SciMedCentral

JSM Dentistry

Research Article

# Assessment of the Mandibular Condyles Using Cone Beam Volumetric Tomography

**Rebecca CT. Liu and Paul A. Monsour***

*Department of Health and Behavioural Sciences, The University of Queensland, Australia*

***Corresponding author**

Paul A. Monsour, Department of Health Sciences, School of dentistry, 288 Herston Road, Herston, QLD 4006, Australia, Tel: 61 7 3365 8065; Email: p.monsour@uq.edu.au

**Submitted:** 29 July 2020

**Accepted:** 12 August 2020

**Published:** 14 July 2020

**ISSN:** 2333-7133



**Keywords**

- Cone beam
- Mandibular condyle
- Temporomandibular joint

**Abstract**

**Objectives:** (1) To examine the horizontal condylar angle (HCA) at different heights through the condyle using cone beam volumetric tomography (CBVT). (2) To investigate the relationship between the HCA and degenerative joint disease (DJD), occlusion, condylar dimensions, joint spaces, age, and gender.

**Study design:** CBVT volumes of 264 joints were orientated according to a specific protocol. The left and right joints were examined independently. A mixed-effects model was used for statistical analysis.

**Results:** Significant differences were found between the mean HCA measured at different heights ($p<0.001$). The mean HCA at 4.0mm, 6.0mm, and 8.00mm were 68.30°, 64.51°, and 61.30°, respectively. A significant difference was found between the right and left sides ($p<0.001$). No other significant correlations were identified.

**Conclusions:** The HCA is dependent on measurement height. Results from this study may be useful as a comparable reference for future studies correlating with clinical findings.

## INTRODUCTION

Temporomandibular (TM), joint imaging forms an integral part of the assessment and management of TM joint dysfunction/disorder (TMD). The significance of radiographic features associated with degenerative joint disease (DJD), and its relationship to clinical symptoms has been an area of interest [1-6].

Plain film imaging and tomography have been traditionally used to evaluate TM joint disorders. However, these methods rely heavily on positioning, radiographic projection, and operator technique [2,7-11], The detection of degenerative osseous changes and the interpretation of plain film studies have been reported to be suboptimal [6,12-16]. Previous studies have used a myriad of landmarks for linear and angular measurements, whereby some reference points may be influenced by beam angulation and patient positioning during image acquisition [10,17-20]. Although useful as baseline assessment of TM joint disorders, the interpretation of plain film imaging and tomography is also compromised by anatomical superimpositions.

Computed tomography (CT), has shown promising results in depicting the osseous components of the TM joint, with high accuracy and excellent inter-observer reliability reported [6,21,22]. However, this imaging modality is higher in cost, more difficult to access and higher in radiation compared to conventional imaging [23,24].

The use of magnetic resonance imaging (MRI), for the detection of osseous changes within the TM joint has been controversial, as the reported accuracy and interpretation reliability has been variable between different studies [6,21,25-27]. On the other hand, MRI assessment of soft tissue components of the TM joint has been shown to be excellent [6,21,26-28].

Cone beam volumetric tomography (CBVT) has many applications in dentistry and is becoming invaluable due to its relatively low radiation dose and high spatial resolution compared to multi-detector CT [24,29-32]. For the diagnosis of osseous changes related to DJD in the TM joints, mixed results have been presented with reported sensitivity ranging from 0.23 to 0.91, and specificity from 0.67 to 1.0 [23,33-35]. Linear and angular measurements obtained from CBVT datasets have been shown to be of slight underestimation, but the dimensional accuracy was deemed to be within acceptable limits [30,31,36-41].

CBVT volumes can be manipulated and reconstructed in multiplanar views without any loss of resolution due to isotropic voxels [32], however orientation of cone beam volumes has not been standardised and tested for reliability. Lagravere et al. [42], raised the question that orientation of the datasets may directly affect the measurements derived from the reformatted images, and suggested several stable anatomical landmarks for plane orientation. Kim et al. [43], also emphasised the importance of midsagittal plane (MSP), determination especially for the quantitative assessment using three-dimensional datasets.

In addition to osseous changes within the TM joint, the horizontal condylar angle (HCA), has also been studied. The HCA refers to the angulation of the long axis of the mandibular condyle in relation to a reference plane. Several authors have explored the significance of this angle, however, the lack of clearly defined landmarks has resulted in difficulties in comparison between different studies. The transmeatal line [18,19,44], frontal/coronal plane [22,45-47], and MSP [48-53], have all been used as reference planes. Possible correlations with DJD and occlusion have been suggested [47,52-55].

A review of literature revealed a lack of research investigating the longitudinal axis of the mandibular condyle in relation to the MSP at different levels using CBVT in the axial plane. This study aims to orientate the CBVT data sets in a systematic manner, and utilise stable osseous landmarks to provide a consistent and reproducible method for measurement and comparison. This study was designed to determine if the angulation of the HCA changes at different heights through the condyle, and whether there is a significant correlation between this angulation and DJD, occlusion, condylar dimensions, joint spaces, gender or age.

## MATERIALS AND METHODS

Ethics approval was obtained from the University of Queensland Dental School Research Committee for this study.

De-identified CBVT datasets were obtained from a private radiology practice (MaxilloFacial Radiology). A total of 145 de-identified datasets (94 females, 51 males) in DICOM format from 213 randomly selected cases were included in this study. The purpose for scan acquisition, joint diagnosis and original radiology reports were not available to the investigators. Poor quality scans with obvious movement, excessive artefact or excessive noise were excluded from this study. Datasets of patients with craniofacial developmental anomalies including bifid condyles, obvious signs of previous TM joint trauma, ongoing orthodontic treatment, edentulous ridges or lack of posterior occlusal support were also excluded. A total of 264 joints (130 left and 134 right), were examined independently by assessor RL (Dento-Maxillofacial Radiology postgraduate student).

All CBVT scans included in this study were obtained using an i-CAT cone beam unit (Imaging Sciences International, Hatfield, PA). Scanning of the patients was carried out at 120 kilovolts (kV), and 5 milliamperes (mA). The resultant volume was 232 millimetres (mm) in width and 170 mm in height, with a total of 324 basis images at 0.4mm voxels.

### Radiographic assessment and measurement

Each CBVT DICOM dataset was imported into and viewed using a DICOM Viewer (Planmeca Romexis Software). Images in the axial, sagittal and coronal planes were generated within the program. All slices were calibrated to 1.0mm thickness spaced at 1.0mm intervals.

Orientation of each volume was carried out according to a specific protocol by Lagravere et al. [42], in the coronal, sagittal and axial views using identifiable and stable landmarks as described previously. In the coronal plane, the line drawn between the right and left superior-lateral border of the external acoustic meatus (r-SLEAM and l-SLEAM) was orientated parallel to the true horizontal plane (Figure 1). In the sagittal plane, the dataset was orientated parallel to the horizontal plane using the Frankfurt plane (Figure 2). A modified technique from those described by Lagravere et al. [42], was used to determine the MSP. In the axial plane, the line drawn between the foramina spinosum (ELSA), was orientated parallel to the horizontal plane. A midpoint bisecting this line joined to the anterior nasal spine (ANS), was used to represent the midsagittal plane (MSP) (Figure 3).

The right and left sides of each patient were examined separately. Angle's molar relationship (Class I, Class II and Class III occlusions) was classified from reconstructed sagittal images (Figure 2). Any side with one or both missing first molars were excluded from this study.

