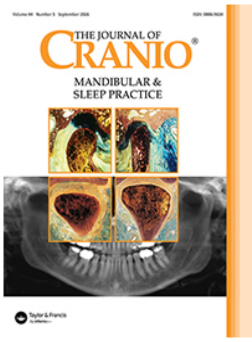

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RESEARCH ARTICLE

What happens to the contralateral condyle after proportional condylectomy? A multicenter study

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ABSTRACT

Objective: This retrospective study evaluated 3D positional and volumetric adaptations of the contralateral condyle after proportional condylectomy performed alone or combined with orthognathic surgery.
Methods: Twenty-three patients were allocated into three groups: isolated proportional condylectomy (G1), simultaneous condylectomy and orthognathic surgery (G2), and staged treatment (G3). CBCT analysis used anatomical landmarks, and condylar volume was assessed by semi-automated reconstruction.
Results: Median follow-up was 12.1, 9.7, and 13.3 months for G1, G2, and G3, respectively (7.7 months for T1–T2 in G3). G1 showed no significant positional changes. G2 exhibited superomedial rotational adaptation, with superior (0.5 mm, $p = .01$) and medial (1.5 mm, $p = .04$) displacements and lateral displacement of −0.5 mm ($p = .048$). G3 showed linear medial displacement of 2.6 mm (p=.04). No significant volumetric changes occurred in any group.
Conclusion: Distinct short-term 3D adaptation patterns of the contralateral condyle occurred according to surgical strategy. Volumetric changes were modest, suggesting adaptive remodeling rather than pathological resorption.

KEYWORDS
Mandibular condyle; hyperplasia; proportional condylectomy; dentofacial deformities; temporomandibular joint disorders

Introduction

Condylar hyperplasia (CH) can be described as an abnormal growth or proliferation at the cellular level in the head of the mandible. Condylar growth plays a fundamental role in the development and function of the temporomandibular joints (TMJs) and, consequently, in craniofacial growth. Consequently, CH commonly results in mandibular prognathism with elongation of the affected hemiface, facial asymmetry with chin deviation to the contralateral side, and a combination of crossbite with unilateral anterior or posterior open bite, resulting in a three-dimensional craniofacial deformity [1–3].

The hyperplastic condyle exhibits structural changes that alter its relationship with the glenoid fossa. The contralateral condyle, located opposite the mandibular growth vector, may also undergo adaptive changes, including compression against the articular eminence [1,2]. Therefore, unilateral intra-articular alterations, such as CH, are expected to induce adaptive responses not only in the affected joint but also in the contralateral TMJ [4,5].

Although adaptive structural changes may occur in the TMJ of patients with unilateral CH, contemporary evidence indicates that anatomical findings alone should not be interpreted as evidence of temporomandibular disorders or as an indication for invasive treatment [6]. Likewise, the diagnosis of isolated CH is not, by itself, an absolute indication for TMJ surgery. Surgical management should be individualized according to the biological stage of condylar growth and the associated dentofacial and occlusal compromise [7].

Several therapeutic protocols have been described in the literature, showing that an accurate diagnosis is essential for selecting the best management approach. Clinical history, facial photographs, study models, and imaging examinations, including computed tomography and bone scintigraphy, are routinely used for diagnosis and treatment planning [7–12].

The primary goals of treatment are to eliminate the active growth site, restore facial symmetry, and establish

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a stable occlusion. Surgical protocols describe isolated condylectomy (low, high, proportional, or condylar shaving) or condylectomy combined with orthognathic surgery. According to the systematic review by Niño-Sandoval et al. [12], proportional condylectomy is an effective procedure in the treatment of CH because it removes the pathological growth while preserving the vertical height of the mandibular ramus, thereby reducing the need for secondary condylar procedures. In selected patients without significant residual dentofacial deformities, it may represent the only surgical procedure required.

Although several studies have described adaptive remodeling of the operated condyle and the associated articular structures following proportional condylectomy [13,14], little is known about the adaptive response of the contralateral condyle after this procedure.

