

In-Vitro Comparison of the Diagnostic Accuracy of CBCT and Helical CT for Detection of Mandibular Condyle Erosions

S. Sharifi Shoostari ¹, V. Maserat ²,  A. Dabbaghi ¹, SH. Shahab ³, H. Shahraki Ebrahimi ⁴, M. Pourmahdi ⁵,
M. Davoodi ⁶, MA. Kavooosi ⁷

¹Assistant Professor, Department of Oral and Maxillofacial Radiology, School of Dentistry, Ahvaz Jundi Shapur University of Medical Sciences, Ahvaz, Iran

²Assistant Professor, Department of Oral and Maxillofacial Radiology, School of Dentistry, Zahedan University of Medical Sciences, Zahedan, Iran

³Assistant Professor, Department of Oral and Maxillofacial Radiology, School of Dentistry, Shahed University, Tehran, Iran

⁴Postgraduate Student, Department of Endodontic, School of Dentistry, Zahedan University of Medical Sciences, Zahedan, Iran

⁵Assistant Professor, Department of Food Hygiene, School of Veterinary Medicine, Shahid Chamran University of Medical Sciences, Ahvaz, Iran

⁶Assistant Professor, Department of Head of Radiology, School of Medicine, Ahvaz University of Medical Sciences, Ahvaz, Iran

⁷Oral and Maxillofacial Radiologist

Abstract

Background and Aim: Temporomandibular joint (TMJ) dysfunction is the most common jaw disorder. TMJ imaging may be necessary to supplement information obtained from the clinical examination. The purpose of this study was to compare the diagnostic accuracy of helical computed tomography (CT) and cone beam computed tomography (CBCT) for detection of simulated mandibular condyle erosions.

Materials and Methods: In this in-vitro study, simulated lesions were created in 15 dry mandibles using a dental round bur. Using CBCT and helical CT techniques, mandibular condyles were radiographed before and after creating the lesions. The images were examined by two oral and maxillofacial radiologists for absence or presence of lesions. The accuracy for detecting mandibular condyle lesions was expressed as sensitivity, specificity, positive and negative predictive values. Differences between the two radiographic modalities were analyzed by McNemar's test. Inter-observer agreement was determined using Kappa coefficient.

Results: The maximum sensitivity, specificity and accuracy were 100%, 100% and 100% for CBCT images, respectively and 88%, 100% and 98% for helical CT images, respectively. No statistically significant difference was found between the accuracy of CBCT and helical CT for detection of mandibular condyle erosions ($p = 1$).

Conclusion: CBCT is a lower-dose cost-effective alternative to helical CT for diagnostic evaluation of erosion of the mandibular condyle.

Key Words: Mandibular condyle, Helical computed tomography, Cone beam computed tomography

 Corresponding author:
V. Maserat, Assistant Professor,
Department of Oral and
Maxillofacial Radiology, School
of Dentistry, Zahedan University
of Medical Sciences, Zahedan,
Iran
vidamaseratt@gmail.com

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Introduction

TMJ is comprised of the mandibular condyle, glenoid fossa, articular eminence and the articular disc [1]. TMJ disorders are among the most common jaw disorders compromising the shape and normal

function of the joint; 28%-86% of adults show one or multiple clinical signs and symptoms [2]. Clinical examinations are often not sufficient to reach a definite diagnosis regarding different conditions affecting the TMJ. In order to detect TMJ disorder

ers, complimentary imaging studies are necessary. Thus, a combination of clinical examinations and imaging workup are required to detect TMJ disorders [3, 4].

Erosion is among the first and most common degenerative changes of the TMJ indicating its instability. Radiographically, erosion manifests as an area with decreased density of the bone cortical plates [5].

Conventional imaging techniques commonly used for the TMJ include panoramic, submentovertex, transcranial, transpharyngeal and lateral cephalometric radiography as well as conventional tomography, computed tomography (CT) and magnetic resonance imaging (MRI). More recent techniques include VCT (CBCT), ultrasonography, 3D reconstructions and rapid prototyping (RP) [4].

