

MIMICS-Based 3D CT Morphometrics of Mandibular Condyles

Hibah Ezzat Rashid Berum^{1,2}, Ayman Hameed Uraibi¹, Haider Ali Hasan¹, Asmaa Sami Jawad¹

¹College of Dentistry, University of Babylon, Babylon, Iraq

²Faculty of Dentistry, Universiti Malaya, Kuala Lumpur, Malaysia

Abstract

Objective: To investigate the influences of age, sex and side on dimensions of the condylar head in a three-dimensional CT DICOM image using MIMICS software. **Patients and Methods:** The study samples consisted of eighty individuals (40 males and 40 females) divided in two age groups (childhood and adolescence). Width and length of condylar head were measured using 3D CT DICOM images processed by MIMICS software from radiology archive in specialist radiology center in different Iraqi hospitals. **Results** Age represented the most remarkable influence on condylar dimensions, with a statistically significant increment from infancy to adolescence. All dimensions were significantly greater for males compared to females, especially condylar width. Age by sex interaction increased sexual dimorphism during adolescence, particularly in transverse dimension. No significant differences between right and left sides were found, indicating bilateral symmetry. **Conclusion** Transverse growth was more sensitive to developmental and sexually dimorphic factors, as mandibular condylar width had higher correlation coefficients with age and sex compared to condylar length. Bilateral symmetry was preserved, as no significant right–left differences were detected. The current study provides normative reference values useful in forensic identification, orthodontics and anthropological assessment for the Iraqi subadult population.

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Email: hibbabayram@gmail.com

Introduction

Investigations on condylar head measurements, sexual dimorphism and CT skull imaging have become significant in forensic sciences, orthodontics and maxillofacial surgery [1,2]. The mandibular condyle is important because it is the last craniofacial structure to ossify, and it faces great growth changes between 7 and 14 years old [3]. Craniofacial features display evidence of sexual dimorphism, which is mainly attributed to the condylar head, however no studies on Iraqi subadults dealing with this subject were found.

Temporomandibular Joint (TMJ) represented the lower jaw connects to the skull and allows movements necessary for speech, eating and swallowing [4]. It is a hinge and gliding synovial joint between the mandibular condyle, the articular disc and glenoid fossa [5, 6]. Mandibular dimorphism, as driven by masticatory muscle size and chewing forces, means that the bones of men are in general larger and stronger than those of women [7, 8].

The use of 3D CT scanning provides the opportunity for a more thorough evaluation of

bone structure, with an ability to generate 3D surface models of bone from CT scans [9]. These models permit accurate landmarking of anatomical points and retrieval of morphometric information [10]. CT Imaging is integral to visualization of TMJ and allows precise imaging and reveals bones including condyle, fossa, and articular disc [11]. This high-resolution imaging is helpful in diagnosing fractures, degenerative process and gives a guide to further surgical management of TMJ disorders [12].

MIMICS software is required for the

processing of TMJ DICOM images and provides highly-sophisticated 3D visualization and segmentation for joint structures (condyle, fossa, articular disc) [13, 14]. It allows the accurate measurement and detection of TMJ disorders or fractures.

MIMICS also creates precise 3D models to plan surgery and personalized treatment [15].

The present study employed 3D CT DICOM images by MIMICS to explore the effect of age, sexual dimorphism and side difference on condylar head measurements among Iraqi subadult population and how this knowledge will increase the accuracy in forensic identifications and assists in building profiles from skeletal remains, thus being important for both forensic caseworks and anthropological studies on human populations.

Subjects and Methods

The current study was analyzed eighty 3D CT DICOM images processed by MIMICS software (40 male and 40 female) divided in to two age groups: childhood (5-11 years) and adolescents (12-18 years) with four exams each one: condylar length and condylar width of right and left sides as shown in Figure 1 and Tables 1 and 2. The CT images from different Iraqi hospitals are acquired using a UNITED IMAGING CT SCANNER uCT530 at scanning parameters: 120 kV, 240 mAs and minimum slice thickness (0.6mm). Exclusion criteria were diseases, fractures and low-quality images. Three-way factorial MANOVA used to find sexual dimorphism, age assessment involving right and left sides relative to anteroposterior and mediolateral condylar head dimensions. Measurements were made with 20% of the sample to test the reproducibility and Inter-rater agreement was measured by Kappa test. Data were entered into Microsoft Excel, grouped into age classes (childhood vs adolescence), sex (male vs female) and side (right vs left).