Therefore, the present multicenter study aimed to evaluate three-dimensional positional and volumetric changes of the contralateral condyle after proportional condylectomy performed alone or in combination with orthognathic surgery.

Material and methods

Study design

A multicenter longitudinal study was conducted in Institute of Maxillofacial Surgery (Teknon Medical Centre, Barcelona, Spain) and São Lucas Hospital (Pontifical Catholic University of Rio Grande do Sul, Brazil).

Data from patients who had undergone proportional condylectomy, with or without associated orthognathic surgery, and had CBCT exams at T0 (preoperatively), T1 (at least 6 months after proportional condylectomy), and T2 (at least 6 months after orthognathic surgery) were included. A minimum follow-up period of 6 months was adopted to allow postoperative skeletal healing and early adaptive remodeling before image acquisition. Patients with a history of trauma, previous surgery on the TMJ, craniofacial syndrome, who had signs and symptoms related to the TMJ arthritis or had medically compromised conditions were excluded. Magnetic resonance imaging was not included in the study protocol because the objective was limited to evaluating osseous positional and volumetric changes using CBCT.

Patients were categorized into three groups based on the procedures performed: G1) Proportional condylectomy as a standalone procedure; G2) Proportional condylectomy and orthognathic surgery performed concurrently during the same operative session; G3) Proportional condylectomy followed by orthognathic surgery at a later time, in two separate operative sessions.

The treatment option was based on the severity of the facial deformity and the occlusion initially presented. Those with less asymmetry and more regular occlusion underwent proportional condylectomy and subsequently completed treatment with orthodontics. Others, who presented with greater facial deformity, were indicated for orthognathic surgery. The decision to perform the procedure concomitantly or at a later stage was related to occlusion stability, that is, whether the patient required prior orthodontics or not.

CBCT acquisition process

An i-CAT scanner (Imaging Sciences International, Hatfield, PA, USA) was used to obtain CBCT images. Patients were instructed to sit upright and position themselves in a natural head position, looking forward as they saw themselves. They were asked to rest the tongue in a relaxed position, breathe lightly, and avoid any other motor reaction. They were instructed to place the mandible in maximum intercuspation. Scans were performed at 120 kV, 8 mA, acquisition time 40 s, and 0.3-mm voxel dimension. The data were reconstructed with 0.3-mm slice thickness, and the resulting digital imaging and communications in medicine (DICOM) images were assessed using Dolphin 3D Imaging software, version 11.95 (Dolphin Imaging and Management Solutions, Chatsworth, CA, USA). A 3D CBCT model was reconstructed in the software, then to reduce the chances of measurement mistakes, each patient's head orientation was configured in the software based on their photos.

Surgical planning and procedure

The method used for surgical planning and procedure followed the technique published by Haas Junior et al. [15]. The 3D planning step consisted of bilateral linear measurements from the mandibular angle to the highest point of the condylar region. The difference in vertical height between the hyperplastic and unaffected sides was used to determine the height of the proportional condylectomy on the hyperplastic side. Orthognathic surgery was subsequently planned when indicated. The cutting guide for condylectomy was 3D printed, as well as the occlusal guides for orthognathic surgery.

During surgery, the condylar region was accessed through a minimally invasive intraoral approach [16]. The cutting guide was positioned in the sigmoid notch, and the proportional condylectomy was performed with a horizontal osteotomy using a piezoelectric surgery device. The hyperplastic condylar portion was separated from the mandible and removed. When indicated, the minimally invasive orthognathic surgery was performed after condylectomy during the same procedure (G2) or after a minimum 6 months period (G3). Bilateral Sagittal Split Osteotomy (BSSO) and Le Fort I Osteotomy were performed in that order. The mandible was fixed with one miniplate and one cortical screw on each side and the maxilla was fixed with one miniplate on each side.

The surgical wounds were closed using continuous absorbable sutures.

Image analysis and measurements

The same image acquisition protocol was used for postoperative CBCT examinations. To ensure the same head position in the condylar assessment, in the same software, the postoperative CBCT was superimposed using the voxel-based technique of the anterior cranial base [17].