Each joint was evaluated according to the method described by Alexiou et al. [56]. Joints with degenerative changes were characterised by the presence of condylar flattening, sclerosis, erosions, osteophytes or subchondral cysts as viewed in the coronal and sagittal planes [23,56,57]. To avoid misinterpretation,

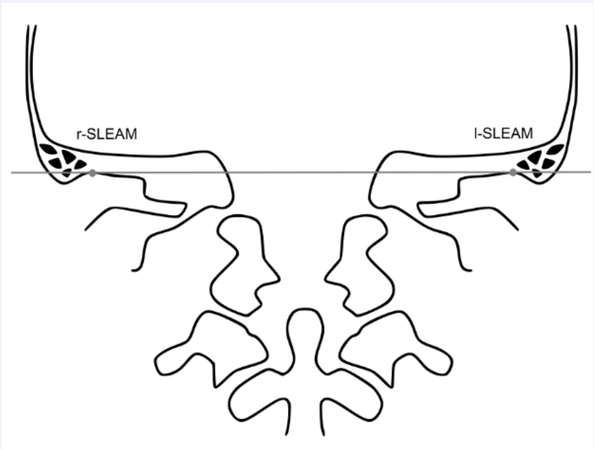


**Figure 1** Coronal Orientation (Lagravere et al) [42].
r-SLEAM – Most superolateral border of the right external acoustic meatus
l-SLEAM – Most superolateral border of the left external acoustic meatus

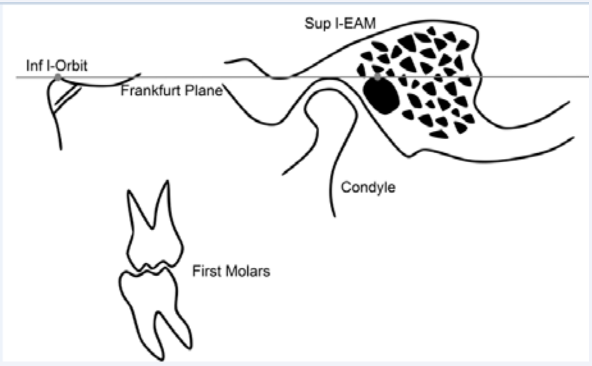


**Figure 2** Sagittal Orientation (Lagravere et al) [42].
Inf l-Orbit – Inferior margin of the left orbit
Sup l-EAM – Superior margin of the left external acoustic meatus

only osseous changes evident in two different planes or on two consecutive slices were recorded by assessor RL.

In the sagittal and coronal planes, the most superior point of the right condyle (SC) on the right side was identified. Axial slices at 4.0mm, 6.0mm and 8.0mm inferior to the SC were generated (Figure 4). For each height, a line drawn from the most medial and lateral poles of the mandibular condyle was used to represent the longitudinal axis of the mandibular condyle. The horizontal condylar angle (HCA), was defined as the angle made by the longitudinal axis of the mandibular condyle and the MSP (Figure 5). The areas of interest in the axial and corrected sagittal views were magnified for measurement. Angular measurements were made using the Romexis software where the angulations are displayed in degrees to the nearest 0.01°. For each joint included in the study, one HCA for each height was recorded (HCA-4, HCA-6, HCA-8).

Oriented volumes were transferred to the TM joint screen. Condylar dimensions were measured for both the right and left sides. In the axial view, the maximum mediolateral (ML), dimension was determined by the line connecting the most medial and most lateral points of the condyle. The median anteroposterior (AP) dimension was the line bisecting and perpendicular to the maximum mediolateral diameter (Figure 6). Linear measurements are displayed in millimetres within the computer software to the nearest 0.01mm.

One mid-condyle corrected sagittal (longitudinal) view per side through the temporomandibular joint was generated by the examiner. The anterior (AJS), superior (SJS) and posterior joint spaces (PJS) were measured as described by Ikeda and Kawamura [58] (Figure 7).

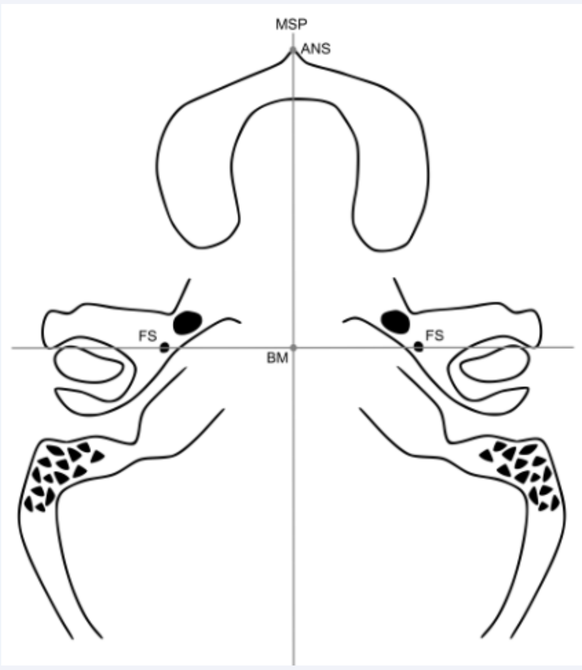


**Figure 3** Axial Orientation (Lagravere et al) [42].
BM – Bisecting Midpoint
FS – Foramen Spinosum
ANS – Anterior Nasal Spine
MSP – Midsagittal Plane

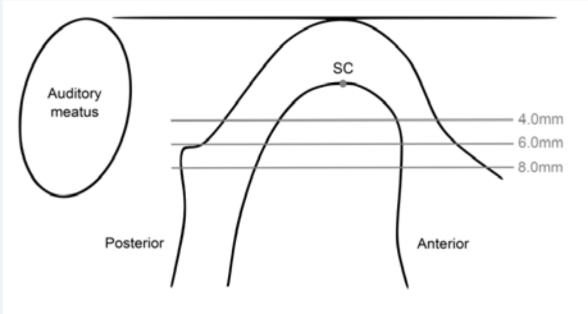


**Figure 4** Axial Slice Selection
(SC) – Most superior point of condyle

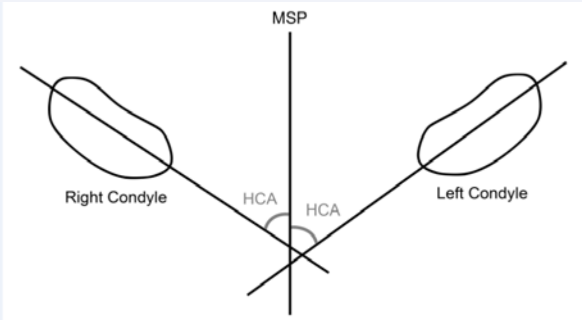


**Figure 5** Horizontal Condylar Angle Measurement (Williamson et al [48], Vitral et al [50])
MSP – Midsagittal Plane
HCA – Horizontal Condylar Angle

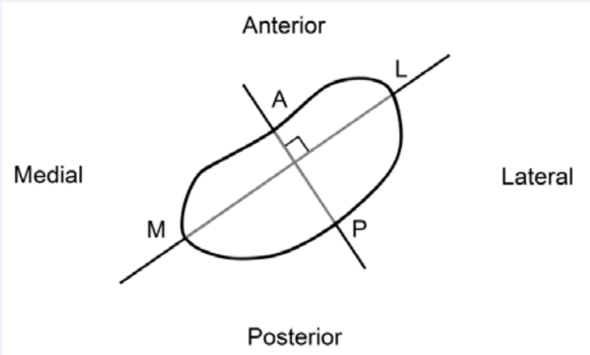


**Figure 6** Condylar Dimension Measurement (Kurita et al [57].
AP – median anteroposterior dimension
ML – maximum mediolateral dimension

Randomly selected volumes (10% of useable data), were re-measured at two additional time points within a six-month period. All collected data was tabulated in spreadsheet form.