Detection of some skeletal changes (such as erosion and osteophytes) is difficult by conventional radiography due to superimposition and overlapping of adjacent anatomical landmarks/structures [3, 4].

At present, new imaging modalities namely CT and MRI are used for radiographic examination of TMJ.

MRI is among the most beneficial imaging modalities for the evaluation of hard and soft tissues of the TMJ. However, it has some shortcomings as well including its contraindication in some patients, high cost, long scanning time, limited accessibility of its equipment, requiring a large space and difficult image interpretation [6, 7].

CT is an imaging modality used for the diagnosis and treatment of bonedefects due to its high sensitivity and specificity. CT well manifests the anatomy of the joint and TMJ disorders. However, its application in the joint area is limited due to its high exposure dose [3, 7].

Recently, use of CBCT for the assessment of the maxillofacial area has gained popularity among dentists. It provides reconstructed images of high diagnostic quality with lower exposure dose and shorter scanning time compared to CT [8].

Knowledge about the diagnostic accuracy of an imaging system is necessary for its use in the clinical setting [9]. Therefore, this study aimed to assess and compare the diagnostic accuracy of helical CT and CBCT for detection of mandibular condyle erosions.

Materials and Methods

This in-vitro study was conducted on 15 dry human mandibles that were collected and coded in order to compare the diagnostic accuracy of CBCT and helical CT for detection of mandibular condyle erosions. The collected specimens were free from fracture or apparent erosion of condyles. However, mild erosions were allowed in some of the samples in order to obtain more accurate results and prevent observer errors. The position of these erosions on the condyles was determined and recorded in a specific form. Due to the difficult collection of specimens and based on the statistician's opinion, each mandible was radiographed twice: before and after creating erosive lesions on condyles. First, intact specimens were radiographed by the helical CT and then by CBCT. For helical CT (Sensation 64 slice, Siemens), mandibles were placed in a plastic container. The container was filled with water in order to simulate soft tissue. Condyles were completely immersed in water. A radiology technician adjusted the beams on the specimens and imaging was performed with inner ear protocol (imaging of the internal ear and its surrounding structures) (Figure 1). Obtained images were evaluated on an Acquisition computer. Images were then coded similar to specimens and saved on a DVD. Helical CT exposure settings included 120 kVp, 70 MAS, 0.6mm slice, 0.6mm thickness and 1.4 pitch.



Figure 1. A. Placing specimens in a plastic container filled with water, B. Helical CT (Sensation 64 slice, Siemens) and positioning of the specimen

For CBCT imaging (NewTom, VGi), mandibles were fixed in a suitable position with adhesive tape following beam adjustment. In order to simulate X ray attenuation by soft tissue, CBCT denture mode was chosen (Figure 2).



Figure 2. CBCT (NewTom VGi) and positioning of the specimen

Images were obtained with 12x8 HRS (high resolution) and maximum field of view (FOV). The exposure settings included 110 kVp and 27.07 MAS. Similar to CT images, CBCT images were also evaluated on an Acquisition computer. Each image was coded similar to the specimen and saved on a DVD. After obtaining helical CT and CBCT images of the erosion-free condyles, 5 areas were selected on each condyle: anterior, posterior, superior, medial and lateral. In order to simulate erosion of condyles, holes were created on the mentioned 5 areas using a high-speed hand piece and a round bur (a total of 75 lesions, 15 in the anterior, 15 in the posterior, 15 in the superior, 15 in the medial and 15 in the lateral surfaces of condyles). Thus, a condyle could have no (zero), one or a maximum of 5 erosive lesions. In terms of size, erosions were equal to the diameter of a round bur (0.1 mm) with a depth equal to half the diameter of a round bur (0.05 mm). All prepared specimens underwent CT and CBCT imaging (with the same technique and exposure settings described earlier). Coding of the 15 sound specimens was different from the coding of 15 specimens with condyle erosions. Eventually, 30 helical CT and 30 CBCT images were evaluated by two observers (both oral and maxillofacial radiologists). They were blinded to the presence or absence, location and number of erosive lesions on condyles. Images were randomly given to the observers. Each ob-

