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Volumetric and Morphometric Condylar Assessment in Patients with Class II and Class III Skeletal Patterns Prior to Orthognathic Surgery: A CBCT 3D Study

Evaluación Volumétrica y Morfométrica de Cóndilos Mandibulares en Pacientes con Patrones Esqueletales Clase II y Clase III Previo a Cirugía Ortognática: Un Estudio CBCT 3D

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SUMMARY: The objective of this study was to compare the mandibular condyles' anatomical characteristics in skeletal class II and III patients' candidates for orthognathic surgery. A total of 71 patients (41 men and 30 women) were classified into skeletal class II (n=33) and class III (n=38) according to standard methods. Two-dimensional and three-dimensional analyses of both left and right mandibular condyles was performed upon CBCT scans. Condylar dimension, condylar position, and condylar morphology ??were quantified and compared between class II and class III skeletal classes. Class III patients exhibited increased condylar width, height, and volume compared with class II patients (p <0.001) bilaterally. Similarly, Class III patients showed a bilateral reduced posterior joint space (P <0.001 and p = 0.027) and left and right condylar axial angles (p = 0.033 and p = 0.006), compared with Class II patients. Skeletal classes variables were associated with the right (p <0.001) and left (p = 0.022) condylar concentricity, and with the right (p = 0.014) and left (p = 0.016) condylar morphology. Thus, class III patients' condyles were more concentric and convex than class II patients' condyles, which were more anterior and flatter. There are significant differences between Class II and class III patients' condyles regarding anatomical, morphological, and positional variables. These data highlight critical anatomical features to consider before orthognathic surgery.

KEY WORDS: Cone beam computed tomography; Mandibular condyle; Skeletal class; Analysis; Malocclusion.

INTRODUCTION

The temporomandibular joint (TMJ) is a crucial piece for diagnosis, treatment planning, and long-term follow-up in patients with dento maxillary abnormalities (REFS). Knowing the normal morphology of condyle and its relationships with surrounding structures allows clinicians to identify TMJ alterations in patients with skeletal deformities/ abnormalities. Sagittal skeletal morphology was classified as class I, which mean ANB angle between 2° and 4°, Wits appraisal -3 to +3 mm, App-Bpp 3 to 7 mm; class II, where means ANB angle >4°, Wits appraisal > +3 mm, App-Bpp > 7mm, and class III, which mean ANB angle <2°, Wits appraisal < -3 mm, App-Bpp < 3 mm (Plaza *et al*., 2019).

Different skeletal morphology leads to different functional patterns, determining the masticatory muscle activity and occlusal forces (Park *et al*., 2014). Consequently, TMJ joint surfaces' remodeling differs according to skeletal types, mainly affecting condylar shape and volume (Arieta-Miranda *et al*., 2013). This factor can have functional repercussions after corrective treatments, especially surgical corrections (osteotomies) (REFS). Indeed, surgically corrected class III patients exhibited minimal dysfunction in the masticatory musculature and TMJ morphology after three years follow-up (REFS). On the contrary, surgically corrected class II patients subjected to significant mandibular

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advances showed a high risk of postoperative pain in the craniomandibular muscles and TMJ (Dolwick & Widmer, 2018). In this line, a preoperative definition of TMJ morphology is essential for planning and determining orthodontic and surgical treatment prognosis. To date, most studies describing TMJ morphology are based on populations having minor sagittal discrepancy of dentoalveolar component and subjected to orthodontic treatments. This study aims to characterize TMJ morphology in a population of patients with major sagittal discrepancies affecting both dentoalveolar and skeletal units.

MATERIAL AND METHOD

Study population. Retrospectively (2019-2021), we collected digital data of complete skull CBCTs from patients diagnosed with dentofacial abnormalities. All these patients were subjected to 3D virtual planning for orthognathic surgery and having pre-surgical orthodontics completed. We excluded patients with previous craniofacial surgery (i.e., trauma, facial clefts, craniofacial syndromes, jaw tumor/cyst, temporomandibular disorders, and absence of teeth (except third molars and premolars extracted for orthodontic indication).