## Statistical analysis

A mixed-effects model was used instead of simple linear regression, where an additional parameter known as the random effect was included to account for the correlation of measurements within each patient. An initial mixed effects model was created to predict the HCA using 11 primary variables (Height, Side, AP, ML,

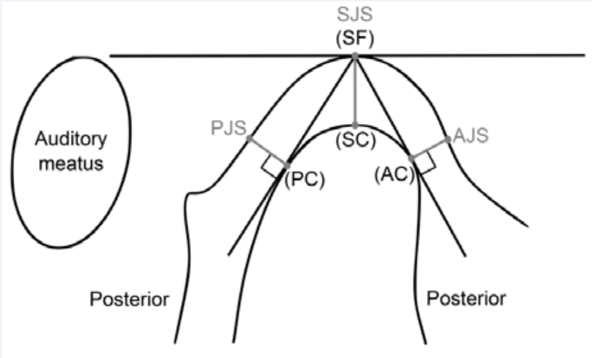


**Figure 7** Joint Space Measurement (Ikeda and Kawamura [58])
AJS – Anterior Joint Space
SJS – Superior Joint Space
PJS – Posterior Joint Space
(SF) – Most superior point of glenoid fossa
(SC) – Most superior point of condyle
(PC) – Most posterior point of condyle
(AC) – Most anterior point of condyle

AJS, SJS, PJS, DJD, Occlusion, Age and Gender). A number of mixed effects models were also built in order to explore the predictive factors for DJD, condylar dimensions, and joint spaces. Correlation of measurements (HCA, AP, ML, SJS, AJS, PJS) between the two sides within the same patient was examined. Investigation of the differences between patients with different Angle's class molar relationships was also carried out. For the analysis of intra-examiner measurement errors, Intra-Class Correlation Coefficient (ICC) was used for all continuous variables (condylar height, dimensions, joint spaces).-

## RESULTS

### Horizontal Condylar Angle (HCA)

Statistically significant differences were found between the HCAs measured at different heights ($p$<0.001). The mean HCA measured at 4.0 mm from the most superior point of the condyle was found to be the greatest, followed by the mean HCA measured at 6.0 mm and 8.0 mm. An average of 3 degrees differed between the height measurements (Table 1). No statistically significant correlations were found between HCA and DJD ($p$>0.05). The mean HCA in Class III occlusion was significantly larger than those in Class I and Class II occlusions ($p$=0.02). Class I and Class II occlusions did not differ significantly ($p$>0.05). The median AP dimension of the condyles increased with increasing HCA ($p$<0.001). A borderline correlation between the HCA and the maximum ML dimension was observed ($p$=0.08), where a trend of decreasing maximum ML was associated with increasing HCA. No statistically significant correlations ($p$>0.05) were found between the HCA and: joint spaces, age, and gender. A statistically significant difference was observed in the mean HCA between the right and left sides, where the right side was found to be larger by approximately 3 degrees ($p$<0.001).

### Condylar Dimensions

The relationships between joint dimensions and other study variables are summarised in Tables 2 and 3. The median AP and maximum ML dimensions were smaller in joints with DJD compared to radiographically normal joints (AP: $p$=0.001, ML: $p$=0.03). Males had significantly larger maximum ML dimensions ($p$<0.001). The maximum ML dimension increased with age. No statistically significant differences were found between the right and left mean maximum ML dimensions ($p$=0.74) and mean median AP dimensions ($p$=0.40).

### Joint Spaces

Overall, the mean SJS was greatest, followed by the AJS and PJS (Tables 4, 5 and 6). Males had significantly larger SJS compared to females ($p$<0.001). The mean PJS on the right side was larger than the left ($p$=0.02). The mean AJS on the right side was smaller than the left ($p$=0.04).

### Other

The results confirmed that DJD is an age-related condition, where the incidence increases with age ($p$<0.001).

### Reproducibility

In this particular study, reproducibility was defined as the possibility of achieving the same results if the same observer and the same method are used to collect multiple sets of results. For the assessment of intra-rater reliability for all continuous variables, Intra-Class Coefficient (ICC), analysis showed an extremely high level of reproducibility (Table 7).

## DISCUSSION

### Horizontal Condylar Angle

The HCA measured at different heights was shown to be statistically significant in the current study. Angulations were taken at specified heights from the most superior point of the condyle so the measurements could be compared consistently between different joints. From the results obtained, it is reasonable to expect that the angles between studies can vary significantly if the landmarks are not standardised, or if the orientation planes are altered, resulting in measurements being taken at different condylar heights, especially between different imaging modalities.

The mean HCA values obtained from this cohort for all joints (61.30-68.30°) lie within the range described by Yale[59]. Results from the study by Sato et al. [45], revealed slightly higher values but this was thought to be due to an ethnicity difference. For normal joints, the mean HCA values (65.11°), were comparable with previous studies [18,19,46-48,50-52,54,55,60].

Joints with DJD in this study were found to have a slightly smaller mean HCA (62.86°) compared to normal joints, but this was not found to be statistically significant. This finding agrees with previous SMV studies which also assessed osseous changes radiographically [19,45]. On the other hand, two MRI studies found significant differences between the two groups where joints with DJD had a significantly smaller mean HCA [54,55]. Inconsistencies in the results between studies using different imaging methods may be explained by the lack of a comparable measurement and/or observational standard. Angle measurements taken from CT and MRI images are from arbitrary transverse sections, and therefore results from these imaging

**Table 1:** Horizontal Condylar Angle.

| | *n* | Mean | SD | Minimum | Maximum | Range | P-Value |
|---|---|---|---|---|---|---|---|
| **HCA-4°** | 264 | 68.30 | 8.33 | 44.14 | 93.09 | 48.95 | |
| **HCA-6°** | 264 | 64.51 | 8.76 | 43.32 | 94.67 | 51.35 | 0.00* |
| **HCA-8°** | 264 | 61.30 | 9.49 | 38.16 | 98.43 | 60.27 | 0.00* |
| **Normal** | 648 | 65.11 | 8.88 | 38.16 | 92.16 | 54.00 | |
| **DJD** | 144 | 62.86 | 10.90 | 43.60 | 98.43 | 54.83 | 0.32 |
| **Class I** | 462 | 64.28 | 8.90 | 43.09 | 98.43 | 55.34 | |
| **Class II** | 201 | 63.32 | 9.41 | 38.16 | 87.84 | 49.68 | 0.34 |
| **Class III** | 129 | 68.40 | 9.76 | 45.00 | 93.09 | 48.09 | 0.02* |
| **10-19** | 126 | 64.93 | 10.32 | 43.32 | 83.66 | 40.34 | 0.50 |
| **20-29** | 162 | 64.62 | 8.93 | 45.00 | 92.16 | 47.16 | |
| **30-39** | 135 | 64.93 | 10.37 | 50.48 | 91.36 | 40.88 | |
| **40-49** | 180 | 66.65 | 7.86 | 47.91 | 98.43 | 50.52 | |
| **50-59** | 138 | 61.86 | 8.57 | 38.16 | 86.91 | 48.75 | |
| **60+** | 51 | 64.62 | 10.20 | 44.17 | 93.09 | 48.92 | |
| **Female** | 522 | 64.45 | 9.03 | 38.16 | 93.09 | 54.93 | |
| **Male** | 270 | 65.19 | 9.85 | 43.32 | 98.43 | 55.11 | 0.43 |
| **Left** | 390 | 63.20 | 8.43 | 38.16 | 91.36 | 53.20 | |
| **Right** | 402 | 66.16 | 9.90 | 43.92 | 98.43 | 54.51 | 0.00* |

