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Literature Review

Cone-Beam Computed Tomography Accuracy for Morphological and Morphometric Evaluation of Mandibular Condyles Using Small FOV and Small Voxel Size

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KEYWORDS

temporomandibular joint;
mandibular condyle;
CBCT;
FOV;
voxel size

ABSTRACT

The objective of this study is to evaluate the accuracy of cone beam computed tomography (CBCT) in determining and visualizing the morphology and morphometry of the mandibular condyle. Narrative reviews with article searches were carried out through NCBI's PubMed database and Scopus from September 2021–October 2021, with the inclusion criteria articles published in 2011–2021. The temporomandibular joint (TMJ) has a crucial role and is closely related to the masticatory system. The diagnosis of temporomandibular disorder (TMD) is not easy and is complex enough to require a comprehensive clinical and radiographic examination. Pathological changes such as erosion of the condyle, fracture, ankylosis, dislocation, and osteophyte can be well seen using CBCT imaging. CBCT images obtained with smaller field of view (FOV) have smaller a voxel size and a higher image resolution. FOV or scan volume refers to the anatomical area that will be included in the data volume or the area of the patient that will be irradiated. The dimension of FOV depends on the detector size and shape, the beam projection geometry, and the ability to collimate the beam. Voxel size is an important component of image quality, related to both the pixel size and the image matrix. Selection of small FOV and small voxel size is recommended because they provide better visualization and detail for the evaluation of morphology and morphometry of the condyle, especially the detection of erosion and defects on the condyle surface.

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INTRODUCTION

The temporomandibular joint (TMJ) is one of the most active joints in the human body. In one day, approximately more than 2000 movements occur during mastication, biting, swallowing, and speaking.[1,2] The TMJ consists of the mandibular condyle located in the glenoid fossa of the temporal bone. The anatomical structure of TMJ consists of the mandibular condyle, temporal bone, and articular disc.[3-5] The TMJ has a crucial role and is closely related to the masticatory system.[6] Dupuy-Bonafe et al. stated that TMJ morphology examination has an essential role in detecting pathological abnormalities that occur in the TMJ.[7] Temporomandibular joint disorder (TMD) is a significant source of non-dental orofacial pain. The most common clinical signs and symptoms of TMD are joint pain, muscle aches, limited mouth opening, clicking, and crepitations.[8–10] The diagnosis of TMD is not easy and is complex enough to require a comprehensive clinical and radiographic examination.[4]

Some radiographic examinations can be performed to evaluate the condition of the TMJ, such as panoramic and transcranial, conventional CT, TMJ-corrected tomography, CBCT, MRI, and arthrography.[11] Conventional radiographs like cephalometric and panoramic usually do not provide a clear view and cannot provide images of TMJ from various views. CBCT is very useful in dental and maxillofacial evaluation. In addition to having a shorter scan time than conventional CT and MRI, CBCT can provide high-resolution images.[12,13] The best radiographic examination for articular disc evaluation is using MRI, while CT is best for viewing bone components.

MRI is the gold standard used to analyze the position and morphology of the TMJ and the position and morphology of the articular disc. MRI can also provide images of the translation of the condyles and discs at the time of mouth opening, joint effusion, synovitis, erosion, and degenerative joint disease. Simultaneously, CBCT has become the gold standard for evaluating bony changes occurring in the TMJ. Pathological changes such as erosion of the condyle, fracture, ankylosis, dislocation, and osteophyte can be well seen using CBCT imaging.[14]

The advantage of CBCT is that it can show anatomical or pathological conditions in several different plane sections. The radiation dose produced by CBCT is lower than conventional CT but can provide more geometrically accurate results with an excellent spatial resolution that can distinguish small details in the image, fast scan times, and software compatible with implant and cephalometric treatment plans. The disadvantage is that the patient must stay immobile during the scan to avoid artifacts, and soft tissue cannot be seen clearly on CBCT.[15] The panoramic radiographic image generated by the software cannot be directly obtained as in conventional panoramic radiography because adjustments need to be made using the existing software. Objects with radiopaque or radio densities such as metal restorations and root-filling materials can produce phosphorescent artifacts, i.e., "beam-hardening" or "streak".[10,16]

CBCT is now easier to find at a lower cost and has several advantages over conventional CT. The first advantage is that the radiation dose from CBCT examination is much lower. Second, CBCT has a higher image spatial resolution, which makes CBCT diagnostic accuracy as good as conventional CT as the study conducted by Barghan S. et al. CBCT is recommended as an imaging tool that can be used to evaluate bony changes in the TMJ. Given the lower radiation dose and the increasing availability of CBCT, this modality is becoming the modality of choice for evaluating the TMJ bone components.[10,17] CBCT has been reported to have an excellent ability to evaluate TMJ bone pathology and has high reliability for detecting cortical erosions on the TMJ articular surface with 95% accuracy.[18] This article aims to see how accurately CBCT can evaluate and visualize TMJ conditions, especially the morphology and morphometry of the mandibular condyle with small FOV and small voxel size.