Data collection and measurements. DICOM files from selected patient's CBCTs were analyzed using Delaire's architectural analysis in Planmeca Romexis® Cephalometric Analysis software (Planmeca, Helsinki, Finland). They were classified into skeletal class II (C-II) and skeletal class III (C-III). CBCTs imaging was performed according to standard protocol. Briefly, CBCTs were taken with the patients using an interocclusal wax register device in mandibular centric relation using a Planmeca Promax 3D device (Planmeca, Helsinki, Finland; 90 Kv and 10 mA, with a FOV of 20x17 cm, a voxel size of 0.4 mm^3 and an examination time of 15.9 seconds). DICOM files were obtained, processed, andexplored in multiplanar directions using the 3D Slicer Software (version 4.10.2; http://www.slicer.org), adjusting the brightness and contrast optimize the image quality. For the three-dimensional reconstruction of the condyle, in all examinations, an anatomical area was cut out, the limits of which corresponded to the lowest point of the sigmoid notch and the most superior, posterior, and anterior points of the condyle. These limits were related perpendicularly and parallel to the Frankfurt plane. Once this cut was made, the automatic reconstruction of the condyle was carried out, like other condylar segmentation studies. For these purposes, the software has a tool that creates a color map based on a range of a grayscale where default Threshold values (500 - 1800) were assigned. Thus, the operator delimits the contour of the condylar surface, removing the excess tissue around the condyle. Thus, the range was reduced until the color circumscribed the anatomy of the mandibular condyle with the subsequent volumetric reconstruction. All images were reoriented to the Frankfurt plane, positioning them parallel to the horizontal reference plane, and the other two orthogonal planes were reoriented perpendicular to it. A previously calibrated examiner carried out the measurements, and the images were visualized using 2D images and 3D reconstructions. The analyzed parameters were classified into three groups: a) Condylar dimension: Width, depth, height, and condylar volume (CV); b) Condylar position: Anterior joint space (AJS), Superior joint space (SJS), posterior joint space (PJS), axial condylar angle, condylar radius, condylar concentricity, and c) Condylar morphology: Round, convex, angled, flat. Both condylar morphology was classified based on previous studies (7–9), and condylar concentricity was evaluated with the Pullinger & Hollender (1985) method: (PJS - AJS) / (PJS + AJS) ¥ 100. Values within ± 12 % indicate concentric position; less than -12 % posterior position and greater + 12 % anterior position. Definitions are detailed in Table I and Figures 1 and 2.

Statistical analysis. The measurements were registered on both right and left condyles independently using numerical values and tabulated using the SPSS V. 25.0 software (Armonk, NY: IBM Corp), where they were descriptively and statistically analyzed with the Student-T and chi square test; considering $p < 0.05$ statistically significant.

RESULTS

Epidemiological data and distribution. Of 71 patients, 41 were (57.7 %) women and 30 (42.3 %) were men, giving a sex ratio of 1.36. The age ranged from 10 to 40 years old, with a mean age of 24.5 years old [IQR=7]. Thirty-three patients (46.5 %) were classified as C-II and 38 patients (53.5 %) as C-III; no significant difference was found between the ages of the C-III patients compared to the C-II patients (p = 0.632) (Table I).

Table I. Demographic data.

Skeletal class	N (%)	Sex (%)	Age mean ± SD (Range)
C-II	33 (46.5)	Male 11 (66.7)	24.7 ±3.4 (20 – 32)
		Female 22 (33.3)	24.8±6.3 (19 – 40)
C-III	38 (53.5)	Male 19 (50)	24.2±3.8 (19 – 32)
		Female 19 (50)	24.2±7.0 (19 – 40)