* Indicates p-values that are significant at the 0.05 level

**Table 2:** Maximum Mediolateral Condylar Dimension.

| | *n* | Mean | SD | Minimum | Maximum | Range | P-Value |
|---|---|---|---|---|---|---|---|
| **All** | 264 | 18.84 | 2.45 | 11.65 | 25.48 | 13.83 | |
| **Normal** | 216 | 18.99 | 2.33 | 11.89 | 25.48 | 13.59 | |
| **DJD** | 48 | 18.16 | 2.87 | 11.65 | 24.06 | 12.41 | 0.03* |
| **Class I** | 154 | 19.02 | 2.49 | 11.65 | 25.48 | 13.83 | |
| **Class II** | 67 | 18.42 | 2.14 | 13.91 | 23.44 | 9.53 | |
| **Class III** | 43 | 18.87 | 2.73 | 11.89 | 24.06 | 12.17 | |
| **10-19** | 42 | 17.56 | 1.89 | 13.91 | 21.05 | 7.14 | 0.02* |
| **20-29** | 54 | 19.28 | 2.45 | 11.89 | 23.05 | 11.16 | |
| **30-39** | 45 | 19.41 | 1.95 | 15.04 | 25.48 | 10.44 | |
| **40-49** | 60 | 19.19 | 2.78 | 11.65 | 23.64 | 11.99 | |
| **50-59** | 46 | 18.22 | 2.13 | 13.30 | 22.24 | 8.94 | |
| **60+** | 17 | 19.61 | 3.15 | 15.23 | 24.06 | 8.83 | |
| **Female** | 174 | 18.12 | 2.33 | 11.65 | 23.64 | 11.99 | |
| **Male** | 90 | 20.25 | 2.04 | 14.42 | 25.48 | 11.06 | <0.001* |
| **Left** | 130 | 18.80 | 2.35 | 11.89 | 23.64 | 11.75 | |
| **Right** | 134 | 18.89 | 2.56 | 11.65 | 25.48 | 13.83 | 0.74 |

* Indicates p-values that are significant at the 0.05 level

**Table 3:** Median Anteroposterior Condylar Dimension.

| | *n* | Mean | SD | Minimum | Maximum | Range | P-Value |
|---|---|---|---|---|---|---|---|
| **All** | 264 | 7.10 | 1.43 | 2.88 | 11.09 | 8.21 | |
| **Normal** | 216 | 7.22 | 1.34 | 4.12 | 11.09 | 6.97 | |
| **DJD** | 48 | 6.54 | 1.70 | 2.88 | 9.51 | 6.63 | 0.001* |
| **Class I** | 154 | 7.09 | 1.44 | 2.88 | 10.38 | 7.50 | |
| **Class II** | 67 | 6.92 | 1.53 | 3.77 | 11.09 | 7.32 | |
| **Class III** | 43 | 7.40 | 1.22 | 4.68 | 9.60 | 4.92 | |
| **10-19** | 42 | 7.20 | 1.41 | 4.47 | 10.03 | 5.56 | 0.59 |
| **20-29** | 54 | 6.99 | 1.11 | 4.66 | 10.00 | 5.34 | |
| **30-39** | 45 | 7.32 | 1.82 | 4.12 | 11.09 | 6.97 | |
| **40-49** | 60 | 7.13 | 1.21 | 4.56 | 10.01 | 5.45 | |
| **50-59** | 46 | 6.94 | 1.53 | 2.88 | 9.51 | 6.63 | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **60+** | 17 | 6.86 | 1.80 | 3.05 | 9.74 | 6.69 | |
| **Female** | 174 | 7.10 | 1.43 | 2.88 | 11.09 | 8.21 | |
| **Male** | 90 | 7.09 | 1.45 | 3.05 | 10.38 | 7.33 | 0.94 |
| **Left** | 130 | 7.04 | 1.35 | 2.88 | 11.09 | 8.21 | |
| **Right** | 134 | 7.15 | 1.52 | 3.05 | 11.01 | 7.96 | 0.40 |

* Indicates p-values that are significant at the 0.05 level

**Table 4:** Superior Joint Space.

| | ***n*** | **Mean** | **SD** | **Minimum** | **Maximum** | **Range** | **P-Value** |
|---|---|---|---|---|---|---|---|
| **All** | 264 | 2.77 | 0.89 | 0.40 | 5.20 | 4.80 | |
| **Normal** | 216 | 2.78 | 0.85 | 0.40 | 5.20 | 4.80 | |
| **DJD** | 48 | 2.73 | 1.07 | 0.40 | 4.80 | 4.40 | 0.70 |
| **Class I** | 154 | 2.74 | 0.86 | 0.40 | 4.80 | 4.40 | |
| **Class II** | 67 | 2.74 | 0.91 | 1.20 | 5.20 | 4.00 | |
| **Class III** | 43 | 2.97 | 0.97 | 0.40 | 4.80 | 4.40 | |
| **10-19** | 42 | 2.50 | 0.59 | 0.40 | 3.20 | 2.80 | 0.50 |
| **20-29** | 54 | 3.01 | 0.81 | 1.50 | 4.80 | 3.30 | |
| **30-39** | 45 | 2.76 | 1.04 | 0.80 | 5.20 | 4.40 | |
| **40-49** | 60 | 2.75 | 0.87 | 0.80 | 4.40 | 3.60 | |
| **50-59** | 46 | 2.78 | 1.01 | 0.40 | 4.40 | 4.00 | |
| **60+** | 17 | 2.81 | 1.02 | 0.80 | 4.80 | 4.00 | |
| **Female** | 174 | 2.63 | 0.90 | 0.40 | 5.20 | 4.80 | |
| **Male** | 90 | 3.06 | 0.82 | 0.80 | 4.80 | 4.00 | <0.001* |
| **Left** | 130 | 2.80 | 0.91 | 0.40 | 4.80 | 4.40 | |
| **Right** | 134 | 2.75 | 0.88 | 0.40 | 5.20 | 4.80 | 0.59 |

* Indicates p-values that are significant at the 0.05 level

**Table 5:** Posterior Joint Space.

| | ***n*** | **Mean** | **SD** | **Minimum** | **Maximum** | **Range** | **P-Value** |
|---|---|---|---|---|---|---|---|
| **All** | 264 | 1.92 | 0.69 | 0.57 | 5.38 | 4.81 | |
| **Normal** | 216 | 1.92 | 0.66 | 0.57 | 5.38 | 4.81 | |
| **DJD** | 48 | 1.95 | 0.83 | 0.57 | 3.96 | 3.39 | 0.46 |
| **Class I** | 154 | 1.83 | 0.59 | 0.57 | 3.96 | 3.39 | |
| **Class II** | 67 | 1.95 | 0.83 | 0.57 | 4.25 | 3.68 | |
| **Class III** | 43 | 2.20 | 0.73 | 0.89 | 5.38 | 4.49 | |
| **10-19** | 42 | 2.09 | 0.51 | 0.89 | 3.39 | 2.50 | 0.11 |
| **20-29** | 54 | 2.06 | 0.63 | 0.89 | 3.96 | 3.07 | |
| **30-39** | 45 | 1.82 | 0.72 | 0.57 | 4.25 | 3.68 | |
| **40-49** | 60 | 1.81 | 0.63 | 0.57 | 2.88 | 2.31 | |
| **50-59** | 46 | 1.94 | 0.81 | 0.89 | 5.38 | 4.49 | |
| **60+** | 17 | 1.70 | 0.91 | 0.57 | 3.39 | 2.82 | |
| **Female** | 174 | 1.90 | 0.75 | 0.57 | 5.38 | 4.81 | |
| **Male** | 90 | 1.97 | 0.56 | 0.57 | 3.39 | 2.82 | 0.42 |
| **Left** | 130 | 1.87 | 0.65 | 0.57 | 4.25 | 3.68 | |
| **Right** | 134 | 1.98 | 0.72 | 0.57 | 5.38 | 4.81 | 0.02* |