TMJ BONE STRUCTURES

The bony structures surrounding the TMJ provide unique characteristics that make this joint difficult to visualize using conventional two dimentional (2D) radiographs (panoramic dan cephalometri). The conventional 2D transcranial radiography technique is good enough to evaluate the position of the TMJ and the shape of the mandibular condyle in the sagittal plane, but this technique has disadvantage, it only provides one view from sagittal that cannot detect if there is a change on the other side.[19]

Examination of the structure of the TMJ with radiographs is critical to evaluate for abnormalities.[9,20,21] Temporomandibular disorder (TMD) often associated with degenerative bone changes involving the TMJ bone structures, such as flattening, erosion, osteophytes, subchondral bone sclerosis, and pseudocysts, as shown in Figure 1.[21] Knowledge and information about changes that occur in the TMJ components are necessary so that dentists can provide the correct diagnosis and treatment plan. Various methods in literature have been used to determine disc position and the relationship between disc position and anatomical differences of the articular bones, such as condyle morphology, condyle head inclination, glenoid fossa depth, and articular eminence

tilt.[18] CBCT can be an alternative to conventional CT, which has several disadvantages: high cost, limited access, and relatively high radiation dose.

ROLE OF CBCT IN EVALUATION OF TMJ STRUCTURES

The complex anatomical structure of the TMJ makes radiographic examination quite difficult, and therefore several types of radiographic examination are required to obtain a correct diagnosis. Cone-beam computed tomography (CBCT) can provide a reasonably clear picture of the TMJ structure with less radiation exposure than conventional CT examinations.[4] Several studies have also reported high accuracy in examining and evaluating the TMJ area using CBCT.[12,17,22] CBCT is quite commonly used in evaluating the position and morphology of condyle because it can provide high-quality images and display a clear anatomical picture with a lower radiation dose than conventional CT.

Journal searches were conducted through Pubmed and Scopus databases. The keywords used in the search were CBCT, TMJ, and morphology condyle. The inclusion criteria in the selection of journals were female and male patients with an age range of 10-89 years, patients with or without complaints, and abnormalities in the TMJ. Exclusion criteria were studies conducted on animals, patients with certain medical conditions, jaw abnormalities, and jaw fractures. The search strategy was carried out from September 25-October 6, 2021, from the Pubmed and Scopus databases with a time limit of 10 years (2011-2021), text availability selection: Free and Full Text. Article type: Clinical Trial, Meta-Analysis, and Randomized Controlled Trial from Dental Journals with the dentistry subject area, document type are article, review, and case report, and choice of language is English. The selection of journals is limited to only Q1 and Q2; thirteen journals were selected from the search. The characteristics of the 13 journals can be seen in Table 1, and the results can be seen in Table 2.

CBCT is frequently used in dentistry, especially orthodontic treatment, implants, and oral surgery. CBCT imaging with small FOV can evaluate impacted teeth location, external resorption associated with unerupted or impacted teeth, and specific evaluation of impacted teeth. Small FOV may also be indicated for examination of infra-bony defects and furcation lesions, periapical evaluation, root canal anatomy in teeth with multiple roots, endodontic surgical planning, complications of endodontic treatment with resorption, perio-endo lesions, perforations and to view atypical pulp anatomy and traumatized teeth with suspected root fracture. Examination of the cleft palate can be performed using a small or medium FOV. Orthodontic or complex surgical treatment planning of maxillofacial bone disorders can use moderate or large FOV. CBCT is not recommended for routine diagnostics, dental caries examination, periodontal examination, and periapical lesion.[10,15,23]

ACCURACY OF CBCT FOR TMJ EXAMINATION

Radiographic examination is part of clinical examination to evaluate abnormalities that occur in the TMJ, and its primary purpose is to verify the occurrence of degenerative bone changes in the condyle.[11] Several studies have shown the measurement and evaluation morphology of the condyles to detect abnormalities in TMJ using CBCT radiography to provide accurate results. Studies on the relationship between skeletal class differences with the volume, position, surface, and morphology of the condyles were also carried out using CBCT examination to provide a complete TMJ anatomical picture. The first study to discuss the accuracy of CBCT for TMJ examination was conducted in 2005. In 2006 several researchers wrote that CBCT has good sensitivity to detect the occurrence of osteophytes or erosions in the condyle. Comparison made by several researchers between CBCT and Multidetector CT showed no significant differences. This means that the results of the TMJ examination using CBCT modality are equivalent to the examination performed using Multidetector CT.[24]