Measurement error was assessed using 10 randomly selected datasets. All measurements were repeated by the same examiner (BMR) after a 21-day interval, and the method error was calculated using Dahlberg's formula. Mandibular deviation was quantified through the horizontal linear distance between the reference point Menton and the facial midline, which was obtained from the union of the glabella and anterior nasal spine points.

The primary structure of interest in the study was the condyle contralateral to the condylectomy performed, the condyle without hyperplasia. To evaluate the 3D position, reference points on the condylar head were used [18]. Each landmark presents a value on each of the three axes: X (transverse), Y (vertical), and Z (antero-posterior).

Five anatomical landmarks were identified. In the coronal view: 1) uppermost limit; 2) lateral limit; 3) medial limit. In the sagittal view: 4) posterior limit; 5) anterior limit (Figure 1).

The condylar volume assessment was conducted through a protocol of semi-automated 3D condylar reconstruction [19].

Landmarks were applied, as well as the condylar volume calculation, in the pre- and postoperative images of all included patients.

Statistical analysis

Statistical analysis was performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). The normality of quantitative variables was assessed using the Shapiro–Wilk test. Quantitative variables with a normal distribution were described as mean and standard deviation, whereas variables with a non-normal distribution were described as median, minimum, and maximum values. Comparisons between evaluation time points were performed using the Wilcoxon signed-rank test. A significance level of 5% ($p < .05$) was adopted for all analyses.

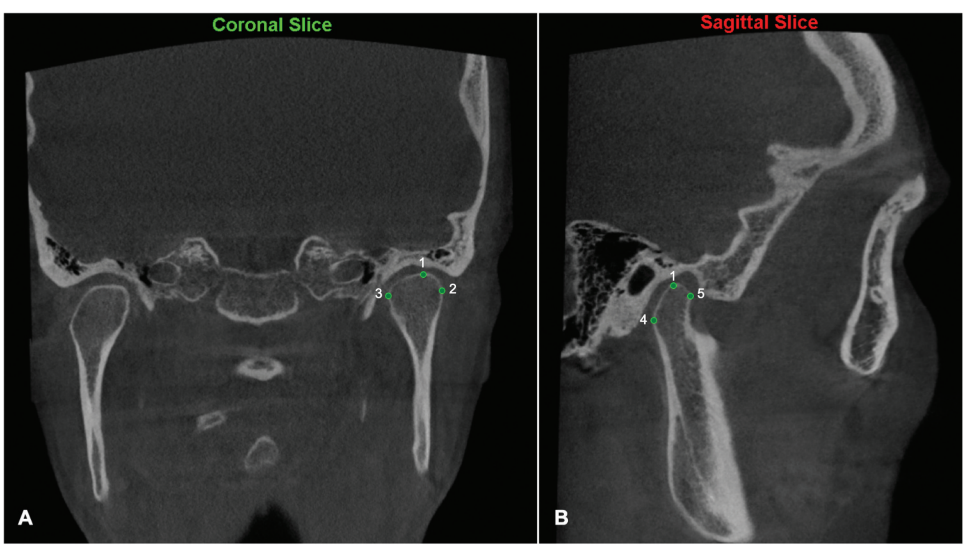

Figure 1. Reference points used in the three-dimensional analysis of condylar positioning. A) Coronal view; B) Sagittal view. (1: superior pole; 2: lateral pole; 3: medial pole; 4: posterior pole; 5: anterior Pole).

Results

The sample consisted of a total of 23 patients, of which 13 were from Brazil and 10 from Spain. The mean age was 25.8 ± 6.3 years, including 18 women and 5 men. The mean condylar hyperplasia height was 6.6 ± 4.1 mm in G1, 11.5 ± 6.2 mm in G2, and 6.4 ± 5.4 mm in G3, with an overall mean of 9.5 ± 6.1 mm. The groups 1, 2, and 3 had an average mandibular deviation of 7.7 ± 1.5 mm; 9.9 ± 5.0 mm; and 9.3 ± 5.1 mm, respectively. The median T0–T1 follow-up periods were 12.1, 9.7, and 13.3 months for Groups 1, 2, and 3, respectively. In Group 3, the median T1–T2 follow-up period was 7.7 months. Table 1 presents the demographic characteristics and follow-up periods in detail by group.