* Indicates p-values that are significant at the 0.05 level

methods against SMV radiographs and CBVT images may differ significantly. Westesson et al. [54], suggested that proliferative bone remodelling associated with DJD may result in a change in HCA. Kurita et al. [55], also postulated that resorption of the lateral pole of the condyle may be associated with DJD and subsequently a decrease in HCA, however the exact mechanism was unknown. The absence or presence of DJD signs in this study were classified according to Alexiou et al.[56], however the severity and type of degenerative changes were not recorded specifically and evaluated as part of this investigation. This may have an effect on the comparison between normal joints and joints with DJD, as those with subtle osseous changes and joints with moderate to marked changes may differ in their HCA, but the distinction may be masked in this particular study where they were placed within the same category.

Limited research is available on the relationship between HCA and Angle's classes of occlusion. The mean HCA values reported

| **Table 6:** Anterior Joint Space. | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***n*** | **Mean** | **SD** | **Minimum** | **Maximum** | **Range** | **P-Value** |
| **All** | 264 | 2.06 | 0.77 | 0.57 | 4.95 | 4.38 | |
| **Normal** | 216 | 2.07 | 0.70 | 0.89 | 4.95 | 4.06 | |
| **DJD** | 48 | 2.02 | 1.02 | 0.57 | 4.66 | 4.09 | 0.85 |
| **Class I** | 154 | 2.08 | 0.79 | 0.57 | 4.95 | 4.38 | |
| **Class II** | 67 | 2.74 | 0.91 | 1.20 | 5.20 | 4.00 | |
| **Class III** | 43 | 1.85 | 0.63 | 0.57 | 3.22 | 2.65 | |
| **10-19** | 42 | 1.92 | 0.67 | 0.89 | 3.94 | 3.05 | 0.61 |
| **20-29** | 54 | 2.18 | 0.69 | 0.89 | 4.08 | 3.19 | |
| **30-39** | 45 | 2.13 | 0.92 | 0.89 | 4.66 | 3.77 | |
| **40-49** | 60 | 2.01 | 0.77 | 0.57 | 4.95 | 4.38 | |
| **50-59** | 46 | 1.93 | 0.68 | 0.57 | 3.22 | 2.65 | |
| **60+** | 17 | 2.32 | 0.95 | 0.57 | 4.33 | 3.76 | |
| **Female** | 174 | 2.02 | 0.77 | 0.57 | 4.95 | 4.38 | |
| **Male** | 90 | 2.14 | 0.77 | 0.57 | 4.57 | 4.00 | 0.29 |
| **Left** | 130 | 2.11 | 0.79 | 0.57 | 4.95 | 4.38 | |
| **Right** | 134 | 2.01 | 0.74 | 0.57 | 4.57 | 4.00 | 0.04* |
| * Indicates p-values that are significant at the 0.05 level | | | | | | | |

| **Table 7:** Measure of Reproducibility. | |
|---|---|
| ICC | Measure of reproducibility |
| HCA-4 | 0.93 |
| HCA-6 | 0.91 |
| HCA-8 | 0.93 |
| ML | 0.94 |
| AP | 0.92 |
| SJS | 0.88 |
| PJS | 0.88 |
| AJS | 0.84 |
| ICC = Intraclass Coefficient | |

in the studies by Rodrigues et al.[52,53], were marginally higher (Class I: 69.96-70.10°, Class II: 67.43-67.80°, Class III: 71.25-72.88°), than those observed in the present cohort. Angular measurements from the present study were averaged from three height measurements for each joint, and therefore may explain the differences in these figures. Similar to the trend described by Rodrigues et al [52,53], the mean HCA for Class II occlusion in this study was found to be slightly smaller compared to Class I occlusion, whereas the mean HCA for Class III occlusion was found to be significantly larger than those in Classes I and II. The explanation for this observation is unclear, however Katsavrias and Halazonetis [61], suggested that functional loading may be vary for different classes of occlusion, especially for Class III where condyle and fossa shapes are dissimilar to Class I and II occlusions, and thus the condylar angulation.

The relationship between the HCA and condylar dimensions has not been explored previously. In the current study, an increase in the median AP dimension of the mandibular condyle was found to be associated with an increase in HCA. The association between maximum ML dimension and HCA was found to be weak but statistically significant. Although statistically significant correlations were found in this study, the clinical significance of these findings is yet to be elucidated.

No statistically significant correlations were found between HCA and joint spaces in the present study. At the time of writing, no known research has been carried out to investigate the direct relationship between HCA and joint spaces. However, several studies have examined the relationship between HCA and internal derangement (ID) [18,54,55,60]. ID was not specifically assessed in the current study, however joints with ADD are associated with increased AJS in the closed position as the articular disc is more anteriorly placed between the mandibular condyle and the articular eminence. Therefore, results from ID studies in relation to the HCA may be extrapolated. Findings from the MRI studies by Westesson et al. [54], and Kurita et al. [55], suggested that anterior disc displacement (ADD), is associated with smaller HCA. On the other hand, results from the studies by Westesson and Liedberg [18], and Sulun et al. [60], did not reveal any significant mean HCA differences between normal joints and those with ADD. Differences in these results from may be due to the use of different transverse planes for angular measurement.

No significant associations were observed between HCA and age or gender in this study. This is consistent with findings from previous studies by several authors [45,46,54,60,62].

## Condylar Dimensions

For normal joints, the mean maximum ML dimension were comparable to those reported by other CBVT [36], and CT [46,47], studies, however other studies using SMV [11,19], and direct visual assessments [63], reported marginally higher figures. Differences in the results could be explained by slight underestimation of measurements from reconstructed CBVT [39-41], and CT [22], images. The mean median AP dimension found in the current study was similar to that reported by Krenkel and Grunert [11], where the AP dimension was also measured at the mid-condylar point. This measurement was distinctly smaller than the maximum AP dimension reported in the other studies [36,63], and this disparity may be explained by the difference in measurement landmarks. The shape of the condyle varies greatly in the axial plane [19], and therefore the median AP measurement would not necessarily correspond to the maximum AP dimension.

Mean ML and AP dimensions of joints with DJD in the present study were found to be significantly smaller than those that were radiographically normal. Kurita et al. [57], also found smaller ML dimensions in joints with resorptive defects as a part of DJD. On the other hand, Ebner et al. [19], found no differences between normal joints and those with early or moderate to marked osseous changes radiographically. Both resorptive and proliferative changes are seen in DJD, and therefore the disease stage may influence the significance of dimensional measurements. Joints with early resorptive changes are more likely to be associated with smaller joint dimensions, whereas those with more marked proliferative changes may have larger joint dimensions due to articular surface flattening [57]. Specific types of degenerative changes were not analysed within this study, therefore it was difficult to determine the exact association between condylar dimensions and DJD. Findings from the current study may be partly attributed to a higher number of joints with resorptive degenerative changes in this particular cohort than those with proliferative changes. Further imaging studies using sub-classifications of degenerative joint changes may be of value in assessing the significance of joint dimensions in relation to DJD.