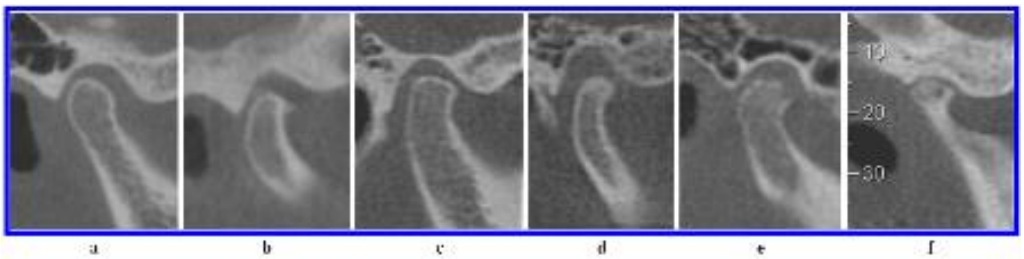

Figure 1. Lateral section of the TMJ. Condyle morphology classification (a) no bone changes, (b) osteophyte, (c) flattening, (d) sclerosis, (e) erosion, (f) pseudocyst (Dos Anjos, et al. 2012)

Table 1. List of Included Research Articles

Author	Year	Type of Study	Number of TMJs	Sample	CBCT Unit	Title	Scopus Index
Saccuci et al	2012	Observational Study	188 TMJs	94 patients (46 females and 48 males; 15–30 years old)	Cone Beam Volumetric Tomography with ILUMATM Reconstructed layer thickness 0.5mm with 512 x 512 matrix. 120 kVp 3 – 8 mA High-frequency generator with fixed anode and 0.5mm focal spot. A single 40-second-high-resolution scan. Voxel size 0.25mm Each condyle is visualized with a range of grayscale from –1350 to 1650	Do skeletal cephalometric characteristics with condylar volume, surface, and shape? A 3D analysis	Q2
Saccuci et al	2012	Observational Study	400 TMJs	200 patients (15-30 years old, 95 males and 105 females)	Cone Beam Volumetric Tomography with ILUMATM Reconstructed layer thickness 0.5mm with 512 x 512 matrix. 120 kVp 3 – 8 mA High-frequency generator with fixed anode and 0.5mm focal spot. A single 40-second-high-resolution scan. Voxel size 0.25mm. Each condyle is visualized with a range of grayscale from –1350 to 1650	The condylar volume, the area, and the morphological index (MI) were compared among class I, class II, and class III young adult subjects.	Q2
Barghan et al.	2012	Review Article	-	-	-	Application of cone-beam computed tomography for assessment of the temporo-mandibular joints	Q1
Larheim TA, et al	2015	Review Article	-	-	-	Temporomandibular joint diagnostics using CBCT.	Q1

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Author	Year	Type of Study	Number of TMJs	Sample	CBCT Unit	Title	Scopus Index
Dos Anjos Pontual et al.	2012	Observational Study	638 TMJs	319 patients (250 women and 69 men, range 10-89 years old) Data from adult subjects were excluded	iCAT Classic 14-bit resolution 120 kVp 5 mAs Voxel size 0.30mm	The differences in the percentage of bone changes among the categories of mobility were compared (ipo, iper, normo, and based on mouth opening), and the right and left sides	Q1
Zhang et al.	2014	Cross-Sectional Study	42 TMJs (dry human skulls)	42 TMJs evaluated by seven dentists	ProMax 3D Normal Res: 84kV, 12mA, 12s FOV 80x80 Voxel size 0.32mm Slice Thickness 0.96mm High Res: 84kV, 12mA, 12s FOV 80x80 Voxel size 0.16mm Slice Thickness 0.48mm DCT PRO Normal Res: 85kV, 6mA, 15s FOV 160x70 Voxel size 0.30mm Slice Thickness 1.00mm High Res: 85kV, 6mA, 24s FOV 160x70 Voxel size 0.20mm Slice Thickness 1.00mm	Detection accuracy of condylar defects in cone-beam CT images scanned with different resolutions and units	Q1
Al-Saleh MAQ et al	2015	Research Article	20 TMJs	Ten adult patients (20 TMJs) with a history of TMJ disorders	iCAT scanner medium FOV 16cm x 13cm 26s Voxel size 0.25mm	Accessing the reliability of MRI-CBCT image registration to visualize the temporomandibular joints	Q1