server independently evaluated the images in a dimly lit room at a specific time of the day (similar lighting conditions) on a 14-inch monitor (LED flat screen, Sony) with 1280x800 resolution. For the observation of CBCT images, NNT software (0.5mm thickness, 1mm step) was used (Figure 3). In order to observe CT images obtained with 0.6mm slice thickness, Syngo software was used (Figure 4). For evaluation of erosion on different surfaces of condyles on CBCT and helical CT images at two different time points (intra-observer), observers evaluated the images again after a 10-day time interval. The results were recorded in a specific form and data were analytically and descriptively analyzed using Excel and SPSS version 16. Sensitivity, specificity, accuracy and positive and negative predictive values of helical CT and CBCT were all calculated and the level of agreement between the two imaging techniques was evaluated using kappa coefficient. Data were analyzed using McNemar's test.

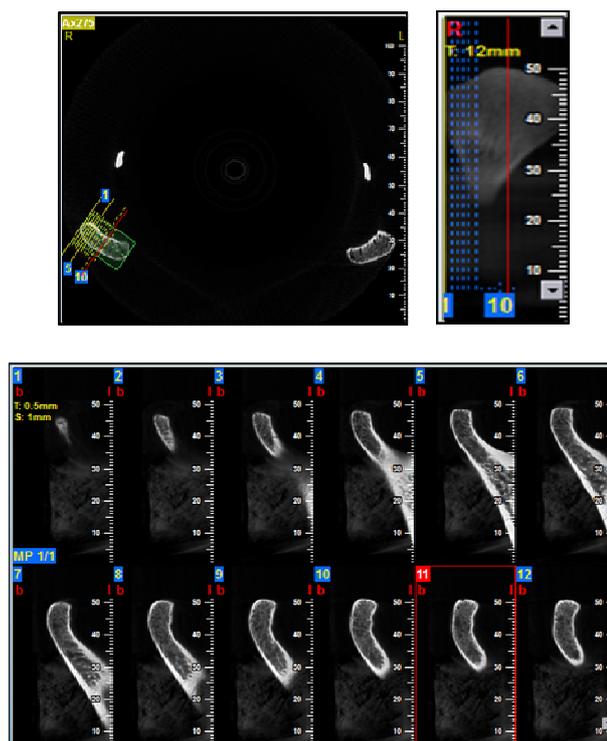


Figure 3. A CBCT image (axial reference parasagittal transerial and panoramic reformatted) observed with NNT software

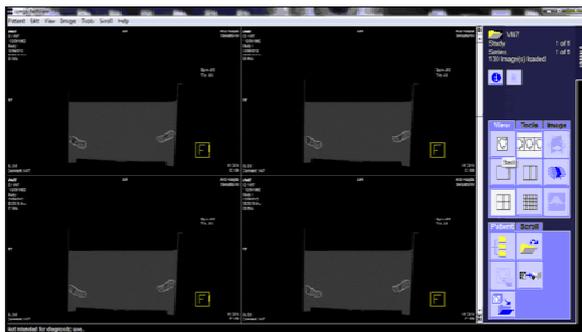


Figure 4. An axial CT image observed with Syngo software

Results

The results of the evaluation of condyle erosions on CBCT images by the observers were not significantly different from the gold standard and the range of agreement was found to be 0.29-1.

The results of the evaluation of condyle erosions on helical CT images by the observers were not significantly different from the gold standard and the range of agreement in the superior, posterior, anterior and lateral surfaces was found to be 0.25-0.93. In the medial surface, this agreement was not statistically significant (0.11).

Comparison of the CBCT results reported by the two observers showed no significant difference in erosion of different surfaces of condyles and the range of agreement was 0.52-1.

Comparison of the helical CT results reported by the two observers showed no significant difference in erosion of different surfaces of condyles and the range of agreement was 0.28-0.61.

Comparison of the CBCT and helical CT results reported by the two observers showed no significant difference between the two imaging modalities in detection of the erosion of different surfaces of condyles and the range of agreement was 0.36-0.93.