The Dahlberg method error for the three-dimensional positional measurements ranged from 0.175 to 0.428 mm, while the method error for condylar volume was 31.64 mm^3.

Regarding the position of the contralateral condyle, in G1, where proportional condylectomy was performed as the sole treatment, no significant differences were found in any direction.

In G2, patients who underwent proportional condylectomy and orthognathic surgery during the same surgical session showed significant vertical displacement (Y) of the superior, lateral, and medial condylar points. The superior and medial points showed displacements of 0.5 mm ($p = .01$) and 1.5 mm ($p = .04$), respectively, whereas the lateral point showed a displacement of −0.5 mm ($p = .048$), indicating a predominantly supero-medial rotational pattern (Table 2 and Figure 2).

In G3, which underwent two distinct surgical stages, comparative analyses were performed after each procedure. After the proportional condylectomy, there was a significant positional change on the transverse axis (X) at the superior ($p = .04$), posterior ($p = .04$), and anterior points ($p = .04$), in addition to a significant anteroposterior movement at the posterior point ($p = .04$). However, after the orthognathic surgery, no significant values of change were observed in the previously unoperated condyle position (Table 2 and Figure 2).

Groups 1 and 2 exhibited small volumetric changes that were not statistically significant. Group 1 showed a median reduction of 24.6 mm^3 (−1.9%; $p = .273$), whereas Group 2 demonstrated a median increase of 31.8 mm^3 (+3.7%; $p = .715$) (Table 3).

In Group 3, a trend toward progressive reduction in condylar volume was observed over time. Following proportional condylectomy (T0–T1), the median volume decreased by 108.9 mm^3 (−7.9%); however, this change was not statistically significant ($p = .345$). After orthognathic surgery (T1–T2), an additional

Table 1. Demographic characteristics and follow-up periods of the study groups.

	Age (years)	Gender (F = female; M = male)	Country (B= Brazil; S= Spain)	Patologic side (R = right; L = left)	Condylar hyperplasia height	Mandibular deviation (mm)	T0–T1 follow-up (months)	T1–T2 follow-up (months)
Group 1 ($n = 4$)	24.3 ± 5.6 (19–30)	4 F	4 S	4 R	6.6 ± 4.1 (3.6–12.7)	7.7 ± 1.5 (5.6–9.1)	12.1 (9.0–15.7)	–
Group 2 ($n = 14$)	24.6 ± 5.2 (17-34)	12 F 2 M	12 B 2 S	11 R 3 L	11.5 ± 6.2 (1.2–24.5)	9.9 ± 5.0 (0.5–14.7)	9.7 (6.0–29.1)	–
Group 3 ($n = 5$)	30.6 ± 8.5 (24 – 44)	2 F 3 M	1 B 4 S	3 R 2 L	6.4 ± 5.4 (1.3–14.3)	9.3 ± 5.1 (2.5–16.5)	13.3 (6.5–27.2)	7.7 (6.8–62.6)
General ($n = 23$)	25.8 ± 6.3 (17-44)	18 F 5 M	13 B 10 S	18 R 5 L	9.5 ± 6.1 (1.2–24.5)	9.4 ± 4.5 (0.5–16.5)	–	–

Age, condylar hyperplasia height and mandibular deviation are presented as mean ± standard deviation (range).
Follow-up periods are presented as median (minimum–maximum).

Table 2. Three-dimensional contralateral condylar position.