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Author	Year	Type of Study	Number of TMJs	Sample	CBCT Unit	Title	Scopus Index
Al-Koshab M et al	2015	Research Article	200 TMJs	100 subjects CBCT images of patients of Malay and Chinese ethnicity (mean age 30.5 years)	iCAT imaging System 120 kVp, 3-7 mA, 20s	Assessment of Condyle and Glenoid Fossa Morphology Using CBCT in South East Asians	Q1
Park IY, et al	2015	Original Article	120 TMJs	CBCT images of 60 adult patients (34 women and 26 men aged 20-40 years old (mean age: 25.52±4.97 years)	Alphard VEGAunit 80kV, 5mAs, 15s Voxel size 0.39mm3 The exposure field is 200mm in diameter and 179mm in height	3D cone-beam computed tomography-based comparison of condylar position and morphology according to the vertical skeletal pattern	Q1
Zhang Y, et al	2017	Research Article	20 TMJs	Ten asymptomatic subjects (4 females and 6 males, 26.75 ± 4.89 years old)	KaVo 3D Exam 120kVp, 3-8mA, 20s Voxel size 0.4mm Resolution cross-sectional 400x400pixels Pixel size 0.4mm Slice thickness 0.4mm	Comparison of Morphologic Parameters of Temporomandibular Joint for Asymptomatic Subjects Using the 2D and 3D Measuring Methods	
Hasebe A, et al	2019	Original Article	332 TMJs	166 Subjects Japanese adults (61 men, mean age 27.2 6 7.6 years; 105 women, mean age 27.4 6 9.2 years)	CB MercuRay 100kVp, 10mA, 9.6s F-mode 512slices/scan Slice width 377m Voxel size 0.378mm KaVo 3D Exam 120kvp, 5mA, 17.8s 432slices/scan Slice width 400m Voxel size 0.4mm	Comparison of condylar size among different anteroposterior and vertical skeletal patterns using cone-beam computed tomography.	Q1
Gorucu-Coskuner H. et al.	2019	Original Article	60 TMJs	30 patients (Age range: 15-22 years old	iCAT imaging system 120kVp, 2mA, 17.8s FOV 23x17cm Voxel size 0.30mm	Reliability of cone-beam computed tomography for temporomandibular joint analysis	Q1
Santander P. et al.	2020	Cross-Sectional Study	222 TMJs	111 participants (49 male and 62 female, mean age 27.0±10.2 years)	PaX Zenith 3D FOV 240 x 190mm Voxel size 0.3mm	Comprehensive 3D analysis of condylar morphology in adults with different skeletal patterns – a cross-sectional study	Q1

Table 2. List of Observation Results and Perspectives of Inclusive Research

Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Saccucci et al.	2015	Observational Study	188 TMJs	94 patients (46 females and 48 males; 15–30 years old)	No significant difference was observed in the entire sample between the right and left sides in the Condylar volume	Higher condylar volume is a common characteristic of subjects with low mandibular plane angles than subjects with normal and high mandibular plane angles. Skeletal class is also related to the volume and surface of the condyles.
Saccucci et al.	2015	Observational Study	400 TMJs	200 patients (15-30 years old, 95 males and 105 females)	The Kruskal-Wallis test and the Mann-Whitney test revealed no significant difference in all samples between the volumes of the right and left condyles. Skeletal Class III* subjects showed significantly higher condylar volumes ($P < 0.05$); A significantly lower Condylar volume was observed in class II* subjects ($P < 0.05$). The condyle volume and condyle surface were significantly higher in men than in women in the whole sample. *classification of malocclusion	Skeletal class relates to the volume and area of the mandibular condyle in the Caucasian population with orthodontic treatment.
Barghan et al.	2012	Review Article	-	-	-	CBCT is a rapidly developing imaging modality of choice used to evaluate the bony component of the TMJ. CBCT provides a high-resolution multiplanar image of the TMJ and a lower radiation dose than CT. CBCT provides essential information to assist in diagnosing various TMDs, including osteoarthritis, inflammatory arthritis, trauma, and developmental disorders.

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Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Dos Anjos Pontual et al.	2012	Observational Study	638 TMJs	319 patients (250 women and 69 men, range 10–89 years old) Data from adults subjects were excluded	Bone changes were present in 227 (71%) patients. A statistically significant relationship between age and sex groups with bone changes (p 0.05). There was no significant difference between the right and left sides (P = 0.556) and in the mobility of the condyles (P = 0.925) associated with the presence of degenerative bone changes.	There is a high prevalence of degenerative bone changes in the TMJ, which are more common in women and are primarily located in the condyle. The prevalence of degenerative bone changes increases with age. There is no correlation between condylar mobility and degenerative bone changes in the TMJ.
Zhang et al.	2014	Cross-Sectional Study	42 TMJs	42 TMJs evaluated by seven dentists	Of the 42 condyle surfaces, 18 were normal, and 24 had defects on the condyle surfaces. No significant differences were found between the standard and high resolution scanned images on the CBCT ProMax 3D (p50,119) and DCT PRO (p50,740) units. There was a significant difference between the groups of DCT PRO and ProMax 3D images (p 0.05). Neither the inter- nor intraobserver variability was significant.	The spatial resolution has no impact on the defect detection accuracy in the condyle. The accuracy of detecting defects in the condyle depends on the CBCT unit used for the examination.
Al-Saleh MAQ et al	2015	Research Article	20 TMJs	Ten adult patients (20 TMJs) with a history of TMJ disorders	75% of the registered "non-guided registration" images showed good quality, and 95% of the "marker guided registration" images showed poor quality. Significant differences were found between "non-guided" and guided." Subcortical erosions and cysts are seen less frequently on MRI-CBCT images than on CBCT images	"Non-guided registration" proved superior to "marker guided registration." Although the combined MRI-CBCT images are slightly more limited than CBCT alone for detecting bony abnormalities, the combined images can improve consistency among examiners in detecting the position of the disc with the condyle.