Comparison of the CBCT results reported by the two observers at two different time points revealed no significant difference in erosion of different surfaces of condyles at two different time points and the range of agreement was 0.52-1.

Comparison of the helical CT results reported by the two observers at two different time points revealed no significant difference in erosion of different surfaces of condyles at two different time points and the range of agreement was 0.77-1.

Comparison of the CBCT results for erosion of different surfaces of condyles reported by the two observers with the gold standard revealed that the sensitivity of CBCT was minimum at the lateral surface (27%) and maximum at the superior, posterior and anterior surfaces (100%). The specificity of CBCT was minimum for the medial and lateral surfaces (94%) and maximum for the superior, posterior and anterior surfaces (100%). The accuracy of CBCT at different surfaces was minimum for the medial and lateral surfaces (83%) and maximum for the superior, posterior and anterior surfaces (100%). The positive predictive value of CBCT was minimum for the medial (50%) and maximum for the superior, posterior and anterior surfaces (100%). The negative predictive value of CBCT was minimum for the lateral surface (85%) and maximum for the superior, posterior and anterior surfaces (100%).

Comparison of the helical CT results for erosion of different surfaces of condyles reported by the two observers with the gold standard revealed that the sensitivity of helical CT was minimum for the medial surface (22%) and maximum for the superior surface (88%). The specificity of helical CT was minimum for the medial surface (88%) and maximum for the superior and posterior surfaces (100%). The accuracy of helical CT was minimum for the medial surface (78%) and maximum for the superior surface (98%). The positive predictive value of helical CT was minimum for the medial (25%) and maximum for the superior and posterior surfaces (100%). The negative predictive value of helical CT was minimum for the medial and lateral surfaces (86%) and maximum for the superior surface (98%).

Discussion

Clinical examinations alone are not sufficient for detection of different conditions compromising the TMJ [4]. Radiography is an adjunct that can suggest presence of a pathology [10]. Thus, a combination of clinical and radiographic examinations of the TMJ is important for detection of TMJ disorders [3, 4]. This joint, due to the relatively small size of condyle (approximately 5x20mm), is covered by the cranial bones and is usually not seen on conventional radiographs. Thus, imaging of this area is difficult [11]. Mandibular condyle erosion

and decreased articular space are among the radiographic patterns indicative of TMJ degenerative conditions [3]. Erosion is among the first and most common degenerative changes of the joint and indicates its instability. Radiographically, erosion manifests as an area with decreased density of the bone cortical plates [5]. Conventional radiography has limited application for the assessment of the TMJ due to the superimposition of the adjacent structures, overlapping of the neighboring anatomical landmarks, providing a 2D view of the area and its innate distortion [3, 4]. CT does not have any of the limitations of conventional radiography and provides a high contrast view of the maxillofacial region with no superimposition [12, 13]. This technique is used for the assessment of TMJ bone lesions with satisfactory results [3]. However, it also has some limitations for use particularly in the TMJ area such as high cost, inaccessibility and more importantly high exposure dose [3,7].

In the recent years, CBCT has been suggested for radiographic assessment of the maxillofacial area [8]. CBCT provides accurate images with high resolution and quality at a much shorter scanning time, lower cost and more importantly lower exposure dose compared to CT [8]. Therefore, it has replaced CT for the assessment of the maxillofacial area and particularly for the evaluation of TMJ bonelesions [14].

Only a few studies have compared CBCT and CT for the assessment of TMJ bonedefects and only one previous study was found resembling our study.