		Group 1		Group 2		Group 3			
		Δ T1 – T0	*p*	Δ T1 – T0	*p*	Δ T1 – T0	*p*	Δ T2 – T1	*p*
Superior point (coronal)	**X**	−0.1	0.57	0.3	0.29	2.6	**0.04***	−0.4	0.07
	Y	−0.7	0.14	0.5	**0.01***	1.8	0.18	−1.1	1.00
	Z	0.8	0.41	1.8	0.36	−0.2	0.41	−0.8	0.47
Lateral point (coronal)	**X**	−0.3	0.20	0.1	0.35	2.6	0.50	−1.8	0.11
	Y	−0.9	0.47	−0.5	**0.048***	4	0.89	−5.8	0.72
	Z	0.8	0.41	1.8	0.36	−0.2	0.41	−0.8	0.47
Medial point (coronal)	**X**	0.2	0.20	1.8	0.38	2.4	0.412	0	0.59
	Y	−0.8	0.72	1.5	**0.04***	3.2	0.50	−5.6	0.47
	Z	0.8	0.41	2.3	0.36	−0.2	0.41	−0.8	0.47
Posterior point (sagital)	**X**	−0.2	0.19	0.3	0.27	2.6	**0.04***	−0.2	0.07
	Y	−0.2	0.72	−0.2	0.21	5.2	0.23	−6.3	0.72
	Z	0.4	0.20	3.6	0.31	1.3	**0.04***	−0.5	0.14
Anterior point (sagital)	**X**	−0.2	0.19	0.3	0.29	2.6	**0.04***	−0.2	0.07
	Y	−0.7	1.00	−1.4	0.22	1.2	0.50	−4	0.72
	Z	0.4	0.72	0.9	0.57	−0.7	0.50	0.1	0.47

Delta (Δ) represents the difference (in mm) between the medians at the analyzed time points in each group. ($p < .05$*).

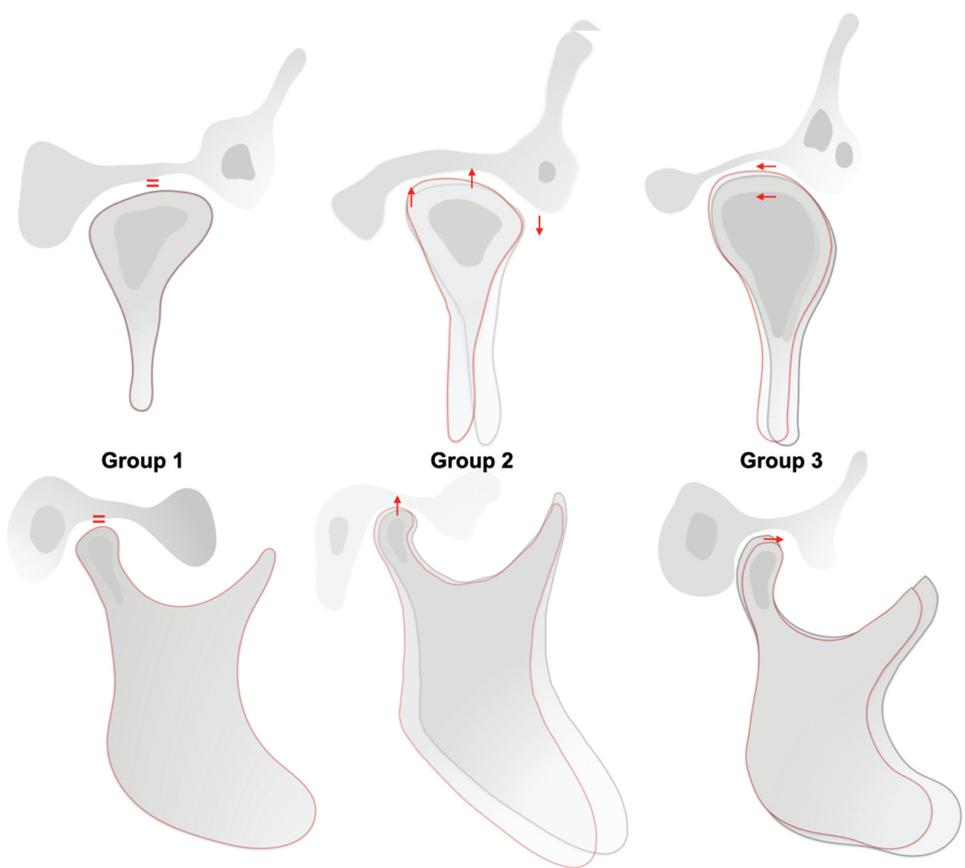

Figure 2. Illustration representing contralateral condylar positioning changes in each group. Top: coronal view; Bottom: sagittal view.