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Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Al-Koshab M. et al.	2015	Research Article	200 TMJs	100 subjects CBCT images of patients of Malay and Chinese ethnicity (mean age, 30.5 years)	There were no significant differences in gender for RGF (Roof of Glenoid Fossa) thickness and condyle length; however, condyle volume, width, height, and joint space were significantly greater among males. The mean condyle volume, width, and length of the right TMJ were significantly higher, while the mean height and thickness of the left RGF condyle were higher than in women. When comparing condyle measurements and RGF thickness between the two ethnic groups, no significant difference was found for all measurements except the higher condyle height among the Chinese population.	The similarity in measurements for the Malay and Chinese populations may be due to coming from the same area of origin. This information can be clinically valuable in establishing diagnostic criteria for condyle volume, metric size, and position in the Malaysian East Asian population.
Park IY, et al.	2015	Original Article	120 TMJs	CBCT images of 60 adult patients, 34 women and 26 men aged 20−40 years (mean age, 25.52±4.97 years)	There were significant differences in the superior joint space, anteroposterior condyle width, mediolateral condyle width, condyle head angle, and condyle shape between the hypodivergent and hyperdivergent groups.	The position and morphology of the condyles vary according to the morphology of the vertical face. This relationship should be considered to predict and establish an appropriate treatment plan for temporomandibular disease during orthodontic treatment
Larheim TA et al.	2015	Review Article	-	-	-	For assessing inflammatory activity and soft tissue abnormalities such as internal disturbances in patients with TMD, MRI is the choice. There is insufficient knowledge about the impact of the resulting CBCT examination on patients.

Table 2. List of Observation Results and Perspectives of Inclusive Research

Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Zhang Y et al.	2017	Research Article	20 TMJs	Ten asymptomatic subjects (4 females and 6 males, 26.75 ± 4.89 years old)	There were statistically significant differences in the angle (HCA = horizontal condylar angle and SRA = sagittal ramus angle) and joint space (MJS = medial joint space, LJS = lateral joint space, SJS = superior joint space, and AJS = anterior joint space) between groups A and B. HCA in group B was more significant than in group A ($p < 0\ 05$). There was no significant difference for CCA between groups A and B ($p > 0\ 05$). SRA in group B was higher than in group A ($p < 0.05$). MJS, LJS, and SJS in group B were more significant than in group A ($p < 001$). AJS in group B was also more significant than group A ($p < 0.05$)	There were significant differences in TMJ morphology parameters measured in 2D CBCT images and 3D reconstruction models. In addition, the reconstructed 3D model shows the actual stereoscopic structure and spatial position of the TMJ, so the 3D measurement method is more accurate for doctors to investigate the morphology of the TMJ.
Hasebe A. et al.	2019	Original Article	332 TMJs	166 subjects Japanese adults (61 men, mean age 27.2 6 7.6 years; 105 women, mean age 27.4 6 9.2 years)	Gender as a covariate showed statistically significant differences in most of the examinations. Condyle heights on both sides had statistically different anteroposterior skeletal patterns ($P < 0.001$). The width of the condyles on both sides also had a statistically different vertical skeletal pattern ($P < 0.001$). After adjusting for gender, the height and width of the condyles on both sides increased from Class II, Class I, and Class III malocclusion classifications. The width of the condyles on both sides increased in the hypodivergent group, the normodivergent group, and the hyperdivergent group.	

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Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Gorucu-Coskuner H. et al.	2019	Original Article	60 TMJs	30 Patients	The ICC values for the measurement of the posterior joint space by observer one and the measurement of the posterior, medial, and lateral joint space by observer 2 were good, while the other intraobserver measurements were very good. Only the mediolateral width measurement showed an excellent interobserver ICC value, while other measurements showed a good interobserver ICC value. Intraobserver agreement for classifying sagittal morphology was moderate (k = 0.479) and almost perfect (k = 0.858) for observers I and II, while the appropriate agreement for the classification of coronal morphology was essential for both observers. Interobserver agreement values for sagittal and coronal morphology were low (k = 0.181) and moderate (k = 0.265).	Measurement of the linear temporomandi-bular joint can be performed and is reliable in intraobserver and interobserver evaluation. However, the agreement between observers for assessing the shape of the condyle is low.