Results and Discussion

This study evaluated the effects of age, sex, and side on condylar width and length using a balanced three-way MANOVA. Significant differences were identified across developmental stages and between sexes, including a significant age by sex interaction, indicating that condylar morphology is strongly influenced by growth and sexual dimorphism. In contrast, no significant right-left differences were observed, confirming that bilateral symmetry is maintained while developmental stage and sex remain the primary determinants of condylar dimensions.

Effect of Age on Condylar Dimensions

As shown in Figures 2 and 3 and Tables 3 and 4; age was the most influencing factor of condylar form. Multivariate main effects of age were significant (Pillai's Trace =.602, $F(2,151) = 114.43$, $p < .001$) resulting in significant differences from childhood to adolescence. These findings were supported by significant univariate effects of the condylar width ($F = 204.42$, $p < .001$) and condylar length ($F = 122.12$, $p < .001$) from childhood to adolescence. The comparison of the highest intensity points revealed that there was a great elevation in condylar width (1.7mm mean increase) and moderate one for condyle length (0.53mm).

These results approve with Saccucci M et al., 2012, Krisjane et al., 2007 and Hinton, 1991 demonstrated significant age-related increases in condylar dimensions as a secondary cartilage responsive to mechanical and hormonal influences, reinforcing our results that pubertal acceleration drives the significant dimensional increases observed in adolescence [16-18].

Importantly, our finding the greater effect size for width than length suggest that transverse condylar growth is more sensitive to local and systemic biomechanical and hormonal influences.

Effect of Sex and Sexual Dimorphism

Sex as a covariate yielded a large multivariate effect as explained in figures (2 and 3) and tables (3 and 5) (Pillai's Trace=0.326, $F(2,151) = 36.53$, $p < .001$). Males had noticeably larger condylar measurements than females, for the width ($F = 72.64$, $p < .001$) and length ($F = 9.21$, $p = 0.003$). The sex effect was notably stronger for condylar width than for length, indicating greater sexual dimorphism in transverse growth. Males have larger mandibular dimensions compared to females [8,19]. This difference is likely related to prolonged mandibular growth and higher pubertal growth velocity influenced by androgenic hormones [20].

Our results crossmatching with Ishwarkumar (2016) and El Bahnasy (2022) and their colleagues definite that the anteroposterior and mediolateral mandibular condyles were larger in males while the females had lesser values [21,22]. In contrast, Alam et al. (2021) reported no significant sex effect on condylar head dimensions with sex prediction rate is nearly the same [23].

Age × Sex Interaction

Multivariate level analysis showed a significantly large Age × Sex interaction effect as shown in Figure 2 and Table 3 (Pillai's Trace =.113, $F(2,151) = 9.66$, $p < .001$). The univariate analyses were significant for condylar

width ($F = 10.40$, $p = 0.002$), but not for condylar length.

This suggests that increased sexual dimorphism in condylar width occurs during growth. Differences in male-female gap were expressed in tables (4 and 5); more limited in childhood and increased markedly during adolescence. This tendency would seem to indicate that sex differences in transverse condylar growth are exaggerated during the pubertal growth period, which may be a result of distinct timing and rate of skeletal maturity for males vs. females.

So, our results of interaction between age and sex effect on condylar dimensions agreed with Yun in 2021 and Ramírez in 2023 and their colleagues concluded that demographic factors, such as sex and age, significantly affect mandibular condylar morphology [24,25].

Condylar Width Across Sex and Age Groups

As shown in Figure 3 and Table 5, the mean condylar width among childhood was higher in males (15.32mm) than in females (14.68mm), and this difference accentuated during adolescence, when respective averages were (17.43mm and 16.02mm) both for males and females. The Model Strength $R^2 = .654$ for Condylar Width indicates that 65% of width variance is explained by the study. The significant age by sex interaction shows that transverse condylar growth is especially susceptible to pubertal as well as hormonal influences, and there appears to be more sexual dimorphism in width than in length of the condyle implying possibly that mediolateral condylar development is more responsive to sex-related differences in growth patterns.