Table 3. Condylar volume (mm3) – condyle contralateral to proportional condylectomy.

	Comparison	Volume at first time point Median (Min–Max)	Volume at second time point Median (Min–Max)	Volume Change
Group 1 (*n* = 4)	T0–T1	1326.0 (1155.0–1973.0)	1301.5 (1039.9–1993.9)	*−24.6 mm³ (−1.9%)* *p = .273*
Group 2 (*n* = 14)	T0–T1	869.5 (661.0–1681.6)	917.2 (684.4–1981.8)	*+31.8 mm³ (+3.7%)* *p = .715*
Group 3 (*n* = 5)	T0–T1	1384.7 (1290.3–1637.1)	1275.9 (1127.7–1691.5)	*−108.9 mm³ (−7.9%)* *p = .345*
Group 3 (*n* = 5)	T1–T2	1275.9 (1127.7–1691.5)	1250.1 (571.0–1463.1)	*−25.8 mm³ (−2.0%)* *p = .080*

Values are presented as median (minimum–maximum). *p*-values were obtained using the Wilcoxon signed-rank test ($p < .05$).

median reduction of 25.8 mm^3 (−2.0%) was observed, also without statistical significance ($p = .080$) (Table 3 and Figure 3).

Discussion

The present study demonstrated that the contralateral condyle exhibits distinct patterns of three-dimensional adaptive remodeling in the short term following treatment of unilateral condylar hyperplasia. Rather than reflecting a simple positional displacement, these findings suggest a process of spatial reorganization in response to altered postoperative mandibular biomechanics. Patients treated with isolated proportional condylectomy (G1) showed no significant positional changes of the contralateral condyle, whereas simultaneous orthognathic surgery (G2) was associated with a predominantly superomedial rotational adaptation. In contrast, staged treatment (G3) resulted in a predominantly linear medial displacement of the contralateral condyle (Figure 2).

Although a previous study evaluating condylar angulation after orthognathic surgery reported no significant angular changes during postoperative follow-up [20], the present findings provide complementary information. By assessing the spatial displacement of multiple anatomical landmarks rather than angular measurements alone, distinct three-dimensional patterns of contralateral condylar adaptation could be identified.

The magnitude of these positional changes should be interpreted in relation to both measurement error and clinical relevance. The Dahlberg method error ranged from 0.175 to 0.428 mm. Thus, the larger displacements, particularly those of 1.5 and 2.6 mm, exceeded the measurement error, whereas the 0.5-mm displacement was close to its upper limit and should be interpreted cautiously. Importantly, exceeding measurement error does not necessarily imply clinical significance, and the clinical relevance of these relatively small positional changes remains uncertain. A possible explanation for the absence of significant positional changes in Group 1 is the lower degree of facial asymmetry observed in these patients (7.7 ± 1.5 mm, the lowest mean among the groups), which may have resulted in less postoperative mandibular adaptation. Olate et al. [21] reported a correlation between condylar hyperplasia and mandibular asymmetry, demonstrating that pathological condylar growth induces mandibular rotation and