The maximum ML dimension was found to increase with age in the present study. It is reasonable to expect the ML dimension to increase with age due to progressive flattening of the condylar articular surface and proliferative osteoarthritic changes over time, as DJD is an age-dependent disease [56,64]. Christiansen et al. [46], found no correlations between condylar dimensions and age in a cohort with normal joints, but these authors mentioned a positive correlation with age in diseased TM joints in a previous study [65]. Results from the study by Ishibashi et al. [63], observed a trend of gradual decreasing condylar dimension especially after the fifth decade. Comparisons with results from previous studies are challenging as different inclusion criteria were used. Differences in study findings may be explained by the assessment of different age cohorts and also joints of different disease status.

Results from the current study revealed that males had significantly larger maximum ML dimensions. This finding was also reported by Christiansen et al. [46], and Goldman and Taylor [66], however two other studies with Asian subjects found no significant differences in condylar dimensions between genders [63,67]. The reasoning behind these findings is unclear, however in a study using human skulls, Hinton [68], found males to have consistently larger craniofacial dimensions and differences were also found between various ethnic groups. Hinton suggested possible genetic influences and also functional demands during growth as contributing factors to these observations [68].

## Joint Spaces

Overall, the mean SJS was found to be significantly larger than PJS and AJS. This is consistent with figures reported in previous studies [46,58,69-72]. No significant differences were found between the overall mean AJS and PJS. The values observed for SJS, PJS and AJS for the group with DJD in this study were smaller than those reported by other studies [66,70]. This difference may be attributed to the fact that only the osseous changes related to DJD was assessed in the present study and not disc displacement. No correlations were observed between any of the joint spaces and DJD. A number of previous tomographic studies found no differences in joint spaces between asymptomatic and symptomatic joints, and that condylar positioning is widely variable in asymptomatic joints [8,71,73]. Pullinger et al. [8], suggested that radiographic analysis alone cannot accurately determine the presence or absence of disc displacement associated with ID. However, the study by Kinniburgh et al. [70], observed a significant difference in joint spaces between normal joints and those with ID. This may be explained by the fact that not all asymptomatic joints are radiographically normal, and not all symptomatic joints are radiographically abnormal [8,74]. Also, joints with anterior disc displacement do not necessarily equate to osseous changes within the mandibular condyle.

Males were found to have significantly larger SJS compared to females. This finding correlates well with those reported by a number of previous studies [70-72]. Kinniburgh et al. [70], theorised that larger SJS in males may be explained by thicker soft tissues within the joint. An overall difference in condyle and glenoid fossa between genders may also explain this observation [68].

Occlusion of the patients at the time of scan was unknown, however a recent CBVT study has shown that the difference in joint space measurements between centric relation (CR), and maximal intercuspation (MI), is negligible [75]. Using a sample of asymptomatic young adult patients with normal occlusion, and Angle's classes of occlusion, these authors found that although there is a wide variation in condyle position in both CR and MI, the measurement differences were statistically insignificant.

## Symmetry

Asymmetry in the HCA between the condyles found in the current study was also observed by several authors [48,59,66]. In two separate studies, HCA symmetry between the two sides was only found in 33% and 48% of the subjects [59,66]. Similar to the findings reported by several authors [11,52,53], no statistically significant differences were found in the mean maximum ML and mean median AP dimensions between the two sides. The mean AJS on the right side was found to be smaller than the left side, and the mean PJS on the right side was larger than the left. These results are in agreement with those reported by Cohlmia et al. [71]. This feature is possibly due to habitual posturing or favouring of one side during function, but the exact cause is yet to be determined [71,76]. It is reasonable to expect a degree of asymmetry within a patient in both normal and abnormal occlusions due to developmental asymmetry. The possibility of unilateral anterior disc displacement may also explain these findings. Although statistical significant differences were reported, Weinberg et al. [73], found no clinical significance from such results.

## Reliability

High ICC values suggest that the intra-examiner error is low and the method of volume orientation is reliable and repeatable. The method of CBVT volume orientation used in this study may be considered as a baseline for developing a standardised reference for quantitative assessment.

### Limitations

Correlation of radiographic features with clinical findings was not assessed in this retrospective study. Prospective studies examining the significance of the HCA in relation to clinical signs and symptoms in TM joint dysfunction is recommended. Changes in HCA within an individual over time in relation to the progression of DJD will require longitudinal studies for further assessment.

## CONCLUSION

This is the first study to explore the significance of mandibular condylar angles measured at different heights through the condyle. Findings show that HCA is dependent on measurement height and may explain inconsistencies in the results from previous studies. HCA measurements from this study may be useful as a comparable reference for further CBVT studies correlating with clinical findings.

A trend of smaller mean HCA was observed in joints with DJD in this study, however further investigation using sub-classifications of DJD differentiating resorptive and/or proliferative degenerative changes would be of value in further assessing the significance of HCA in relation to DJD and possibly the mechanisms involved. Positive correlations were identified between HCA and Class III occlusions, and HCA and condylar dimensions, however the clinical significance of these findings may be determined by prospective studies including clinical assessments. No significant correlations were identified between HCA and joint spaces. An assessment including disc status may provide further information regarding this finding as only osseous changes were assessed in the present study. No correlations were found between the HCA and age or gender.

## ACKNOWLEDGEMENTS

In Memory of Dr Rebecca Liu who very sadly passed away before having this research published. Thanks also to Dr. Mark Griffin for assistance with the statistical analyses. Thanks also goes to MaxilloFacial Imaging for providing de-identified CBVT datasets for this research.