Condylar Length Across Sex and Age Groups

As shown in Figure 3 and Table 5 observed for condylar length, although the magnitude of differences was smaller. In those of childhood the average length in males was 8.29mm and in females 8.08mm. In the adolescent period, these values rose to 8.76mm in males and 8.67mm in females. The Model Strength $R^2 = .466$ for Condyle Length indicated that 47% of length variance is explained by the study. The sexual size dimorphism of the length was smaller for both groups than in width. This means that condylar anteroposterior growth is more parallel during the longitudinal development of both males and females, while transverse growth has a greater degree of sexual dimorphism.

Side Differences in Condylar Dimensions

In the analysis of the right and left condyles

shown in Figure 3 and Table 5, no significant differences in width or length were found at any age in either sex. In childhood, the mean width was right 15mm and left 14.99mm; in adolescence, this was right 16.73mm and left 16.71mm. Also, for condylar length the right-left difference in both age groups was minimal. Inferential analysis revealed no statistically significant effect of side on condylar width ($p=0.9$) nor the condylar head length ($p=0.9$), and none of the side interactions was significant. This supports previous evidence that healthy individuals exhibit minimal asymmetry in condylar dimensions. Our results agree with [21, 24, 25]. In contrast, Alam et al. reported right and left condyles are asymmetry in relation to condyle morphometry of anterior-posterior and medio-lateral aspect [23].

Conclusion

The current results have shown the condylar morphology is highly related to both age and sex, particularly in adolescence that appeared as a rapid growth period and sexual dimorphism at this time. Condylar width showed the greatest sensitivity to developmental and sex-specific factors. On the other hand, bilateral symmetry is preserved and no significant side differences were pronounced. In summary, these results supply normative reference information for the developmental appraisal of mandibular condylar shape with its width is more strongly determined by age and sex factors than length.

Limitations and Future Directions

Despite that, the cross-sectional design of the study does not allow the inference of individual growth pathways. Longitudinal studies would provide more evidence for differences in timing and velocity of growth. It might be useful to conduct additional studies that include the skeletal maturity index, hormonal status and three-dimensional shape analysis to provide a better understanding of biological courses in condylar growth.

Recommendations

Thus, we highlight the need to perform more studies involving different population groups with larger samples and other methodological types of studies that conduct, for example, morphometric evaluation in dry skulls so that we can achieve a better level of evidence scientific regarding this to add another possibility of sexual differentiation within forensic anthropology.

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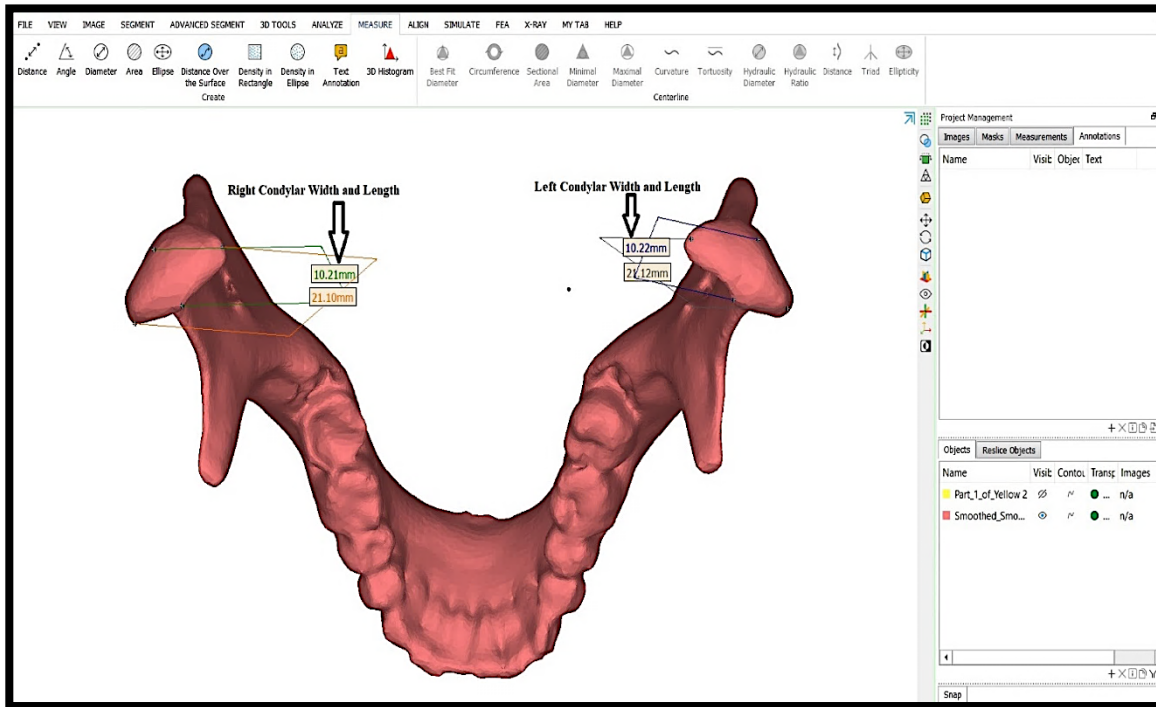