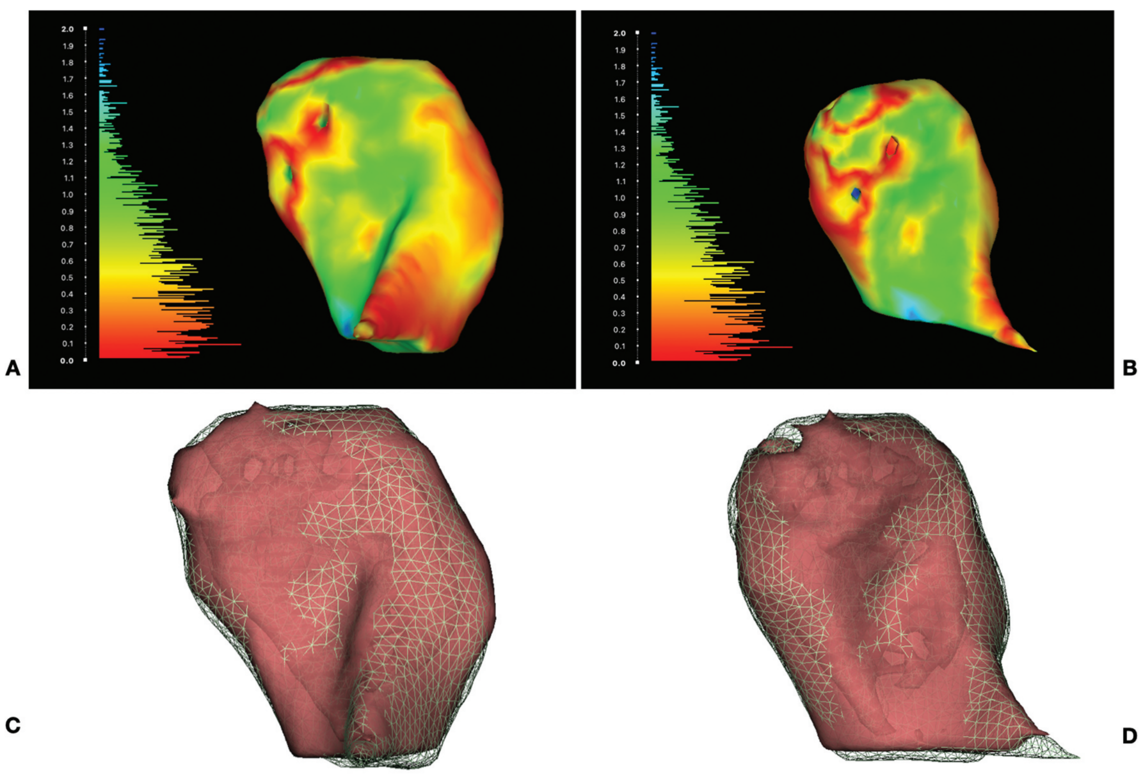

Figure 3. Superimposition of condylar volume (image from a patient in group 3). A, B: the color scale shows areas of convergence and divergence in the overlap between T1 and T2; C, D: the green mesh represents the condylar volume in T1, while the reddish surface represents the volume in T2.

deviation of the chin toward the contralateral side. However, the extent of condylar hyperplasia is not necessarily proportional to the degree of facial asymmetry, as factors such as the direction of condylar growth (vertical or horizontal), concomitant maxillary development, and occlusal condition also contribute to the final skeletal deformity. Likewise, Ishizaki et al. [4] described mandibular rotation accompanied by contralateral condylar displacement in asymmetric patients.

Recent evidence further supports this concept by demonstrating that condylar height is one of the main determinants of facial asymmetry, particularly in patients with dentofacial deformities [22]. In the present study, condylar hyperplasia height, defined as the vertical difference between the hyperplastic and unaffected sides, was greater on average in G2 (11.5 ± 6.2 mm) than in G1 (6.6 ± 4.1 mm) and G3 (6.4 ± 5.4 mm). However, this variable was reported descriptively and was not analyzed for its association with facial asymmetry or contralateral condylar adaptation; therefore, no direct relationship between these variables can be established.

Following the second surgical stage, no statistically significant positional changes of the contralateral condyle were detected in G3. Nevertheless, the absolute three-dimensional displacements (ΔT2–T1) indicated measurable positional changes. Given the limited number of patients in this group, the absence of statistical significance should be interpreted cautiously.

Volumetric analysis provided additional information on contralateral condylar adaptation. Although no statistically significant changes were observed, G1 exhibited a slight reduction in median condylar volume, G2 a modest increase, and G3 a progressive reduction, with a 7.9% decrease following proportional condylectomy and an additional 2.0% reduction after orthognathic surgery. These trends may reflect adaptive condylar remodeling.