## REFERENCES

1. Brooks SL, Brand JW, Gibbs SJ, Hollender L, Lurie AG, Omnell KA, et al. Imaging of the temporomandibular joint: a position paper of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1997; 83: 609-618.
2. Westesson PL. Reliability and validity of imaging diagnosis of temporomandibular joint disorder. Adv Dent Res. 1993; 7: 137-151.
3. Larheim TA. Current trends in temporomandibular joint imaging. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995; 80: 555-576.
4. Hussain AM, Packota G, Major PW, Flores-Mir C. Role of different imaging modalities in assessment of temporomandibular joint erosions and osteophytes: a systematic review. Dentomaxillofac Radiol. 2008; 37: 63-71.
5. de Senna B, dos Santos Silva V, França J, Marques L, Pereira L. Imaging diagnosis of the temporomandibular joint: critical review of indications and new perspectives. Oral Radiology. 2009; 25: 86-98.
6. Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL, et al. Research diagnostic criteria for temporomandibular disorders (RDC/TMD): development of image analysis criteria and examiner reliability for image analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009; 107: 844-860.
7. Pullinger A, Hollender L. Assessment of mandibular condyle position: a comparison of transcranial radiographs and linear tomograms. Oral Surg Oral Med Oral Pathol. 1985; 60: 329-334.
8. Pullinger AG, Hollender L, Solberg WK, Petersson A. A tomographic study of mandibular condyle position in an asymptomatic population. J Prosthet Dent. 1985; 53: 706-713.
9. Gray RJ, Quayle AA, Horner K, Al-Gorashi AJ. The effects of positioning variations in transcranial radiographs of the temporomandibular joint: a laboratory study. Br J Oral Maxillofac Surg. 1991; 29: 241-249.
10. Lysell L, Petersson A. The submento-vertex projection in radiography of the temporomandibular joint. Dentomaxillofac Radiol. 1980; 9: 11-17.
11. Krenkel C, Grunert I. The mandibular condyles in the submentovertex projection--their morphology and topographical relationship to the foramina spinosa. J Oral Rehabil. 1989; 16: 417-424.
12. Cholitgul W, Petersson A, Rohlin M, Tanimoto K, Akerman S. Diagnostic outcome and observer performance in sagittal tomography of the temporomandibular joint. Dentomaxillofac Radiol. 1990; 19: 1-6.
13. Liedberg J, Rohlin M, Westesson PL. Observer performance in assessment of condylar position in temporomandibular joint radiograms. Acta Odontol Scand. 1985; 43: 53-58.
14. Ludlow JB, Davies KL, Tyndall DA. Temporomandibular joint imaging: a comparative study of diagnostic accuracy for the detection of bone change with biplanar multidirectional tomography and panoramic images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1995; 80: 735-743.
15. Flygare L, Rohlin M, Akerman S. Microscopy and tomography of erosive changes in the temporomandibular joint. An autopsy study. Acta Odontol Scand. 1995; 53:2 97-303.
16. Schmitter M, Gabbert O, Ohlmann B, Hassel A, Wolff D, Rammelsberg P, et al. Assessment of the reliability and validity of panoramic imaging for assessment of mandibular condyle morphology using both MRI and clinical examination as the gold standard. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2006; 102: 220-224.
17. Danforth RA, Otis LL, Kipnis V, Ong SH, Voss R. Corrected TMJ tomography: effectiveness of alternatives to SMV tracing. Am J Orthod Dentofacial Orthop. 1991; 100: 547-552.
18. Westesson PL, Liedberg J. Horizontal condylar angle in relation to internal derangement of the temporomandibular joint. Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics. 1987; 64: 391-394.
19. Ebner KA, Otis LL, Zakhary R, Danforth RA. Axial temporomandibular joint morphology: a correlative study of radiographic and gross anatomic findings. Oral Surg Oral Med Oral Pathol. 1990; 69: 247-252.
20. Maxwell MF, Farman AG, Haskell BS, Yancey JM. Submentovertex radiology: cephalometric considerations in temporomandibular dysfunction. Cranio. 1995; 13: 15-21.
21. Westesson PL, Katzberg RW, Tallents RH, Sanchez-Woodworth RE, Svensson SA. CT and MR of the temporomandibular joint: comparison with autopsy specimens. AJR Am J Roentgenol. 1987; 148: 1165-1171.
22. Christiansen EL, Thompson JR, Kopp S. Intra- and inter-observer variability and accuracy in the determination of linear and angular measurements in computed tomography. An in vitro and in situ study of human mandibles. Acta Odontol Scand. 1986; 44: 221-229.

23. Zain-Alabdeen EH, Alsadhan RI. A comparative study of accuracy of detection of surface osseous changes in the temporomandibular joint using multidetector CT and cone beam CT. Dentomaxillofac Radiol. 2012; 41: 185-191.

24. Tsiklakis K, Syriopoulos K, Stamatakis HC. Radiographic examination of the temporomandibular joint using cone beam computed tomography. Dentomaxillofac Radiol. 2004; 33: 196-201.

25. Alkhader M, Ohbayashi N, Tetsumura A, Nakamura S, Okochi K, Momin MA, et al. Diagnostic performance of magnetic resonance imaging for detecting osseous abnormalities of the temporomandibular joint and its correlation with cone beam computed tomography. Dentomaxillofac Radiol. 2010; 39: 270-276.

26. Widmalm SE, Brooks SL, Sano T, Upton LG, McKay DC. Limitation of the diagnostic value of MR images for diagnosing temporomandibular joint disorders. Dentomaxillofac Radiol. 2006; 35: 334-338.

27. Tasaki MM, Westesson PL. Temporomandibular joint: diagnostic accuracy with sagittal and coronal MR imaging. Radiology 1993; 186: 723-729.

28. Tasaki MM, Westesson PL, Raubertas RF. Observer variation in interpretation of magnetic resonance images of the temporomandibular joint. Oral Surg Oral Med Oral Pathol. 1993; 76: 231-234.

29. Cohnen M, Kemper J, Mobes O, Pawelzik J, Modder U. Radiation dose in dental radiology. Eur Radiol 2002; 12: 634-637.

30. Kobayashi K, Shimoda S, Nakagawa Y, Yamamoto A. Accuracy in measurement of distance using limited cone-beam computerized tomography. Int J Oral Maxillofac Implants. 2004; 19: 228-231.

31. Abboud M, Guirado JL, Orentlicher G, Wahl G. Comparison of the accuracy of cone beam computed tomography and medical computed tomography: implications for clinical diagnostics with guided surgery. Int J Oral Maxillofac Implants. 2013; 28: 536-542.

32. Scarfe WC, Farman AG, Sukovic P. Clinical applications of cone-beam computed tomography in dental practice. J Can Dent Assoc. 2006; 72: 75-80.

33. Marques AP, Perrella A, Arita ES, Pereira MF, Cavalcanti Mde G. Assessment of simulated mandibular condyle bone lesions by cone beam computed tomography. Braz Oral Res 2010; 24: 467-474.

34. Honda K, Larheim TA, Maruhashi K, Matsumoto K, Iwai K. Osseous abnormalities of the mandibular condyle: diagnostic reliability of cone beam computed tomography compared with helical computed tomography based on an autopsy material. Dentomaxillofac Radiol 2006; 35: 152-157.

35. Hintze H, Wiese M, Wenzel A. Cone beam CT and conventional tomography for the detection of morphological temporomandibular joint changes. Dentomaxillofac Radiol. 2007; 36: 192-197.

36. Hilgers ML, Scarfe WC, Scheetz JP, Farman AG. Accuracy of linear temporomandibular joint measurements with cone beam computed tomography and digital cephalometric radiography. Am J Orthod Dentofacial Orthop. 2005; 128: 803-811.

37. Lascala CA, Panella J, Marques MM. Analysis of the accuracy of linear measurements obtained by cone beam computed tomography (CBCT-NewTom). Dentomaxillofac Radiol. 2004; 33: 291-294.

38. Ludlow JB, Laster WS, See M, Bailey LJ, Hershey HG. Accuracy of measurements of mandibular anatomy in cone beam computed tomography images. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007; 103: 534-542.

39. Pinsky HM, Dyda S, Pinsky RW, Misch KA, Sarment DP. Accuracy of three-dimensional measurements using cone-beam CT. Dentomaxillofac Radiol. 2006; 35: 410-416.

40. Panzarella FK, Junqueira JL, Oliveira LB, de Araujo NS, Costa C. Accuracy assessment of the axial images obtained from cone beam computed tomography. Dentomaxillofac Radiol. 2011; 40: 369-378.

41. Torres MG, Campos PS, Segundo NP, Navarro M, Crusoe-Rebello I. Accuracy of linear measurements in cone beam computed tomography with different voxel sizes. Implant Dent. 2012; 21: 150-155.

42. Lagravere MO, Hansen L, Harzer W, Major PW. Plane orientation for standardization in 3-dimensional cephalometric analysis with computerized tomography imaging. Am J Orthod Dentofacial Orthop. 2006; 129: 601-604.

43. Kim TY, Baik JS, Park JY, Chae HS, Huh KH, Choi SC. Determination of midsagittal plane for evaluation of facial asymmetry using three-dimensional computed tomography. Imaging Sci Dent. 2011; 41: 79-84.

