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# ACCURACY OF CONE BEAM COMPUTED TOMOGRAPHY IN VOLUMETRIC EVALUATION OF THE MANDIBULAR CONDYLE

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***KEYWORDS***

*Cone beam computed tomography, Mandibular Condyle, Volumetric accuracy, Water displacement method*

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## *ABSTRACT*

**Introduction:** The final size of the mandible and several malocclusions are significantly influenced by the condyle. Recently, there has been a lot of interest in using CBCT imaging to evaluate condyle shape and volume. In order to suggest its use in clinical decision-making, it is required to confirm that the information received from CBCT is accurate and trustworthy for measuring condylar volume. **Aim:** To assess the precision of cone-beam computed tomography's volumetric analysis of the mandibular condyle (CBCT) in comparison with real physical volumetric measurements (gold standard). **Materials and Methods:** The present study was conducted on 6 dry human mandibles including 12 condyles. Volumetric measurements of each condyle were carried out using CBCT by automatic segmentation. A replica model of the condyle was obtained and utilized to evaluate the condyle's actual physical volume using the water displacement method (gold standard). The radiographic volumetric measurements of the condyles were compared to the real volumetric measurements and assessed for accuracy. **Results:** Condylar real physical and CBCT volumetric measurements showed very good intra and inter observer agreement**.** Condylar volume assessment showed higher CBCT values in comparison to the physical ones with a mean error = 0.34 $cm^3$, denoting an overestimation in CBCT readings =17.74 %. Despite the fact that the mean physical and CBCT measures were statistically different, the correlation coefficient (r) showed a strong direct correlation between physical and CBCT volume estimations. **Conclusion:** CBCT volumetric measurements using automatic segmentation is a reproducible, fast and feasible method for volume segmentation of mandibular condyles. However, for application in the dental office, clinicians should be cautious when planning treatment procedures involving condylar volume assessment since CBCT tends to significantly overestimate the obtained measurements.

## INTRODUCTION

The development of 3-dimensional imaging technology has allowed physicians and researchers to thoroughly examine diverse cranio-facial structures which were not clearly visualized with 2-dimensional image radiography. CBCT is a relatively recently developed 3-D imaging modality which has become a significant diagnostic technique used for evaluation of dentofacial anatomy assisting clinicians in establishing precise diagnoses and treatment plans. Mainly, it is due to user-friendly software, image accuracy and its capability to perform volumetric and linear measurements on 3-D skeletal models while patients are exposed to a minimal radiation dosage when compared to traditional computed tomography (CT) [1-3]. Ever since its development, CBCT has been extensively used for temporomandibular joint imaging (TMJ), where this technique has shown superiority in assessing condylar shape, morphology and dimensions for both, physiological and pathological diagnostic purposes. The condyle, the main growth center in the jaw, responds to ongoing stimuli through remodeling, and as a result, it is crucial to the final dimensions of the mandible as well as the relation between the maxillary and mandibular bases and some malocclusions [4,5].

Nowadays, accurate linear, angular and volumetric measurements have become essential in most of the dental branches. Volumetric assessment of an object using CBCT involves segmentation where the object of interest is isolated from the background followed by volume calculation using different methods. Depending on the software used, different segmentation techniques can be applied such as Manual, Semi-automatic and Automatic segmentation methods [2].

The morphological assessment of certain anatomical structures depends on the precision of 3D volumetric reconstructions of the craniomaxillofacial region. In this regard, it becomes necessary to ascertain that the data obtained is accurate and reliable. Our understanding of condylar osseous changes in growth, TMJ dysfunctions, orthopedic functional appliances and surgical manipulation may be significantly impacted by reliable and precise methods to measure condylar morphology and volume [6].

For so, the current investigation on diagnostic accuracy was conducted to assess the accuracy of the CBCT in volumetric assessment of the condyle in comparison to the real condylar volume.