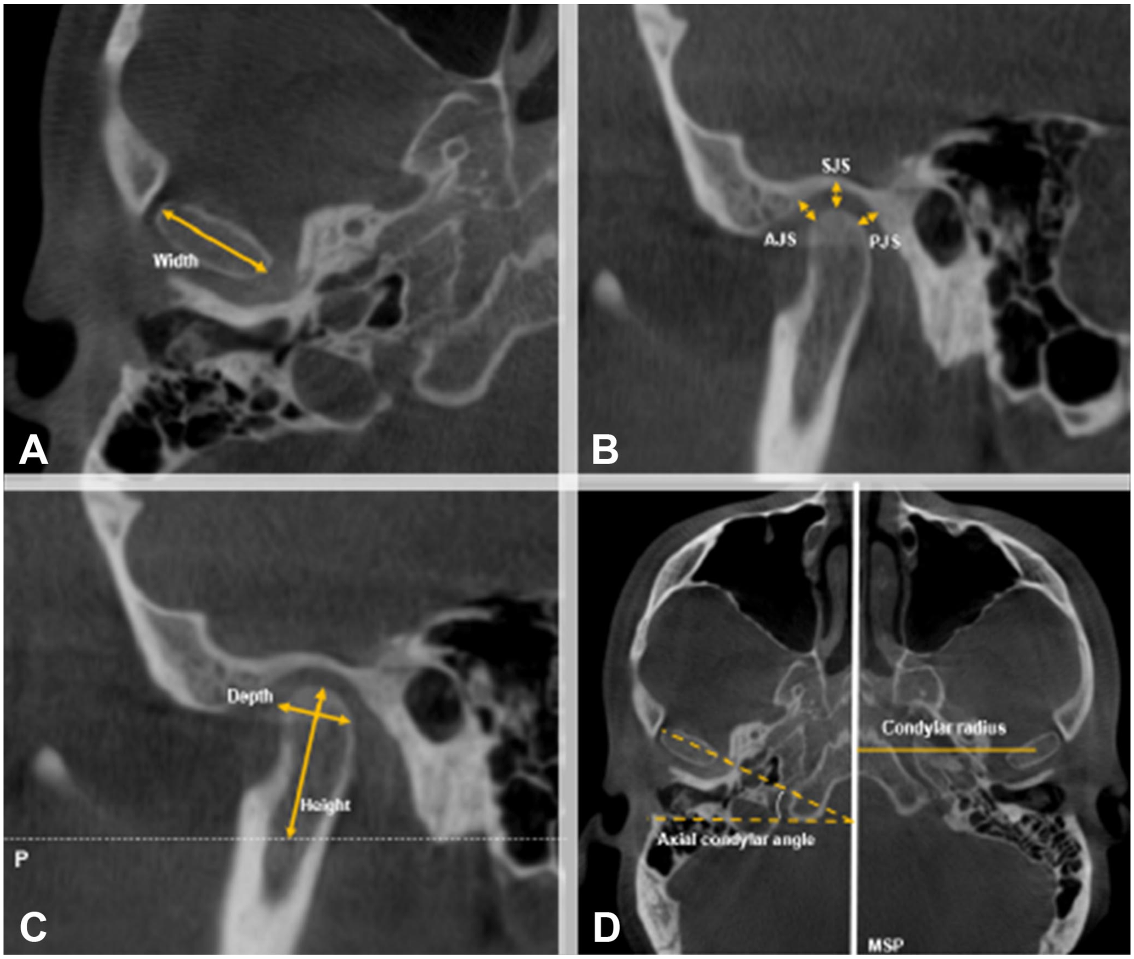

Fig. 1. (A) Cross-sectional view with measurement of condylar width is observed. (B) A sagittal view is observed with measurement of the anterior joint space (AJS), superior joint space (SJS) and posterior joint space (PJS). (C) A sagittal view is observed with measurement of condylar height and width. P: horizontal line through the lowest point of the sigmoid notch. (D) A cross-sectional view is observed with measurement of the axial condylar angle and the condylar radius. MSP: Mid-sagittal plane.