44. Higley LB. A new and scientific method of producing temporomandibular articulation radiograms. Int J Orthodontia Oral Surg. 1936; 22: 983-991.

45. Sato H, Fujii T, Kitamori H. The clinical significance of the horizontal condylar angle in patients with temporomandibular disorders. Cranio-the J Craniomandibular Practice. 1997; 15: 229-235.

46. Christiansen EL, Chan TT, Thompson JR, Hasso AN, Hinshaw DB, Jr., Kopp S. Computed tomography of the normal temporomandibular joint. Scand J Dent Res. 1987; 95: 499-509.

47. Raustia AM, Pyhtinen J. Morphology of the condyles and mandibular fossa as seen by computed tomography. J Prosthet Dent. 1990; 63: 77-82.

48. Williamson PC, Major PW, Nebbe B, Glover KE. Landmark identification error in submentovertex cephalometrics. A computerized method for determining the condylar long axis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998; 86: 360-369.

49. Vitral RWF, da Silva Campos MJ, Rodrigues AF, Fraga MR. Temporomandibular joint and normal occlusion: Is there anything singular about it? A computed tomographic evaluation. Am J Orthodontics and Dentofacial Orthopedics. 2011; 140: 18-24.

50. Vitral RW, Telles Cde S. Computed tomography evaluation of temporomandibular joint alterations in class II Division 1 subdivision patients: condylar symmetry. Am J Orthod Dentofacial Orthop. 2002; 121: 369-375.

51. Seren E, Akan H, Toller MO, Akyar S. An evaluation of the condylar position of the temporomandibular joint by computerized tomography in Class III malocclusions: a preliminary study. Am J Orthod Dentofacial Orthop. 1994; 105: 483-488.

52. Rodrigues AF, Fraga MR, Vitral RW. Computed tomography evaluation of the temporomandibular joint in Class I malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofacial Orthop. 2009; 136: 192-198.

53. Rodrigues AF, Fraga MR, Vitral RW. Computed tomography evaluation of the temporomandibular joint in Class II Division 1 and Class III malocclusion patients: condylar symmetry and condyle-fossa relationship. Am J Orthod Dentofacial Orthop. 2009; 136: 199-206.

54. Westesson PL, Bifano JA, Tallents RH, Hatala MP. Increased horizontal angle of the mandibular condyle in abnormal temporomandibular joints - a magnetic-resonance-imaging study. Oral Surgery Oral Medicine Oral Pathology Oral Radiology and Endodontics. 1991; 72: 359-363.

55. Kurita H, Ohtsuka A, Kobayashi H, Kurashina K. Relationship between increased horizontal condylar angle and resorption of the posterosuperior region of the lateral pole of the mandibular condyle

in temporomandibular joint internal derangement. Dentomaxillofacial Radiol. 2003; 32: 26-29.

56. Alexiou K, Stamatakis H, Tsiklakis K. Evaluation of the severity of temporomandibular joint osteoarthritic changes related to age using cone beam computed tomography. Dentomaxillofac Radiol. 2009; 38: 141-147.

57. Kurita H, Koike T, Narikawa J, Nakatsuka A, Kobayashi H, Kurashina K. Relationship between alteration of horizontal size and bony morphological change in the mandibular condyle. Dentomaxillofac Radiol. 2003; 32: 355-358.

58. Ikeda K, Kawamura A. Assessment of optimal condylar position with limited cone-beam computed tomography. Am J Orthod Dentofacial Orthop. 2009; 135: 495-501.

59. Yale SH. Radiographic evaluation of the temporomandibular joint. J Am Dent Assoc. 1969; 79: 102-107.

60. Sulun T, Akkayan B, Duc JMP, Rammelsberg P, Tuncer N, Gernet W. Axial condyle morphology and horizontal condylar angle in patients with internal derangement compared to asymptomatic volunteers. Cranio-the J Craniomandibular Practice. 2001; 19: 237-245.

61. Katsavrias EG, Halazonetis DJ. Condyle and fossa shape in Class II and Class III skeletal patterns: a morphometric tomographic study. Am J Orthod Dentofacial Orthop. 2005; 128: 337-346.

62. Eisenburger M, Haubitz B, Schmelzeisen R, Wolter S, Tschernitschek H. The human mandibular intercondylar angle measured by computed tomography. Arch Oral Biol. 1999; 44: 947-951.

63. Ishibashi H, Takenoshita Y, Ishibashi K, Oka M. Age-related changes in the human mandibular condyle: a morphologic, radiologic, and histologic study. J Oral Maxillofac Surg. 1995; 53: 1016-1023; discussion 1023-1014.

64. Duan X, Wu J, Mao Y, Wang H, Wang M. A retrospective study on the relationship between aging and tomographic findings in 174 patients with TMD. Oral Radiol. 1999; 15: 9-17.

65. Christiansen EL, Thompson JR, Kopp SF, Hasso AN, Hinshaw DB, Jr. Radiographic signs of temporomandibular joint diseases: an investigation utilizing X-ray computed tomography. Dentomaxillofac Radiol. 1985; 14: 83-91.

66. Goldman SM, Taylor R. Retrospective radiographic evaluation of 100 temporomandibular joint patients. J Prosthetic Dentistry. 1985; 53: 566-569.

67. Meng F, Liu Y, Hu K, Zhao Y, Kong L, Zhou S. A comparative study of the skeletal morphology of the temporo-mandibular joint of children and adults. J Postgrad Med. 2008; 54: 191-194.

68. Hinton RJ. Relationships between mandibular joint size and craniofacial size in human groups. Arch Oral Biol. 1983; 28: 37-43.

69. Major PW, Kinniburgh RD, Nebbe B, Prasad NG, Glover KE. Tomographic assessment of temporomandibular joint osseous articular surface contour and spatial relationships associated with disc displacement and disc length. Am J Orthod Dentofacial Orthop. 2002; 121: 152-161.

70. Kinniburgh RD, Major PW, Nebbe B, West K, Glover KE. Osseous morphology and spatial relationships of the temporomandibular joint: comparisons of normal and anterior disc positions. Angle Orthod. 2000; 70: 70-80.

71. Cohlmia JT, Ghosh J, Sinha PK, Nanda RS, Currier GF. Tomographic assessment of temporomandibular joints in patients with malocclusion. Angle Orthod. 1996; 66: 27-35.

72. Dalili Z, Khaki N, Kia SJ, Salamat F. Assessing joint space and condylar position in the people with normal function of temporomandibular joint with cone-beam computed tomography. Dent Res J (Isfahan) 2012; 9: 607-612.

73. Weinberg LA. An evaluation of asymmetry in TMJ radiographs. J Prosthet Dent. 1978; 40: 315-323.

74. Brand JW, Whinery JG, Jr., Anderson QN, Keenan KM. Condylar position as a predictor of temporomandibular joint internal derangement. Oral Surg Oral Med Oral Pathol. 1989; 67: 469-476.

75. Henriques JC, Fernandes Neto AJ, Almeida Gde A, Machado NA, Lelis ER. Cone-beam tomography assessment of condylar position discrepancy between centric relation and maximal intercuspation. Braz Oral Res .2012; 26: 29-35.

76. Taylor RC, Ware WH, Fowler D, Kobayashi J. A study of temporomandibular joint morphology and its relationship to the dentition. Oral Surg Oral Med Oral Pathol. 1972; 33: 1002-1013.

**Cite this article**

*Liu RCT, Monsour PA (2020) Assessment of the Mandibular Condyles Using Cone Beam Volumetric Tomography. JSM Dent 8(3): 1132.*