## Materials and methods

The present study was carried out on 6 human dry mandibles (12 condyles) provided from the Department of Anatomy, Faculty of Medicine, Suez Canal University. The study was performed in the Oral Radiology Department, Faculty of Dentistry, Suez Canal University after waving from the approval of the research ethical committee NO 45/2017, since it was conducted on unidentified 6 human mandibles.

The number of condyles used in this study was calculated using G*Power Version 3.1.9.2. The minimum estimated sample size was 5 mandibles (10 condyles), based on the findings of Garcia *et al.*[7], where the effect size regarding volume measurement was found to be 0.952; using an alpha ($\alpha$) level of 0.05 and Beta ($\beta$) level of 0.1 i.e., power = 90%. The sample was increased to 12 condyles for compensation in case of sample fracture or crack.

### Inclusion criteria

The mandibular condyles (mandibles) included in the present study were selected to fulfil the criteria of being intact, absence of fractures or pathological lesions at the examined areas. The specimens were not identifiable by age, gender or ethnic group [8].

### Sample preparation

The condyles were prepared for standardization of the assessed region dimensions by creating a groove using a small round bur size 1, tangent to the coronoid process's distal slope and extending to the ramus's posterior border. The mandibular condyle, which is the portion of the mandible above this groove, was employed for actual physical and radiological investigation [8].

**Physical volume measurements**

An impression was made for the area of the condyle above the groove previously mentioned using a silicone duplicating material. Epoxy resin was then mixed and poured into the silicon mould, and was allowed to set, then removed from the impression. The part of the model below the groove, was carefully cut with a scalpel and discarded to produce an accurate model (replica) of the condyle (**Figure. 1**).

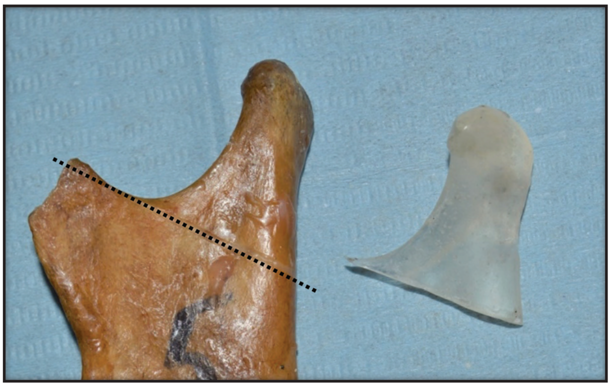

Fig. (1) A photograph showing the dry condyle and the epoxy resin condylar replica. The dotted line represents the reference groove.

In order to determine the physical volumes of the condyle models, they were submerged in a measuring cylinder that had been filled with water to a certain level based on the water displacement method (Archimedes principal). The volume of each condyle was assessed twice at two different times by the principal investigator and a second investigator.

**CBCT volume measurements**

The radiographic examination of the condyles was performed using SCANORA CBCT scanner (Scanora 3DX, Soredex, Finland). The FOV and the exposure parameters were selected and fixed for all samples as follows; FOV 80*165 mm, 90kV, 10mA, exposure time 2.4 s and standard resolution made with voxel size 0.350 mm using a flat panel detector.

The vertical and horizontal light-positioning guides were used to position the mandibles that were rested on the chin rest and adjusted as directed by the manufacturer. The projection data was reconstructed with the machine dedicated OnDemand 3D (Cybermed.Co., Seoul, Korea) software application.

**Image analysis and CBCT volume calculation**

Image analysis was performed using the built in OnDemand 3D software application.

For volumetric measurements, the acquired image data was transferred into DICOM format, then segmentation was performed to create the condyles out of a 3-D volume. The volumetric assessment of the segmented condyle was automatically calculated when the *Segmentation* function was used.