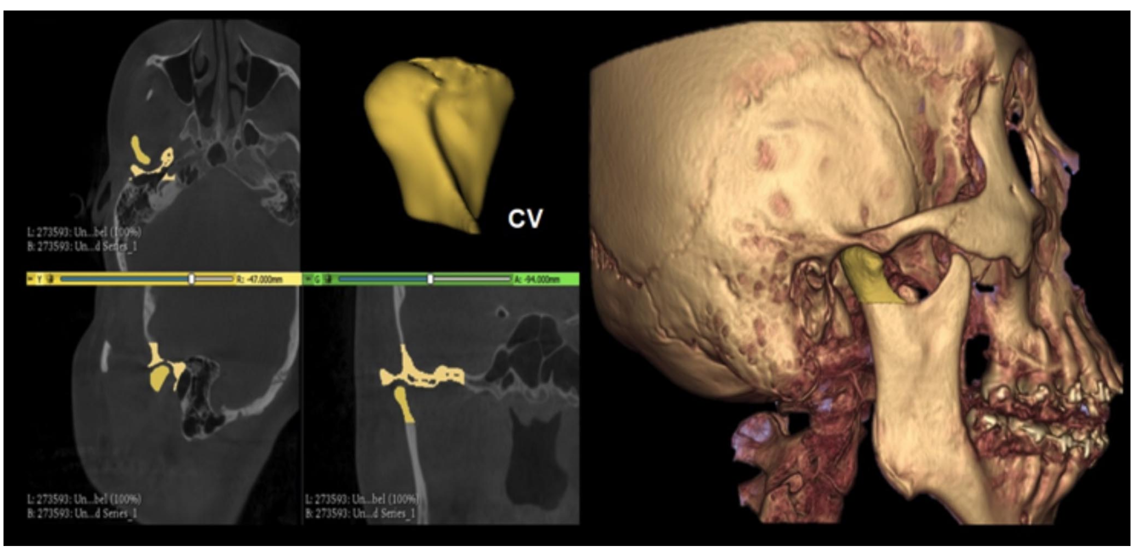

Fig. 2. Reconstruction and segmentation of the mandibular condyle for calculation of condylar volume (CV)

Outcomes, criteria, and criteria definitions are detailed in Table II. Comparing condylar dimensions, we observed that C-II exhibited reduced width and height versus C-III both in the right ($p < 0.001$) and on the left side ($p < 0.001$) (Table III). Otherwise, C-II and C-III patients showed similar condylar depth on both sides (Table III). Finally, the condylar volume (CV) of C-III patients was significantly higher than in C-II patients on both sides ($p < 0.001$) (TableIII).

Regarding condylar morphology, 42.4 % of C-II patients featured a flat shape on both sides, followed by 36.4 % with a convex shape, 15.1 % with a round shape, and 6.1 % with an angled profile. On the other hand, 57.9 % of C-III patients showed a convex morphology on both sides, followed by 23.7 % with a round shape, 10.5 % with an angled shape, and 5.2 % with a flat form (Fig. 3; Table IV).

Regarding the condylar position, CIII patients showed the posterior joint space (PJS) lower compared to C-II patients on the right and left side ($p < 0.001$ and $p = 0.027$, respectively) (Table III). At the same time, the anterior joint space (AJS) was slightly higher in C-III patients than C-II patients on the right side; however, this value doesn't reach statistical differences (Table III). In the same way, the superior joint space (SJS) was slightly lower in C-III patients versus C-II, again, without statistically significant differences (Table III).

Table II. Outcomes, criteria and criteria definitions evaluated in the study.

Outcome	Criteria	Criteria definition
	Width (Wd)	Largest distance (mm) existing between the most lateral point to the most medial point of the mandibular condyle.
	Depth (Dp)	Largest distance (mm) existing between the most anterior and the most posterior point of the condyle.
Condylar dimension	Height (He)	Distance of the condylar process (mm) measured from an axis passing through the lowest point of the mandibular notch to the highest point of the condyle in the sagittal plane
	Condylar Volume (CV)	Total volume of the mandibular condyle (mm^3), analyzed from the axis that crosses the lowest point of the mandibular notch.
Condylar morphology	Morphology	Mandibular condyle shape, categorized in coronal sections in 4 shapes: oval, rounded, flat and angled, according to the observational classification of Yale et al. (1963).
	Anterior joint space (AJS)	Shortest distance (mm^2) between the most anterior point of the condyle and the posterior wall of the articular tubercle, measured in the sagittal plane
	Superior joint space (SJS)	Distance (mm) between the highest point of the condyle and the highest point of the mandibular fossa, measured in the sagittal plane
Condylar position	Posterior joint space (PJS)	Shortest distance (mm^2) measured between the most posterior point of the condyle and the posterior wall of the mandibular fossa, measured in the sagittal plane
	Axial condylar angle	Angle (°) formed by the intersection of the mediolateral axes of the mandibular condyle and the midsagittal plane.
	Condylar radius	Distance (mm) measured from the geometric center of the mandibular condyle to the midsagittal plane
	Condylar concentricity	Positional relationship of the condyle with respect to the mandibular fossa.

