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Full Length Article

Deep learning–assisted cone-beam computed tomographic analysis of condylar changes after mandibular setback surgery

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Abstract

This study aimed to assess condylar changes using a fully automated deep learning–based cone-beam computed tomography (CBCT) workflow. Preoperative and postoperative CBCT scans of 50 skeletal Class III patients (100 condyles) were analysed using a fully automated pipeline integrating nnU-Net–based segmentation, rigid surface registration, and standardised surface cropping. Condylar changes were quantified using volumetric and linear measurements and surface-based metrics. Segmentation accuracy was high (Dice: mandible 0.98, condyle 0.99). Mean (SD) condylar volume changes ranged from −12.3 (6.2) to −0.03 (11.1) mm^3 on the left and from −11.3 (10.7) to −0.95 (12.6) mm^3 on the right. Significant differences in inter-side volume were observed in left and right rotation groups ($p = 0.003$), but not in the non-rotation group ($p = 0.442$). Direction of mandibular rotation significantly affected change in condylar volume bilaterally ($p = 0.039$). Surface-based metrics differed significantly among rotation groups ($p = 0.036$). Change in condylar volume showed a negative correlation with preoperative volume ($r = -0.44$ to -0.77, $p < 0.001$). Condylar remodelling after mandibular setback surgery is rotation-dependent and regionally heterogeneous. The proposed automated CBCT-based workflow enables reproducible, operator-independent quantification of condylar changes, and provides a standardised framework for postoperative assessment.

Keywords: Condylar remodeling; Mandibular set-back surgery; Deep learning; Automated segmentation; Temporomandibular joint

Introductıon

In skeletal Class III malocclusions, mandibular setback surgery alters mandibular position and loading patterns, and potentially induces short-term and long-term adaptive or adverse changes in the temporomandibular joint (TMJ).[1] Postoperative condylar remodelling in particular, may range from physiological adaptation to progressive condylar resorption, which has been associated with skeletal instability, relapse, and TMJ-related symptoms.[2,3] Consequently, accurate and reproducible quantification of condylar changes is essential for evaluating postoperative outcomes and long-term stability following orthognathic surgery.[3,4]

Cone-beam computed tomography (CBCT)-based three-dimensional superimposition techniques enable reliable quantification of condylar changes; however, findings vary due to differences in segmentation, registration, and analysis protocols.[5,6] Lack of standardisation remains a major limitation.[4] Accurate condylar segmentation is essential, as errors

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directly affect measurements. Deep learning–based methods provide improved reproducibility compared with manual approaches.[7]

The aim of this study is to evaluate condylar changes following mandibular setback surgery using a fully automated, end-to-end CBCT-based workflow. By integrating deep learning–based segmentation, standardised registration, and multiple volumetric and surface-based analysis metrics, this study seeks to provide a reproducible and operator-independent framework for three-dimensional quantification of condylar remodelling in skeletal Class III patients. It may also be considered a proof-of-concept investigation demonstrating the feasibility and potential clinical applicability of a fully automated deep learning–based CBCT workflow for the assessment of condylar remodelling.

Materıal and methods

This study was approved by the Sivas Cumhuriyet University Health-Sciences Research Ethics Committee under approval number 25_11_20_73. The retrospective data used in the study were anonymised, and no additional data or radiographic images were obtained from patients specifically for the study.

Study population

The study included skeletal Class III patients treated at the Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Ondokuz Mayıs University. All patients underwent isolated mandibular setback surgery without concomitant maxillary osteotomy. This approach was intentionally adopted to ensure a homogeneous study population and to eliminate potential confounding effects associated with bimaxillary procedures. All patients underwent presurgical orthodontic treatment, and a surgery-first protocol was not applied. Preoperative CBCT scans were obtained approximately one week prior to surgery, and postoperative CBCT imaging was performed 12–18 months after surgery to allow sufficient time for condylar remodelling to occur. No cases of progressive condylar resorption or clinically evident relapse or TMJ symptoms were observed during the follow-up period.

Artificial ıntelligence model development stages

An end-to-end Python-based workflow was developed to automatically analyse condylar changes after mandibular setback surgery (Fig. 1). Preoperative and postoperative CBCT datasets were imported in DICOM format, anonymised, quality-checked, and converted to a Neuroimaging Informantics Technology Initiative (NıfTI) format for standardised processing.

Data annotation

A total of 350 CBCT scans obtained from the Sivas Cumhuriyet University Faculty of Dentistry were used to train the deep learning segmentation model. Manual annotations were performed by two experienced researchers using 3D Slicer (v5.10.0).

Preprocessing and data standardisation

CBCT volumes were resampled to 0.3 mm isotropic resolution and standardised using intensity normalisation and region of interest (ROI)-based cropping. Data were split into training, validation, and test sets in a patient-wise basis.

Segmentation model: mandible and condyle segmentation using nnU-Net v2

Segmentation was performed using nnU-Net v2,[7] a self-configuring deep learning framework implemented on a PyTorch platform with CUDA-enabled GPU acceleration. A two-stage segmentation strategy was adopted: initial segmentation of the mandible to establish a stable anatomical reference and ROI, followed by isolation and segmentation of the condylar region from the mandibular mask.

Post-processing included the removal of small disconnected components, hole filling, and surface smoothing using connected-component analysis and morphological operations.

Preoperative–postoperative registration and cropping

Segmented preoperative and postoperative condylar surfaces were exported as stereolithographic (STL) files and rigidly registered using the iterative closest point (ICP) algorithm, aligning postoperative models to preoperative references with a six-degree-of-freedom transformation. Registration quality was assessed using transformation parameters and the ICP-derived root mean square error (RMSE).