Previous studies have reported reductions in condylar volume following orthognathic surgery in skeletal Class II and Class III patients, regardless of the surgical movement performed [20,23–27]. Postoperative condylar remodeling is a dynamic process involving simultaneous bone apposition and resorption at different condylar surfaces, resulting in continuous structural adaptation rather than a unidirectional volumetric change [20]. Progressive condylar resorption has also been described, with volumetric reductions ranging from 12% to 32% [25,28]. Notably, Xi et al. [28] reported clinical signs of progressive condylar resorption in patients with postoperative volume loss exceeding 19% of the preoperative condylar volume. In comparison, the reductions observed in the present study were smaller (maximum median reduction of 7.9%) and did not reach statistical significance, supporting an interpretation of physiological adaptive remodeling rather than pathological condylar resorption.

Goulart et al. [29] demonstrated that the condylar volume of skeletal Class III patients is comparable to that of hyperplastic condyles. In this context, the modest volumetric changes observed in the present study may represent part of the physiological adaptation of the temporomandibular joint to the new functional and skeletal relationship established after treatment. However, the follow-up periods may not be sufficient to determine whether these changes remain stable, progress, or undergo further remodeling over the long term.

The clinical implications of the observed adaptations remain uncertain. No patient reported postoperative pain, joint sounds, or limitation of mouth opening during follow-up. Given the retrospective design and the primary objective of assessing osseous positional and volumetric changes using CBCT, MRI was not included in the analysis and was not available for all patients; consequently, articular disc position and intra-articular soft tissue adaptations could not be evaluated.

The literature remains inconclusive regarding the relationship between contralateral condylar adaptation and temporomandibular disorders. Ishizaki et al. [4] suggested that adaptive displacement of the contralateral condyle in patients with unilateral condylar hyperplasia may predispose affected individuals to temporomandibular disorders by increasing compression of the articular disc against the fossa during function. Conversely, López et al. [5] did not observe a reduction in the contralateral joint space that would support disc compression in patients with condylar hyperplasia.

Importantly, structural or positional changes of the mandibular condyle should not be interpreted in isolation as evidence of temporomandibular disorders or as necessarily associated with symptoms. Current evidence discourages invasive treatments based solely on mechanical concepts of an "ideal condylar position" or dental occlusion, as such approaches may lead to unnecessary or inappropriate interventions. In addition to their clinical implications, inappropriate treatments may have psychological and economic consequences for patients [6,30–32]. Therefore, the three-dimensional adaptations observed in the present study should be interpreted as imaging findings and not, by themselves, as pathological changes or indications for additional treatment.

This study has several limitations, including its retrospective design, small and unequal group sizes, variable postoperative follow-up, and absence of MRI. These limitations should be considered when interpreting the findings, particularly regarding the long-term significance of the observed adaptations. Future prospective studies with larger and more balanced cohorts, longer follow-up, three-dimensional imaging, MRI, and standardized clinical assessment are warranted to evaluate the long-term progression of these condylar changes and their potential association with clinical signs and symptoms.

Distinct patterns of three-dimensional adaptation of the contralateral condyle were observed in the short term following proportional condylectomy, with positional changes varying according to the surgical strategy employed. The modest volumetric changes observed appear more consistent with adaptive remodeling than with patterns of pathological condylar resorption described in the literature. These findings provide a three-dimensional characterization of contralateral condylar adaptation after proportional condylectomy and contribute to the understanding of postoperative remodeling in patients with unilateral condylar hyperplasia.

Author contributions

CRediT: **Adaia Valls-Ontañón MD, DDS, PhD, FEBOMS:** Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing; **Rubens Martins Bastos DDS, MSc:** Conceptualization, Formal analysis, Methodology, Resources, Visualization, Writing – original draft; **Rogério Belle de Oliveira DDS, MSc, PhD:** Conceptualization, Resources, Writing – original draft; **Federico Hernández-Alfaro MD, DDS, PhD, FEBOMS:** Conceptualization, Methodology, Project administration, Resources, Supervision, Writing – original draft; **Orion Luiz Haas Jr. DDS, MSc, PhD:** Conceptualization, Formal analysis, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Disclosure statement

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Patient consent

Written patient consent was obtained.

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