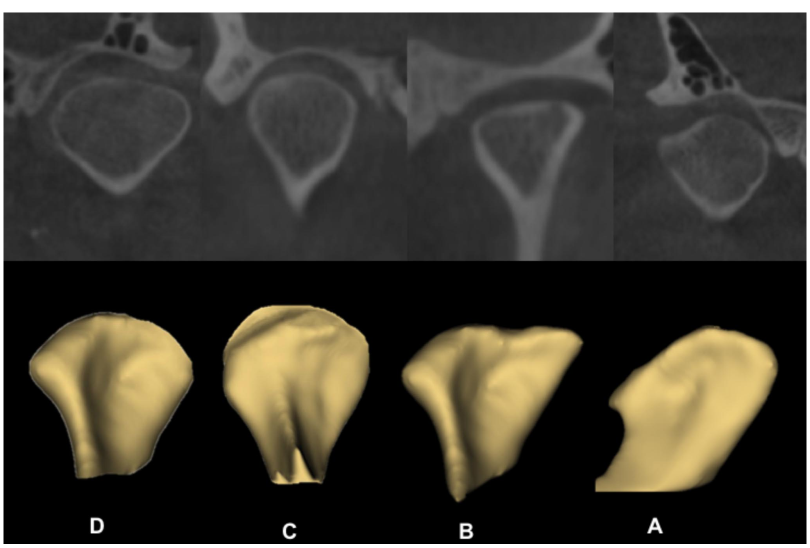

Fig. 3. Coronal CBCT slices and three-dimensional reconstructions evaluating the different morphologies of the mandibular condyle (A) Convex; (B) Rounded; (C) Flat; (D) Angled.

On the other hand, the condylar axial angle was significantly lower in C-III patients than in C-II patients, both on the right (p = 0.033) and left (p = 0.006); however, the distance from the condyle to the midsagittal plane did not differ in both types of skeletal patterns (Table III).

Finally, we analyzed the condylar concentricity. We observed that both right and left mandibular condyles of C-II patients are located in an anterior position than C-III patients, which is frequently located in a concentric place (Table V; Fig. 4).

Table III. Comparison between skeletal class II and class III individuals.

Outcome	**Criteria**	**C-II** Mean ± SD	**C-III** Mean ± SD	**p - value**
	Width (mm)			
Condylar dimension	*Right*	15.41 ± 2.11	17,61 ± 2,82	<0.001*
	Left	15.16 ± 2.24	17,52 ± 1,95	<0.001*
	Depth (mm)			
	Right	8.09 ± 1.53	8.22 ± 1.38	0.713
	Left	8.14 ± 1.70	7.68 ± 1.58	0.246
	Height (mm)			
	Right	15.48 ± 1.92	17.47 ± 2.06	<0.001*
	Left	14.64 ± 2.46	17.28 ± 2.68	<0.001*
	Condylar volume (mm^3)			
	Right	1126,55 ± 231,05	1447,40 ± 267,01	<0.001*
	Left	1143,54 ± 317,62	1431,52 ± 299,41	<0.001*
Condylar position	Anterior joint space (mm)			
	Right	1.75 ± 0.49	1.94 ± 0.42	0.070
	Left	1.94 ± 0,44	1.98 ± 0.70	0.788
	Superior joint space (mm)			
	Right	2.04 ± 0.58	1.94 ± 0,78	0.529
	Left	2.40 ± 0.64	2.27 ± 0,99	0.528
	Posterior joint space (mm)			
	Right	2.80 ± 0.88	1.77 ± 0.67	<0.001*
	Left	2.51 ± 1.00	2.04 ± 0.75	0.027*
	Axial condylar angle (°)			
	Right	24.82 ± 12.93	19.56 ± 6.90	0.033*
	Left	25.56 ± 11.98	18.85 ± 7.76	0.006*
	Condylar Radius			
	Right	49,16 ± 2,94	49,93 ± 3,01	0,279
	Left	49,85 ± 2,99	49,59 ± 3,20	0,730

T- student was used. * p <0.05 statistically significant difference.

