing temporomandibular disorders (TMD). The study included 120 patients with TMD, and 231 TMJs were examined. The main focus of the study was to assess the diagnostic reliability of CBCT-MRI fused images in detecting anterior disc displacement and bone changes in the TMJ. The results showed that CBCT-MRI fused images significantly improved the accuracy of diagnosis, and it can be particularly useful for inexperienced residents [39].

This is in line with the study by Al-Saleh et al., were also found that the diagnostic value of MRI-CBCT images in detecting osseous abnormality is comparable to CBCT alone, except for small osseous changes such as erosions. The MRI-CBCT fused images improved the consistency among examiners with varying levels of experience in classifying disc position in relation to the condyle [40].

CONCLUSION

In summary, CBCT has become a cost- and dose-effective alternative to CT for examining the condyle and also TMJs within a short period of time. Although it may be more sensitive to motion artifacts, this imaging modality is superior to conventional radiographic methods and MRI in assessing osseous TMJ abnormalities.

In addition, CBCT-MRI fused images can significantly improve the reliability of observers in determining anterior disc displacement and bone changes of the TMJ. This technology can also be utilized to improve diagnostic efficacy, especially for inexperienced residents.

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