Table 2. List of Observation Results and Perspectives of Inclusive Research

Author	Year	Type of Study	Number of TMJs	Sample	Result	Conclusion
Santander P. et al.	2020	Cross-Sectional Study	222 TMJs	111 participants (49 male and 62 female, mean age 27.0±10.2 years)	(1) Transverse: Asymmetrical patients showed significantly higher differences in the C/Mand volumetric ratio on the deviated and non-deviated sides compared to symmetrical patients. (2) Sagittal: Class III patients showed longer and thicker condyles with higher anteroposterior and mediolateral inclination angles compared to Class II patients. (3) Vertical: hyperdivergent patients have smaller condyles with a higher anteroposterior inclination angle than hypodivergent patients. No interaction of skeletal class and vertical relationship regarding condyle morphology was observed.	This study demonstrated a clear correlation between skeletal pattern and condyle morphology in the adult population. Description of radiographic condyle characteristics related to craniofacial morphology makes orthodontic treatment planning better and can assist in diagnosing temporomandibular joint pathology.

Although CBCT can provide an accurate image, several parameters can affect CBCT image quality, including the X-ray factor, FOV, detector type, and reconstructed voxel size. Each CBCT unit has different parameters but can be adjusted on most CBCT units. It should be a concern for practitioners to adjust the parameters of the CBCT unit to produce optimal images according to the purpose of the examination being carried out.

Scans with a small FOV can provide sufficient anatomic coverage for the condylar head area, glenoid fossa, and TMJ articular eminence. Although using a small FOV, some researchers claim that image results can provide an excellent visualization, especially when there is a change in the TMJ. CBCT unit with a full FOV scan can also be used to evaluate TMJ. Image size varies from 10 cm–20 cm, and voxel size from 200 µm–400 µm. Larger FOV and voxel size needs to be considered because the image result has a smaller resolution and is less detailed, so it is not suitable to detect early changes that occur in bone.[17]

FOV, VOXEL SIZE AND TIME

Different parameters have a direct influence on the resolution of an image. Voxel size is one of the most important parameters; however, FOV, scan time, number of basis images, and type of detector also influence the resolution and quality of the scan. FOV refers to the anatomical area that will be included in the data volume or the area of the patient that will be irradiated. The dimension of FOV depends on the detector size and shape, the beam projection geometry, and the ability to collimate the beam.[25,26] Voxel size or volumetric element is an important component of image quality, related to both the pixel size and the image matrix. A voxel is the smallest 3D element of the volume. It is represented as a cuboidal or box-shaped part of the 3D image with height, width, and depth. Voxel size needs to be smaller than the desired anatomical structure for adequate representation.[26,27]

Spatial resolution or sharpness is the ability to distinguish small details in the image that can differentiate two adjacent structures as being distinct from one another. Other related terms include definition or visibility of detail and also determines the accuracy to which anatomic detail can be measured.[28] Spatial resolution is expressed in line pairs per mm (lp mm). The absence of spatial resolution in an image may be referred to as blur.[26,29] Lowering the resolution may reduce the quality of images, increase noise and artifacts, and reduce the amount of anatomical information about the target area.[25]

Several studies have been conducted to investigate the effect of voxel size in detecting defects in TMJ, one of which is Patel et al., who conducted a study on the accuracy of CBCT images in diagnosing erosion of the mandibular condyle with voxel sizes 0.200 mm^3 and 0.400 mm^3. They reported that detecting less than 2mm defects using a voxel size of 0.400 mm3 was more difficult than using smaller FOV and voxel sizes. This concludes that smaller voxel sizes can provide more accurate information in detecting erosion in the mandibular condyle.[30,31] Saccucci et al. compared the volume and position of the condyles based on different skeletal classes. Another study also used CBCT to examine condyle volume in subjects with different mandibular angles and skeletal classes. They stated that examination of the condyle using CBCT provides a complete analysis of multiplanar images in the axial, sagittal, and coronal planes and three-dimensional information that is very useful for evaluating volume, morphology, and seeing the presence or absence of pathological abnormalities in the condyle. In addition, the time required for examination with CBCT is shorter than conventional CT.[12,13] Park IY et al. used the CBCT modality to compare the position and morphology of the condyles based on the vertical skeletal pattern. CBCT is a powerful radiographic examination to evaluate the TMJ, especially in diagnosing pathological conditions and seeing the shape and position of the condyles, because it provides accurate three-dimensional visualization.[4] This is in line with the cross-sectional studies conducted by Santander et al. and articles by Barghan S. et al., which demonstrated that CBCT could produce anatomical images of the TMJ that can be reconstructed in a parallel and perpendicular plane according to the condylar axis so that the position of the condyle to the glenoid fossa can be seen more clearly without overlapping with other anatomical structures. The distortion that occurs is very minimal.[17,32]