**Automatic segmentation** was performed as follows:

- The type of volume rendering options (bone) was first selected.
- Pressing the [*Auto Preset*] tool set the proper opacity and density values automatically for the selected rendering type.
- The sculpt tool (*a segmentation tool*) was selected in the 3-D module, then the "*apply to opaque voxels only"* option was selected to avoid including surrounding air spaces.
- A polyline was drawn to surround the selected region of interest (condyle) till the upper border of the demarcated groove to delineate the area of the condyle to be measured.
- With the last point drawn, the software automatically calculates the volume of the condyle already selected in cubic centimeters (cc) (**Figure.2**).

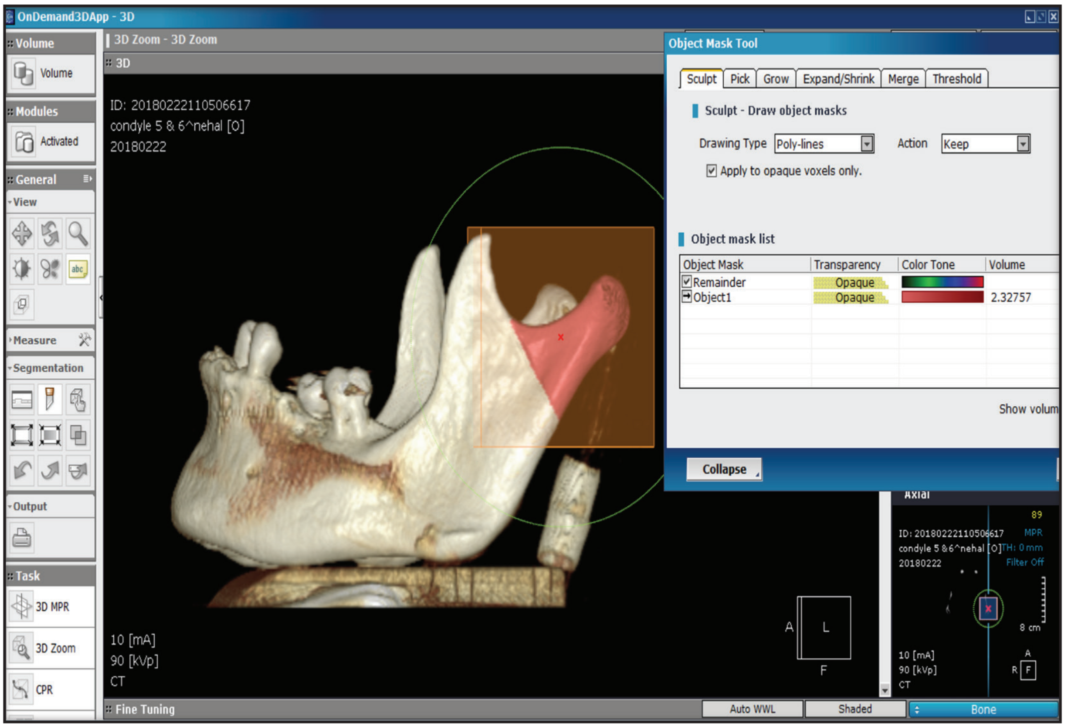


Fig. (2) A photograph showing segmentation of the condylar area in relation to the rest of the mandible.

- Volumetric analysis was performed twice by each investigator (operator 1 and operator 2 with five- and fifteen-years' experience in oral radiology respectively) at two weeks' interval period.

### Statistical analysis

Numerical data were explored for normality by checking the distribution of data and using tests of normality (Kolmogorov-Smirnov and Shapiro-Wilk tests). Data showed normal (parametric) distribution. Data were presented as mean, standard deviation (SD), mean difference and 95% Confidence Interval (95% CI) for the difference values. Intra and inter-observer reliability were assessed using Cronbach's alpha reliability coefficient and Intra-Class Correlation Coefficient (ICC). Paired t-test was used to compare between physical and CBCT measurements. The significance level was set at $p \leq 0.05$. Pearson correlations coefficient (r) and simple linear regression ($R^2$) were performed to assess the relationship between physical (gold standard) and CBCT measurements. Statistical analysis was performed with IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.