This study was conducted on 15 dry human mandibles. However, in contrast to Honda's study, ours was an in-vitro study. Specimens were radiographed after soft tissue simulation. We only evaluated simulated erosive lesions created in 5 surfaces of the condyles. The results showed that the sensitivity of CBCT was minimum in the lateral surface (27%) and maximum in the superior, posterior and anterior surfaces (100%). The sensitivity of helical CT was minimum in the medial surface (22%) and maximum in the superior surface (88%). The specificity of CBCT was minimum in the medial and lateral surfaces (94%) and maximum in the superior, posterior and anterior surfaces (100%). The specificity of helical CT was minimum in the medial (88%) and maximum in the

superior and posterior surfaces (100%). The accuracy of CBCT was minimum in the lateral and medial surfaces (83%) and maximum for the superior, posterior and anterior surfaces (100%). The accuracy of helical CT was minimum in the medial (78%) and maximum in the superior surface (98%). Similar to the study by Honda et al, our study showed that CBCT was superior to helical CT for the assessment of erosion at different surfaces of condyles. No significant difference was found between helical CT and CBCT for the assessment of condyle erosion by the observers. The agreement in this regard was found to be 0.36-0.93.

Honda et al, in 2006 (14) compared the diagnostic value of CBCT (3DX) and helical CT for detection of mandibular condyle bone defects. They used macroscopic assessments as the gold standard. They evaluated 21 TMJs (autopsy material) and radiographed them with CBCT (3DX) and helical CT. Specimens were macroscopically evaluated for detection of osteophytes, erosion and sclerosis. Of 21 specimens, 10 mandibular condyles and one fossa had bone defects. CBCT in 8 condyles and helical CT in 7 condyles detected the lesion. The sensitivity of CBCT and helical CT was 0.8 and 0.7 and their accuracies were 0.9 and 0.86, respectively. The specificity of both techniques was found to be 1. No statistically significant difference was found between the helical CT and CBCT for detection of mandibular condyle bone defects ($P=0.286$). Our results confirmed the findings of Honda's study.

Tsiklakis et al, [7] in 2003 radiographically examined TMJs of 5 patients using CBCT and concluded that this technique enables complete radiographic assessment of the bony components of the joint. They reported obtaining reconstructed images of high diagnostic quality, shorter examination time and lower number of patients compared to conventional CT. Eventually, they introduced CBCT as the method of choice for the assessment of TMJ bonelesions. Their study was conducted under in-vivo conditions; which is a strength point for their study. However, their small sample size might have affected the results. Our study was conducted under in-vitro conditions and probably provides greater accuracy compared to the clinical setting where bones are surrounded by the soft tis-

sue. Thus, lower accuracy and specificity values are expected in the clinical setting. However, due to a larger sample size, our results probably have greater reliability. On the other hand, they reported that CBCT was superior to conventional CT while we compared CBCT with helical CT (which is more advanced) and reported similar results.

Honey et al, [15] in 2007 compared the diagnostic accuracy of CBCT with panoramic radiography and linear tomography for TMJ imaging. They evaluated 37 joints of 30 human skulls out of which, 18 had erosion in the lateral bridge. TMJ imaging was done by corrected angle linear tomography (TOMO), normal (Pan-N) and TMJ-specific (Pan-TM) panoramic radiography, and CBCT. CBCT multi-planar images were presented statically (CBCT-S) and interactively (CBCT-I). The inter-observer reliability was assessed using kappa coefficient and the diagnostic accuracy was calculated using area under the roc curve. The inter-observers reliability was moderate (0.22 ± 0.57). Pan-N, CBCT-I and CBCT-S had higher reliability than TOMO. The diagnostic accuracy of CBCT-I and CBCT-S was higher than other techniques. Also, CBCT-I was more accurate than CBCT-S and Pan-N was more accurate than Pan-TM and TOMO. The results of this study showed that CBCT images have reliability and diagnostic accuracy higher than TOMO and TMJ panoramic images for detection of condyle erosions. Their methodology was similar to ours as well. However, they only evaluated erosion in one surface (lateral). Considering our results regarding no significant difference between CBCT and helical CT for evaluation of condyle erosions, the results of Honey et al, (comparing CBCT, panoramic radiography and linear tomography) are not far from expectations. Use of statistical analyses was similar as well. Our study found no difference between the findings of the two observers evaluating CBCT and helical CT for the assessment of condyle erosions at different surfaces ($P > 0.05$).

Marques et al (3) in 2010 evaluated 2 CBCT protocols for detection of simulated condyle bone defects. Spherical defects were created on 30 human dry mandibles using dentist drills with drill bits sizes 1, 3 and 6.