Another study stated that a smaller FOV and voxel size could provide a more accurate picture in detecting erosion of the TMJ.[33] Bone changes that occur in the TMJ associated with osteoarthritis can be detected by CBCT in detail. Synovial chondromatosis in the TMJ can be detected by CBCT examination by showing multiple calcifications, widening of the joint space, and a sclerotic glenoid fossa. Trauma evaluation using CBCT can also provide accurate three-dimensional information. Gorucu-Coskuner et al., in their study of the reliability of TMJ analysis with CBCT, wrote that examination of anatomical structures using two-dimensional radiographs is not easy to do because of many overlapping anatomical structures. Hence the use of CBCT as a modality to evaluate bone structure in the TMJ is increasing.[14] Previous case reports also stated that CBCT could be

used to detect abnormalities that occur in the TMJ, such as fractures, osteoarthritis, and ankylosis. Studies that examined TMJ dimensions and joint space measurements of dry human skulls using CBCT showed very similar results to actual measurements.[34,35]

COMPARISON BETWEEN CBCT WITH OTHER RADIOGRAPHY EXAMINATIONS

Other studies have also revealed that the evaluation of the TMJ with CBCT is more accurate than using 2D radiography. Yuanli Zhang et al. compared TMJ examination using 2D images and 3D images from CBCT. The study results showed that 3D reconstructed images from CBCT are more accurate than 2D images from CBCT for morphology examination of the condyle head.[36]

Al-Saleh et al. conducted a study on MRI-CBCT image registration to visualize TMJ using Miranda XD software. It was found that the combination of images from MRI and CBCT can provide a more accurate picture in the interpretation of TMJ characteristics, especially for detecting and evaluating disc position. The relationship between the disc position and condyle head and articular eminence was also seen as more optimal using these image combinations than using only MRI, although MRI is the gold standard for viewing the condition of the articular disc.[18] The study conducted to compare CBCT with Multidetector CT showed no significant difference between the results of the TMJ examination with CBCT and Multidetector CT. It was concluded that CBCT has the same reliability and accuracy as Multidetector CT for examining the TMJs space and changes in the TMJ.[37] Honda et al. reported that several studies have shown that CBCT has high accuracy when used to evaluate TMJs structures. Their research found that the results of condyle measurements with CBCT did not have a significant difference from the actual size of the condyle. This became the basis for the study conducted by Al-Koshab et al. on the condyle and glenoid fossa morphology in the South-East Asian group using CBCT examination.[22] Most studies that have been carried out have shown that CBCT has a high specificity; hence it can replace CT examination for a TMJ evaluation. Researchers who compared the level of accuracy between CBCT, CT, micro CT, and microscopic examination stated that CBCT had the highest accuracy rate for detecting erosions in the condylar bone cortex.[24] This is in line with research conducted by Hintze et al., which states that erosion on the condyle surface is easier to detect with CBCT.[38]

IMAGE QUALITY OF CBCT

Spatial resolution is considered a determining indicator of CBCT image quality; thus, many CBCT units provide a choice of high or standard spatial resolution. However, the image quality of CBCT images is not only determined by the selected spatial resolution but is also determined by several other factors such as detector type, field of view (FOV), and tube voltage (kVp). One of the main advantages of CBCT is its ability to produce scans with multiple FOVs; therefore, the scan can be determined according to the need or purpose of the examination.[39] Although CBCT with a large FOV has limited utility in most conditions, the American Academy of Oral and Maxillofacial Radiology suggests that image acquisition with a medium or large FOV may be indicated for evaluation of anteroposterior, vertical, and transverse differences, asymmetry, and signs and symptoms of TMD.[40] Another study stated that CBCT with small FOV and voxel size has a high level of accuracy in detecting erosion that occurs in the TMJ.[17] One of the studies conducted in 2010 by Librizzi Z., et al. compares 6-inch, 9-inch, and 12-inch FOV CBCT results. This study suggests that 6-inch FOV and 0.2mm voxel size (CB MerCurayTM) could provide a significantly better picture (Figure 2).[37] Examination of the condyle with 0.25mm voxel size (ILUMATM) was also detailed. Most studies evaluating the condyles' defects, morphology, and morphometry used small voxel sizes (0.2mm – 0.4mm).

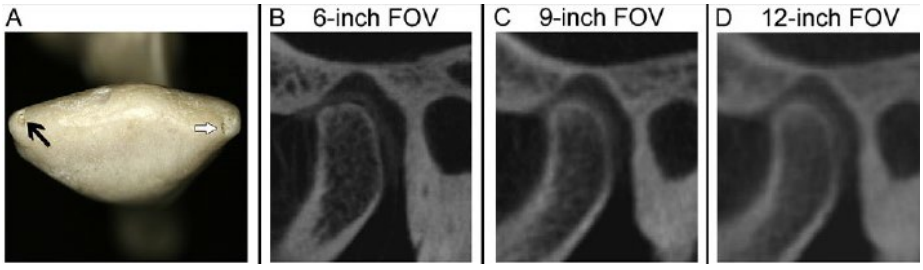

Figure 2. A: Simulation view of the TMJ with erosions (black arrows) and bone defects (white arrows). B-D: Comparison of the reconstructed image of the CBCT with 6-inch, 9-inch, and 12-inch FOV. Seen a smaller FOV gives a more detailed picture. (Librizzi Z, et al. 2010)