## RESULTS

### I. Reliability analysis

As shown in tables 1 and 2, the results of Cronbach's alpha reliability coefficient and intraclass correlation coefficient indicated very strong intra and inter observer agreement for real physical and CBCT volumetric measurements.

**Table (1)** *Results of intra-observer agreement using Cronbach's alpha and the Inter-Class Correlation Coefficient (ICC)*

| Measurement | Intra-observer agreement | | Difference | | Sign. |
|---|---|---|---|---|---|
| | Cronbach's alpha | ICC | mm | % | |
| **Physical volume** | 0.986 | 0.97 | 0.03 | 1.30 | <0.001* |
| **CBCT** | 0.98 | 0.961 | 0.02 | 1.14 | <0.001* |

**: Significant at P ≤ 0.05*

**Table (2).** *Results of inter-observer agreement using Cronbach's alpha and the Inter-Class Correlation Coefficient (ICC)*

| Measurement | Inter-observer agreement | | Difference | | Sign. |
|---|---|---|---|---|---|
| | Cronbach's alpha | ICC | mm | % | |
| **Physical volume** | 0.979 | 0.958 | 0.03 | 1.30 | <0.001* |
| **CBCT** | 0.960 | 0.924 | 0.02 | 1.14 | <0.001* |

**: Significant at P ≤ 0.05*

## II. Comparison between real physical (gold standard) and CBCT condylar volume measurements:

Results of the comparison between physical condylar volume and CBCT condylar volume are shown in Table (3). The estimated mean physical volume ranged between 1.3 to 2.8cm$^3$ with an average of 1.93 cm$^3$, however, the CBCT volume ranged between 1.72 to 3.28cm$^3$ with an average of 2.27cm$^3$. Between mean physical and CBCT values, there was a statistically significant difference (*P*-value <0.001), where CBCT showed higher condylar volume measurements in comparison to physical measurements with a mean error = 0.34cm$^3$, denoting an overestimation in CBCT readings =17.74 %.

**Table (3)** *Comparison between real physical (gold standard) and CBCT condylar volumes*

| | Physical volume (cm$^3$) | CBCT volume (cm$^3$) |
|---|---|---|
| Min | 1.3 | 1.72 |
| Max | 2.8 | 3.28 |
| Mean | 1.93 | 2.27 |
| SD | 0.43 | 0.42 |
| Mean difference(error) | 0.34 cm$^3$ (17.74 %) | |
| SD of difference | 0.18 | |
| 95% CI for Difference | *Lower bound* | 0.22 |
| | *Upper bound* | 0.46 |
| P-value | <0.001* | |
| Effect size (d) | 0.801 | |

**: Significant at P ≤ 0.05*

### III. Correlation between physical (gold standard) and CBCT condylar volume:

Pearson correlations coefficient (r) and simple linear regression ($R^2$) were performed to assess the relationship between physical (gold standard) and CBCT measurements (Table.4, *fig.17*). The correlation coefficient (r) showed a strong positive correlation between physical and CBCT volume estimations (r=0.883; $p<0.001$*).

**Table (4)** *The correlation between real physical and CBCT condylar volumes.*

| | |
|---|---|
| Pearson's correlation (r) | 0.883 |
| Simple linear regression ($R^2$) | **0.7781** |
| Sign. (2-tailed) | **<0.001*** |

*: *Significant at* $P \leq 0.05$

## DISCUSSION

Since the mandibular condyles are the most important component regulating overall mandibular growth, morphological and dimensional modifications to them can affect craniofacial growth. Furthermore, abnormal temporomandibular disorder (TMD) and dysfunction, as well as the emergence of sagittal, transverse, and/or vertical malocclusions, may all be significantly influenced by improper mandibular condylar growth and development. On the other hand, there are situations when condylar morphological alterations are sought, such as during functional orthopedic treatments intended to stimulate, inhibit, or modify the pattern of mandibular growth. In order to accurately diagnose any pathology and develop TMD treatments, all of these clinical situations necessitate a thorough evaluation of condylar morphology, dimensions, and volume [9].