Figure 1. Three-dimensional assessment of right and left mandibular condylar dimensions using MIMICS software.

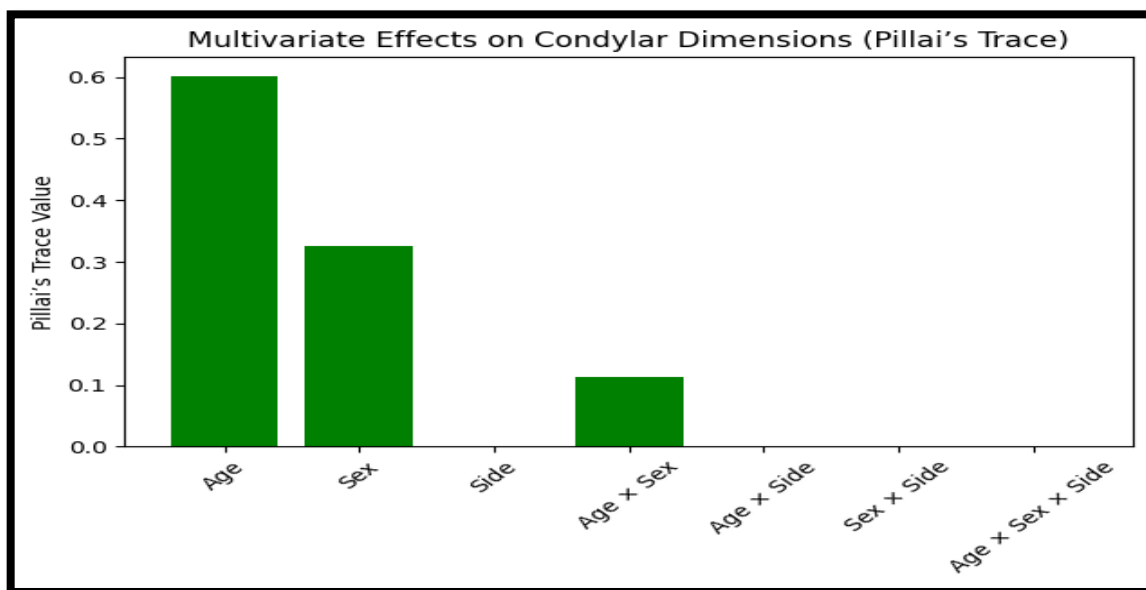


Figure 2. Bar chart representing Pillai's trace values: Green bars = Statistically significant effects. Gray bars = Not significant effects.