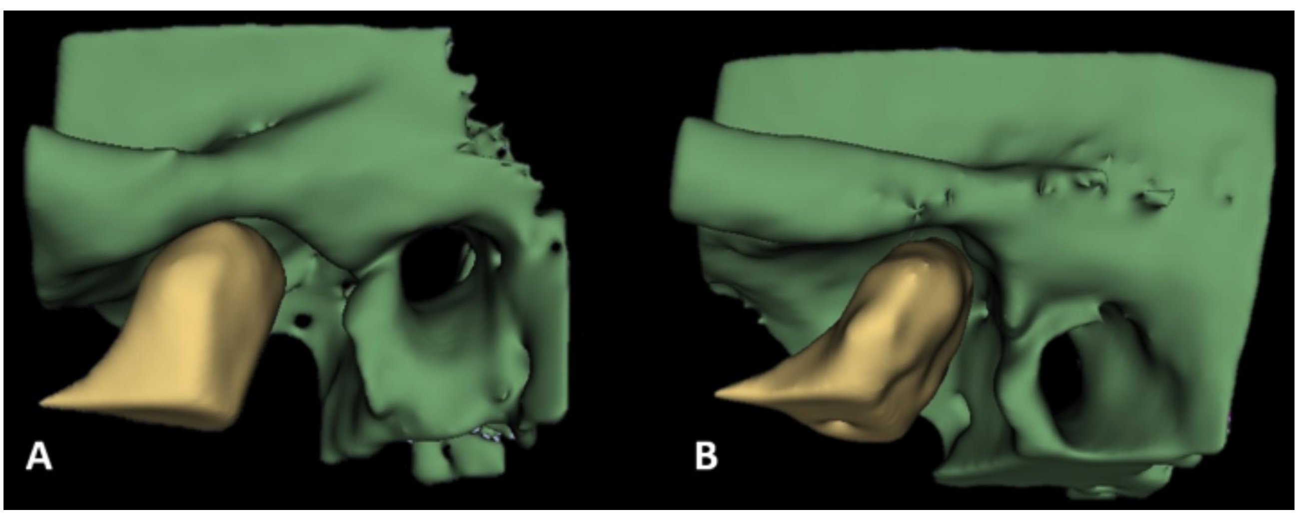

Fig. 4. Three-dimensional reconstruction evaluating anterior condylar position of skeletal class II patient (A) with respect to concentric position in skeletal class III patient (B).

Table IV. Description of condylar morphology.

	Class II No. of joints(%)	Class III No. of joints(%)	p-value
Right condylar morphology			
• Round	5 (15.1 %)	12 (31.6 %)	
• Convex	12 (36.4 %)	19 (50 %)	0.014*
• Angled	2 (6.1 %)	4 (10.5 %)	
• Flat	14 (42.4 %)	3 (7.9 %)	
Left condylar morphology			
• Round	5 (15.1 %)	9 (23.7 %)	
• Convex	12 (36.4 %)	22 (57.9 %)	0.006*
• Angled	3 (9.1 %)	5 (13.2 %)	
• Flat	13 (39.4 %)	2 (5.2 %)	

Chi square test was used; * P <0.05 statistically significant.

Table V. Description of condylar concentricity.

	Class II No. of joints (%)	Class III No. of joints (%)	p-value
Right condylar position			
• Anterior	20 (60.7 %)	6 (15.8 %)	<0.001*
• Concentric	11 (33.3 %)	17 (44.7 %)	
• Posterior	2 (6 %)	15 (39.5 %)	
Left condylar position			
• Anterior	17(51.5 %)	8 (21.1 %)	0.022*
• Concentric	12 (36.4 %)	20 (52.6 %)	
• Posterior	4 (12.1 %)	10 (26.3 %)	

Chi square test was used; * P <0.05 statistically significant.

DISCUSSION

In the present study, a quantitative-morphological analysis was carried out based on the classification of skeletal classes (C-II; C-III). This could have more reliable measurements and results compared to studies based only on molar relationships that allow evaluating only sagittal discrepancies based on teeth (Song *et al*., 2020), while studies with cranio-architectural analysis show skeletal discrepancies, being more compatible with TMJ problems (Loiola *et al*., 2023).