The best imaging techniques for assessing TMJ dysfunctions linked to soft-tissue or bone imbalance are MRI (magnetic resonance imaging) and CT, respectively. However, CT requires a high radiation dose and has a low availability in private practice settings, whereas MRI has inherent limits in the assessment of osseous changes of the TMJ. Due to its great accuracy in identifying bone characteristics, CBCT stands out as the preferred 3-D imaging modality in the oral and maxillofacial areas in this regard [10].

However, since CBCT is a relatively recent three-dimensional imaging modality, the accuracy of condylar volumetric measurements obtained from its images need to be further investigated for confirmation due to the scarcity of studies conducted on the topic, contrary to other anatomical structures and spaces in the maxillofacial region (e.g. maxillary sinus, teeth sockets and upper airway space) which have been extensively studied for volume accuracy[11-13].

Various *in vivo* researches have assessed the shape and the volume of the condyle using CBCT to establish relationships with different parameters, such as condylar relation with skeletal morphology. The volume and surface of mandibular condyles were investigated by Tecco *et al*.[14] , who discovered significant morphological variation among the patients. Additionally, Saccuci *et al*.[15] evaluated the condyle's volume and discovered relationships between volume and skeletal classes. However, in these trials, the precision of CBCT in getting the desired measurements was questionable and could not be confirmed.

In the present study, the real physical method used for measuring the condylar volume was the water displacement technique. The same technique was used by Bayram *et al*.[8] , Garcia *et al*.[7] and Kim *et al*. [2] in the determination of condylar replica volume, dry condyle volume and 3-D printed condylar volume respectively. This technique was proven to be simple, consistent and accurate in measuring the volume of a given object with homogenous density as stated by Hughes [16] in his review comparing various techniques of volume measurement.

Volumetric assessment of the condyles involves condylar segmentation for volume calculation. The most widely applied method for CBCT image analysis is automatic segmentation. This segmentation protocol was applied in the present study since it is built in the dedicated software (OnDemand) of the Scanora 3Dx CBCT scanner. The software's volumetric sculpting and segmentation tool was used to remove structures outside the volume of interest. Since the threshold can be selected or adjusted to enhance the borders and the density of the object of interest which in turn affects the resultant segmentation and volume, as a result, the procedure is quite individualized. This issue is resolved by the software's usual pre-set thresholds for bone, soft tissue, and teeth, which are established automatically and independently of the observer. Automatic segmentation used in our study was applied by several researchers like Loubele *et al.* [17] and Hassan *et al.* [18] for segmentation of the dental arches [19].

The primary advantages of the current automatic segmentation technique and volume calculation used, included greatly decreased computing time, excellent reproducibility, and improved software user friendliness, all of which made it possible to quickly implement the currently suggested method for rendering condyles in three dimensions in a clinical setting [20,21].

Regarding the results of our present study, a very good intra and inter-observer agreement was demonstrated regarding both the physical actual volume determination, and the CBCT measurements which indicates the high reliability and reproducibility of the current protocol used.

Regarding the comparison between the physical method and CBCT, our results showed a statistically significant difference between the condylar volume obtained from the physical means (the gold standard) and that obtained from CBCT images using the automatic segmentation technique where CBCT measurements showed mean error 0.34 $cm^3$ indicating an over estimation of the radiographic condylar volume value by 17%.