Zhang et al., in their study, showed that there was no significant difference between condylar examination with large FOV and standard FOV. Another study also showed no significant difference between high spatial resolution and standard spatial resolution in detecting defects on the condyle surface.[37] Comparison of 6-inch, 9-inch, and 12-inch FOV with voxel sizes 0.2mm, 0.3mm, and 0.4mm concluded that small FOV could provide high diagnostic effectiveness for detecting condyle erosion.[33] Previous studies conducted by Marques et al. to see the sensitivity of CBCT in detecting minor defects in the condyle found that CBCT has a reasonably high sensitivity (72.9% - 97.5%) in detecting defects on the bone surface of the condyles with small FOV.[41] Based on research conducted by Kurt et al., voxel size 0.100 mm^3 and 0.075 mm^3 have a higher success rate in detecting defects that occur in the TMJ. There is a significant increase in the success of defect detection by reducing voxel size from 0.400 mm^3 to 0.075 mm^3. From the resulting image, it can be seen that there is an increase in image detail when the voxel size is reduced (Figure 3).[31] Although there is an increase in noise when the voxel size gets smaller,[42–45] This study states that a small voxel size can provide better diagnostic results and more details.[31]

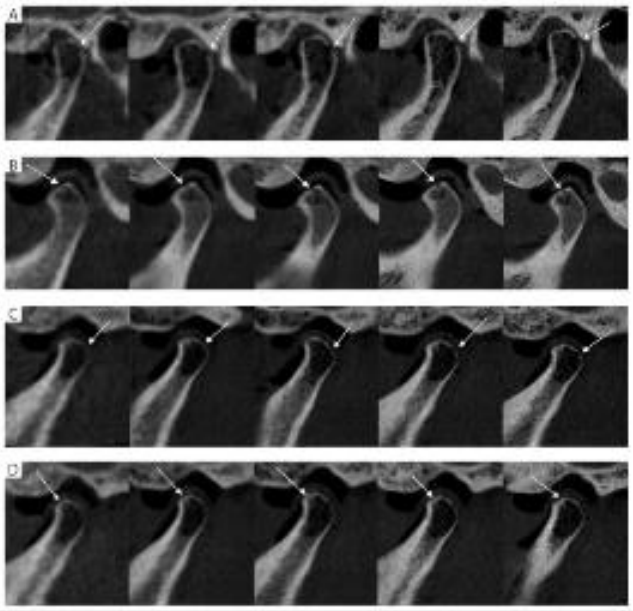

Figure 3. CBCT image of the visible defect in the mandibular condyle with various voxel sizes. **A)** Defect measuring 1.6mm with voxel size of 0.400 mm^3, 0.200 mm^3, 0.150 mm^3, 0.100 mm^3, or 0.075 mm^3. **B)** Defect measuring 1mm defect at a voxel size of 0.400 mm^3, 0.200 mm^3, 0.150 mm^3, 0.100 mm^3, or 0.075 mm^3. **C)** Defect measuring 0.8mm defect at a voxel size of 0.400 mm^3, 0.200 mm^3, 0.150 mm^3, 0.100 mm^3, or 0.075 mm^3. **D)** No defects with voxel size of 0.400 mm^3, 0.200 mm^3, 0.150 mm^3, 0.100 mm^3, or 0.075 mm^3. (Kurt MH, et al. 2020)

The dentists need to determine the radiographic modality for examination of the TMJ as a support for the diagnosis and appropriate treatment plan. Based on several studies that have been carried out, it appears that CBCT can produce an accurate picture to evaluate the morphology and morphometry of the condyle, especially in detecting and diagnosing abnormalities that occur. Further research may need to be carried out to obtain more significant results considering that the research conducted did not use a large sample and was only conducted on a few ethnicities and races; hence it cannot be generalized to a population.

CONCLUSION

CBCT can produce images with high resolution, but the radiation dose remains low compared to conventional CT. The result of high-resolution images can provide an excellent three-dimensional image for viewing bone changes in TMJ. However, in practice, high spatial resolution is not better than standard spatial resolution. High spatial resolution causes radiation also to increase. Thus for TMJ evaluation is recommended to use standard spatial resolution because it provides a lower radiation dose. The selection of FOV and small voxel size is also recommended because they provide a better description and detail for evaluating morphology and morphometry of the mandibular condyle, especially the detection of erosion and defects on the condyle surface.

CONFLICT OF INTEREST

The authors declare no interest in business regarding the content of this manuscript.

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