Regarding the results obtained, the size of the mandibular condyles was greater in patients C-III than in patients C-II with larger diameters in width and height. Even though the literature is ambiguous regarding these measurements, there is an agreement that condylar diameters in class II patients tend to be smaller than in C-III patients (Ma *et al*., 2018; Hasebe *et al*., 2019). Ma *et al*. (2018) and Song *et al*. (2020), found that both depth and width were significantly higher in C-III patients, a situation that was only found in width in our study, since the same difference was not observed in depth. In the same way, it has been described that skeletal C-III patients have more elongated condyles (Katsavrias & Halazonetis, 2005; Hasebe *et al*., 2019), a situation that was consistent with this study, but there are some authors who found no significant differences in this parameter (Song *et al*., 2020). Finally, a higher CV was observed in subjects with C-III, with respect to subjects with C-II, which was consistent with what was described by Santander *et al*. (2020), and Saccucci *et al*. (2012a). This disagrees with the studies by Loiola *et al*. (2023) and Saccucci *et al*. (2012b), in which, although a trend towards higher volumes has been found in C-III patients in relation to C-II, these differences have not been statistically significant. The results of this study also differ from the results obtained by Katayama *et al*. (2014), who found that the CV was greater in class II patients than in class III and I patients, however, they also found no statistically significant association. This heterogeneity could be associated with the different delimitation of the condyle by the different studies. In addition, it has been proposed that the CV would depend on various factors, where the skeletal patterns would determine different functional loads during mastication, thus influencing the TMJ dimensions (Meikle, 2007; Saccucci *et al*., 2012a,b). In fact, in a study with 25 subjects with different diets, the condylar width was significantly greater in the groups with a hard diet than in those with a soft diet after one week, suggesting that marked changes in the masticatory pattern affect the growth of the condylar cartilage and the condylar morphology (Enomoto *et al*., 2010). On the other hand, larger condyles would provide stable support for occlusal changes, which would be associated with C-III patterns, these being more resistant to displacement due to the close condyle-fossa relationship, while small condyles would frequently be associated to C-II moving easily in the mandibular fossa (Krisjane *et al*., 2009).

With respect to the condylar position, in the present study only a significant difference was found in the PJS, being less in the C-III patients with respect to the C-II, which would mean that the condyle would be in a more posterior position in the mandibular fossa, however, it was found that the C-III condyles were preferentially in a centric position while the C-II were in an anterior position. These findings are consistent with previous studies who identified that the condyles were positioned more anteriorly in C-II subjects than in C-III subjects, which tended to be in more concentric or posterior positions in the mandibular fossa (Kikuchi *et al*., 2003; Krisjane *et al*., 2009; Arayapisit*et al*., 2023). Contrary to this, Arieta-Miranda *et al*. (2013) and Lobo *et al*. (2019), found that the condyle in the group of patients C-III is in a more anterior position compared to the group of C-II. This fact is controversial since it has been described that more posterior condylar positions would be more associated with the appearance of joint disorders due to a greater physical load and excessive compression of the articular disc, while concentricity would be optimal (Chae *et al*., 2020). On the other hand, no relationship was found between the SJS between C-II and C-III, unlike other studies where the condyles of the participants with C-II skeletal patterns were placed in a lower position, while the condyles of participants with C-III skeletal patterns were positioned closer to the glenoid fossa, where the SJS in C-III was significantly smaller than in other groups, with a greater proximity of the condyle to the fossa (Katsavrias & Halazonetis, 2005; Arieta-Miranda *et al*., 2013; Ma *et al*., 2018; Song *et al*., 2020). Finally, regarding the condylar angles, it was found that they were smaller in C-III than in C-II, which would support a more anterior condylar position in C-II patients, while the condylar radius would not have differences between the different skeletal classes, because there would be no lateral or medial variations of the condyles in patterns C-II and C-III, in agreement with the studies realized by Ma *et al*. (2018), and Song *et al*. (2020). TMJ disorders associated with the position of the condyle are currently controversial, since the condylar position would also depend on other factors, such as disc thickness, soft tissues and eminence (Katsavrias & Halazonetis, 2005). The different condylar positions present in the studies could be associated as an adaptive response of the masticatory system rather than as a sign of TMJ dysfunction. Even so, the discrepancies between these results may be due to differences in the methods of analysis. However, it is essential to take into account these possible variations in the condylar position when planning corrective dentoskeletal treatments, since there are studies that have reported postoperative improvements in TMJ symptoms after surgical dentoskeletal corrections, and there are also studies that have suggested that positional modifications of the condyle-fossa relationship may promote postoperative occlusal instability, relapses, progressive condylar resorption, and temporomandibular disorders. In fact, statistically significant early changes have been reported in the condylar position after bilateral sagittal ramus osteotomy in mandibular advances with greater positional variations at the posterior and lateral level of the condyle (Lobo *et al*., 2019), so that it´s an aspect to be consider in the studies before and after orthodontic-surgical treatments.