Such result may be attributed to several reasons; the relatively low condylar bone density, the inherent low contrast resolution and distortion of Hounsfield Units (HU-value) in CBCT scans, as well as the partial volume effect that manifests at sharp edges with high contrast to neighboring structures, especially if a voxel is at the junction of two objects with different densities (for example, bone and air), therefore the voxel will show a value that is an average of the condyle and air's actual values. As a result, these artefacts may be included in the reconstructed condylar volume, which might result in greater volumes and be challenging to remove throughout the segmentation and 3D reconstruction processes. These factors lead to volume error, especially in the segmented boundary as well as reconstruction artifacts such as a blurry or irregular edge, that may have resulted in a such substantial percentage error [21].

The aforementioned result was in accordance with Nicolielo *et al.* [22], who showed an overestimation of CBCT by 0.4 $mm^3 \pm 0.3$ $mm^3$ when the accuracy of a dry condylar volume was assessed and compared with the gold standard. However, in their study they used micro-CT as a gold standard where they performed a semi-automatic segmentation technique.

The results mentioned by Lo Giudice *et al.* [6], provide more support for our finding. They compared semi-automatic threshold-based segmentation and the manual segmentation technique which was considered by the author as "the ground truth". They showed an overestimation of condylar boundaries and therefore its volume. Even though semi-automatic segmentation demonstrated superior accuracy in earlier research, the study highlighted that condylar morphological data acquired with this method should be treated cautiously when an accurate characterization of condylar borders is needed, despite the method's excellent reliability.

However, another study performed by Bayram *et al.*[8] showed that CBCT is a useful method for estimating the volume of the mandibular condyle. Despite the lack of statistically significant discrepancies between the measurements, it was found that some samples tended to overestimate or underestimate the gold standard achieved using the water displacement method. The volume of each condyle was calculated from the CBCT images of the mandibles used in their investigation using manual segmentation.

In addition, Garcia *et al.* [7] used STL surface models of the dry condyles that were acquired using a 3D scanner, then the STL models were superimposed on the CBCT scans of dry cadaver condyles with intact soft tissue. Using the surface models as a guide, condyles were segmented, isolated, and their volumes measured on the CBCT render volume. Since there were no statistically significant disparities between the measurements, the results demonstrated that CBCT is a dependable and accurate approach for obtaining volumetric data. In contrast to their work, the current study performed the volumetric measurements on CBCT epoxy condylar models rather than true cadaver condyles with the water displacement method as the gold standard.

Another study performed by Kim *et al.* [2], 3D printed mandible models were scanned using CBCT, and the condyles were segmented semi-automatically. The results were compared with the water displacement method as a gold standard and showed that CBCT is a reliable and precise approach as well. Unlike the present study, they performed semiautomatic segmentation using CBCT scans of the 3-D-printed model. In contrast to human mandibular condyles evaluated in clinical settings, 3-D-printed materials' CBCT scans have a different gray-scale value. This can have an impact on the segmentation process carried out by the software algorithm, which in turn can have an impact on the volumetric measurements.

Nevertheless, our findings revealed a substantial, direct, and statistically significant association between physical and CBCT measures. Consequently, CBCT volumetric measurements may be used for diagnostic and clinical purposes, as long as the percentage of overestimation in the findings is taken into consideration.

### Limitation

The most significant limitation in this study was the absence of soft tissue simulation which is important to mimic the real clinical situations as closely as possible, since soft tissue attenuation coefficients affects image quality, consequently affecting the segmentation process.

## CONCLUSION

Automatic segmentation performed in CBCT scans is a reproducible, fast and feasible method for volume segmentation of mandibular condyles that can be used for diagnostic and clinical purposes as long as the degree of overestimation in the obtained results is kept into consideration.

## RECOMMENDATIONS

More studies should be conducted with soft tissue simulation to mimic the real clinical situations as closely as possible, since soft tissue attenuation coefficients affects image quality, consequently affecting the segmentation process. More in-vitro studies with smaller voxel sizes should be conducted since this may result in superior image quality and better segmentation process. Future evaluation of condylar volume should include comparative studies of CBCT scans acquired with different scanners, different software and different segmentation techniques as well.

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