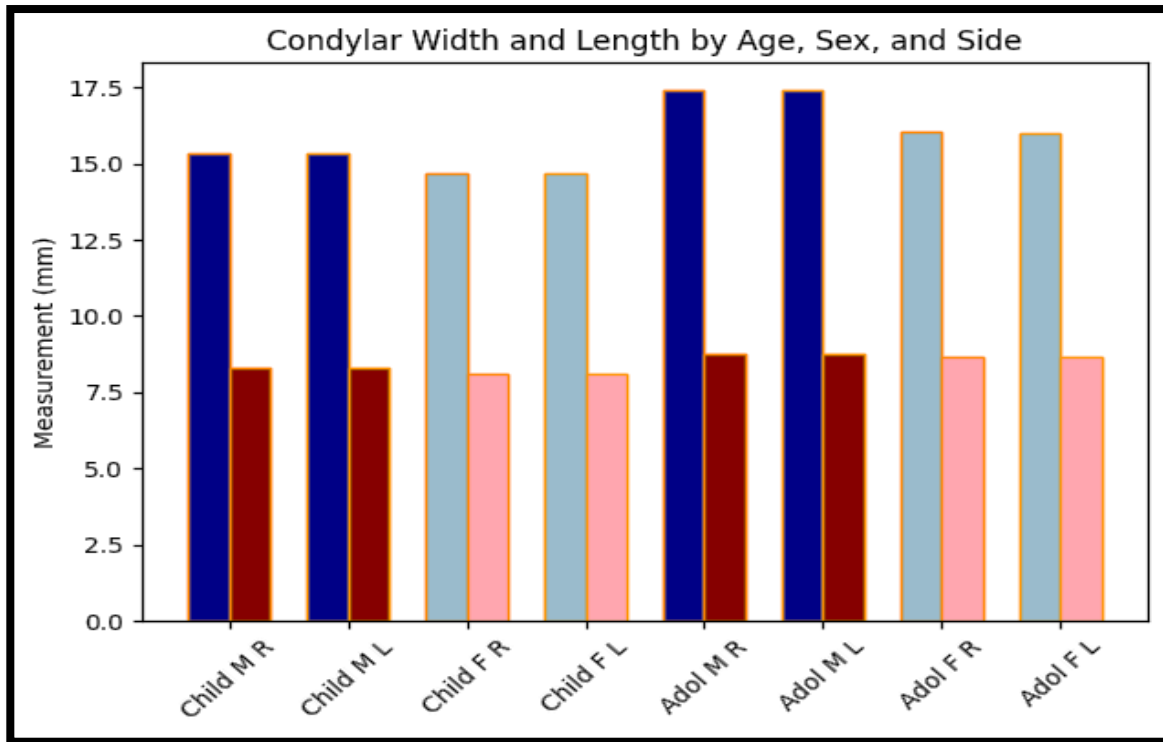


Figure 3. The bar chart summarizes condylar dimensions across age, sex, and side, with width represented in dark blue (males) and light blue (females), and length shown in dark red (males) and pink (females). Right and left sides measurements are highlighted with dark orange edges, allowing clear visualization of sexual dimorphism and bilateral symmetry.

Table 1. Anatomical landmarks used in the study described by Krisjane and Hilgers methods [26,27].

Posterior mandibular condyle (PCo)	The maximum posterior extent of the mandibular condyle at a distance of 4 mm inferior to the apex of the superior condylar surface
Anterior mandibular condyle (ACo)	The maximum anterior extent of the mandibular condyle at a distance of 4 mm inferior to the apex of the superior condylar surface
Lateral mandibular condyle (LCo)	Coronal view of most lateral extent of mandibular pole of condyle
Medial mandibular condyle (MCo)	Coronal view of the most medial extent of the mandibular pole of condyle

Table 2. The dimensions of the condylar head described by Krisjane and Hilgers methods [26,27].

Condylar Length (CL) PCo – ACo	Coronal linear distance between posterior mandibular condyle and anterior mandibular condyle
Condylar Width (CW) MCo – LCo	Coronal linear distance between medial mandibular condyle and lateral mandibular condyle

Table 3. Multivariate analysis summary for the effects of age, sex, and side on condylar dimensions based on Pillai's trace.

Effect	Pillai's Trace	Significance (p-value)	Interpretation
Age	0.602	< 0.001	Significant
Sex	0.326	< 0.001	Significant
Side	0.000	0.994	Not Significant
Age × Sex	0.113	< 0.001	Significant
Age × Side	0.000	0.98	Not Significant
Sex × Side	0.000	0.96	Not Significant
Age × Sex × Side	0.000	0.94	Not Significant

Table 4. Age-related differences in mean condylar dimensions (mm).

Variable	Childhood Mean	Adolescence Mean
Width	14.999 mm	16.723 mm
Length	8.187 mm	8.719 mm

Table 5. Mean ± standard deviation of condylar width and length (mm) according to age group, sex, and side.

Age Group	Sex	Width Right	Width Left	Length Right	Length Left
Childhood	Male	15.32 ± 0.46	15.32 ± 0.46	8.29 ± 0.11	8.29 ± 0.12
	Female	14.68 ± 0.52	14.68 ± 0.52	8.09 ± 0.17	8.08 ± 0.19
Adolescence	Male	17.43 ± 0.98	17.43 ± 0.97	8.77 ± 0.50	8.76 ± 0.51
	Female	16.03 ± 0.94	16.00 ± 0.95	8.68 ± 0.27	8.67 ± 0.27