Condylar morphology was different in both skeletal classes, being flattened in C-II and convex in C-III. This may suggest that condyle morphology differences could be associated with function due to the difference in magnitude, direction and distribution of stress in the condyle, where the condylar cartilage responds to physiological or pathological mechanical stress in the joint area causing condylar anatomical change (Meikle, 2007). In this way, functional patterns could influence morphological changes at the condylar level in the different skeletal classes. These findings differ from that studied by Ma *et al*. (2018), who found that convex morphology was the most prevalent, followed by round, angled and flat in all skeletal classes studied without significant differences; this is consistent with the studies by Park *et al*. (2014) and Yalcin & Ararat (2019). However, most authors have not correlated a skeletal pattern to the shape of the mandibular condyle (Yalcin & Ararat, 2019) or have pointed out that the shape of the condyle is not affected by a skeletal pattern (Park *et al*., 2014). On the other hand, morphological studies of the condyle and the mandibular fossa have been carried out based on measurements and points (Katsavrias & Halazonetis, 2005; Santander *et al*., 2020).

It should be noted that this study has some limitations. First, a retrospective study was conducted with a limited number of CBCT examinations, where only C-II and C-III patients were included, this due to the use of rigorous exclusion criteria with the aim of accurately reflecting the morphometric and positional condylar differences in these two types of skeletal classes. On the other hand, an analysis by gender and age was not carried out, so it is suggested for future research to consider these parameters with a larger sample size. Finally, the morphology was analyzed through an observational classification, so in future studies the analysis must be carried out based on parametric methods.

CONCLUSIONS

The present study, based on CBCT analysis, shows that condylar size, position, and morphology may be related to the skeletal classes studied, being a parameter to be evaluated by clinicians prior to orthodontic and surgical treatments. Our findings led us to conclude that:

1) The condyle size and volume of C-III dentoskeletal patients tend to be greater than in C-II dentoskeletal patients.
2) moreover, the condyles of C-II dentoskeletal patients tend to be in a more anterior position in the mandibular fossa, unlike those of C-III, which are in a more centered position.
3) The condyles tend to be convex in C-III dentoskeletal patients, while the tendency in C-II dentoskeletal patients is flat.

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RESUMEN: El objetivo de este estudio fue comparar las características anatómicas de los cóndilos mandibulares en pacientes con patrones esqueléticos de clase II y III candidatos a cirugía ortognática. Un total de 71 pacientes (41 hombres y 30 mujeres) fueron clasificados en clase esquelética II (n = 33) y clase III (n = 38) de acuerdo con los métodos estándar. Se realizaron análisis bidimensionales y tridimensionales de los cóndilos mandibulares izquierdo y derecho en exploraciones CBCT. La dimensión condilar, la posición condilar y la morfología condilar se cuantificaron y compararon entre las clases esqueléticas II y III. Los pacientes de clase III exhibieron un aumento del ancho, la altura y el volumen condilares en comparación con los pacientes de clase II ($p < 0,001$) bilateralmente. De manera similar, los pacientes de clase III mostraron un espacio articular posterior reducido bilateralmente ($P < 0,001$ y $p = 0,027$) y ángulos axiales condilares izquierdo y derecho ($p = 0,033$ y $p = 0,006$), en comparación con los pacientes de clase II. Las variables de clase esquelética se asociaron con la concentricidad condilar derecha ($p < 0,001$) e izquierda ($p = 0,022$), y con la morfología condilar derecha ($p = 0,014$) e izquierda ($p = 0,016$). Así, los cóndilos de los pacientes de clase III fueron más concéntricos y convexos que los de los pacientes de clase II, que fueron más anteriores y planos. Existen diferencias significativas entre los cóndilos de los pacientes de clase II y clase III en cuanto a variables anatómicas, morfológicas y posicionales. Estos datos resaltan características anatómicas críticas a considerar antes de la cirugía ortognática.

PALABRAS CLAVE: Tomografía computarizada de haz cónico; Cóndilo mandibular; Clase esquelética; Análisis; Maloclusión.

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