Two CBCT protocols were performed on each mandibular condyle:

1. Axial, coronal and sagittal multiplanar reconstruction (MPR)

2. Sagittal plus coronal slices along the longitudinal axis of the mandibular condyles

Presence or absence of lesions in these protocols was assessed by two observers. Z test was used for statistical analysis. The results showed no statistically significant difference between these two protocols. Detection of small simulated defects (drill 1) was more difficult. Their methodology was somehow similar to ours. Although in our study, defects of the same size (diameter of 0.1mm and depth of 0.05mm) were created. They did not evaluate erosion at different surfaces. They reported that MPR protocol was slightly superior to the other protocol. In our study, observers could observe images in all 3 planes; which is similar to the MPR protocol.

NikKerdar et al, [16] in 2010 evaluated the sensitivity of two different protocols of CBCT for detection of condyle erosions. Based on their results, sensitivity for detection of condyle erosions in the axial and coronal sections (protocol 1) was 81.5%. This rate was 84.8% for the MPR view (protocol 2). The specificity for detection of condyle erosion was 90.7% in protocol 1 and 93.8% in protocol 2. Accuracy was 81.8% in protocol 1 and 89.3% in protocol 2. Based on their results, sensitivity, specificity and accuracy of protocol 2 were higher; however, the difference between the two protocols was not statistically significant ($P > 0.05$). The statistical agreement between the two protocols was relatively complete ($\text{kappa} > 0.61$). No statistically significant difference was found between observers ($P > 0.05$). The highest sensitivity was observed in the erosion of the posterior surface of both protocols. The lowest sensitivity belonged to the erosion of the anterior surface of protocol 1; these differences were not statistically significant ($P > 0.05$). They concluded that the sensitivity of CBCT for all articular surfaces regardless of the site of erosion was high. They only evaluated CBCT; whereas, we compared the accuracy of CBCT and helical CT for the assessment of condyle erosions. By obtaining results superior or even similar to those of CBCT, patients can be spared from the high cost and exposure dose of CT.

Although in our study, the sensitivity, specificity and accuracy of CBCT were higher than those of

helical CT, the difference in this respect between the two imaging modalities was not statistically significant ($P>0.05$) and the range of agreement was 0.36-0.93. Also, similar to their findings, in our study no significant difference was noted between the observers in CBCT (range of agreement 0.52-1) and helical CT (range of agreement 0.28-0.61) images ($P>0.05$). The highest sensitivity for detection of erosion by CBCT belonged to the superior, posterior and anterior surfaces. The lowest sensitivity belonged to the lateral surface of CBCT and medial surface of helical CT. The difference in sensitivity among different surfaces is probably due to the low number of specimens.

Zain-Alabdeen et al, [17] in 2012 compared the accuracy of detection of surfaceosseous changes in the TMJ using multidetector CT and CBCT. They evaluated 110 areas on 10 TMJs of 5 dry skulls. Two radiologists evaluated the images. The sensitivity, specificity and kappa coefficient were calculated. They concluded that both techniques had low sensitivity and high specificity. The intraobserver agreement was high and the interobserver agreement for CBCT was better than for MDCT. Their methodology was similar to ours; although they had a smaller sample size. One limitation of both studies is that only the created lesions were evaluated and other changes such as sclerotic changes and subcortical degeneration of condyles were not assessed.

In previous studies (such as the one by Honda) with no soft tissue simulation, image distortion was less than that in other studies and thus high sensitivity and specificity values are obtained for detection of bone defects. These results are not similar to the results of in-vivo studies. Soft tissue simulation by using a container filled with water is among the similarities between our study and that of Zain-Alabdeen.

Evidence shows that CBCT with low exposure dose (compared to CT) and high resolution can provide high sensitivity, specificity and diagnostic accuracy for the assessment of mandibular condyle erosions compared to helical CT. Also, evaluation of erosion in different surfaces of the mandibular condyle on CBCT and helical CT images revealed no significant difference between these two diagnostic modalities.

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