After registration, automatic surface cropping was applied to standardise the region of interest. The inferior 35% and anterior 50% of the condyle were excluded, isolating the superior–posterior condylar head and ensuring consistent spatial coverage across time points.

Output generation

Point-based surface distance analysis was performed on registered condylar surfaces by computing the distance from each postoperative surface point to the nearest preoperative point. Maximum Hausdorff distance, 95th percentile Hausdorff distance (HD95), surface-based root mean square (RMS) distance, and ICP-derived RMSE were calculated to assess surface correspondence.[8,9] Volumetric parameters, including preoperative and postoperative volumes, appositional and resorptive volumes, and net volume change, were calculated using a voxel-based approach. In addition to absolute volumetric differences (mm^3), relative volume change (%) was calculated to improve clinical interpretability, using the following formula:

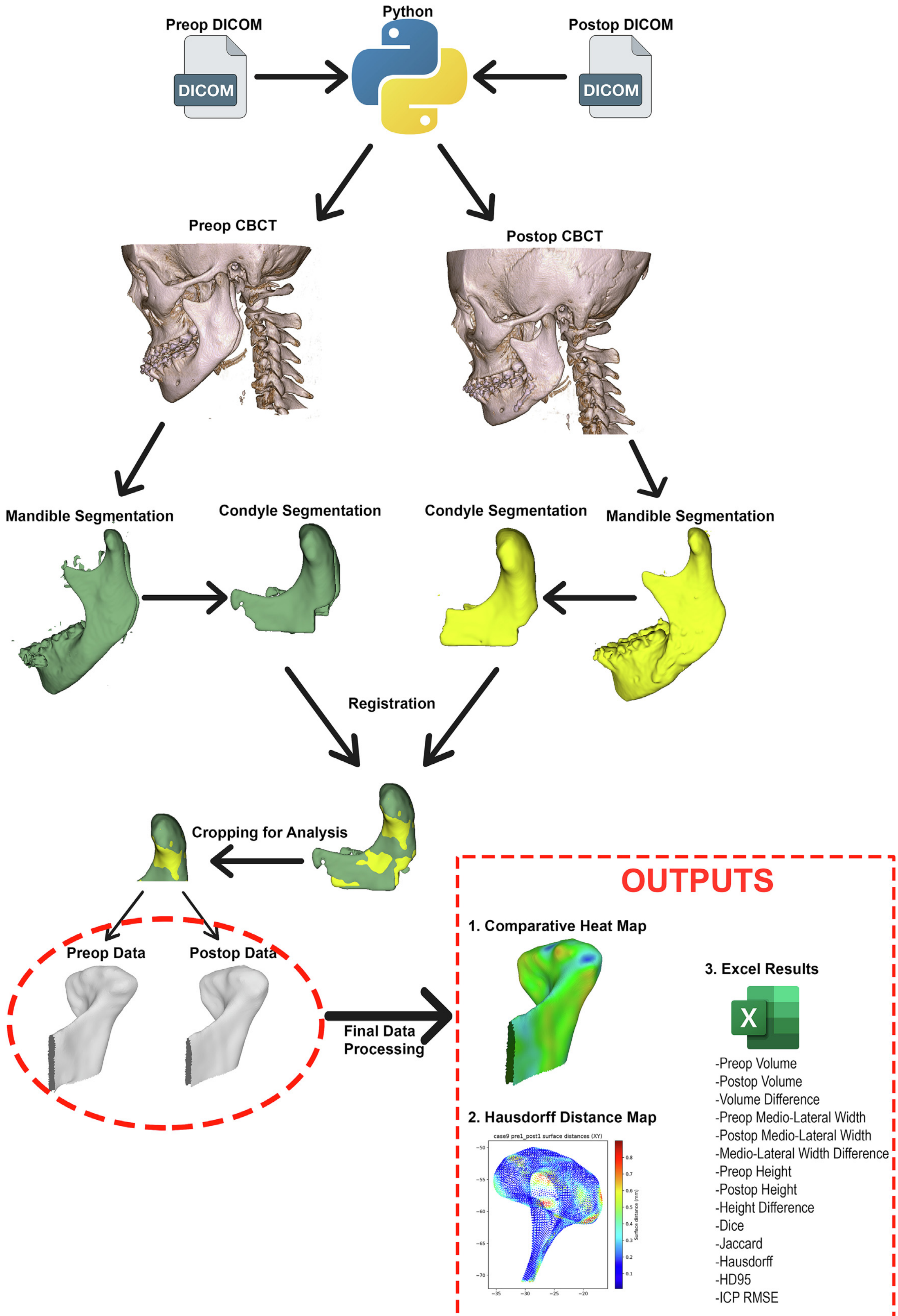

Fig. 1. Schematic overview of the fully automated end-to-end cone-beam computed tomography (CBCT)-based workflow for three-dimensional quantification of condylar changes following mandibular setback surgery.

$$Volume\ percentage\ change\ (\%) = [(postoperative\ volume - preoperative\ volume)\ /\ preoperative\ volume] \times 100$$

Segmentation overlap was evaluated using the Dice similarity coefficient and Jaccard index. All results were summarised per patient and exported in tabular format, with automated PDF reports generated.

Statistical analysis

Statistical analyses were performed using JASP software version 0.19.1.0 (JASP Team), with statistical significance set at $\alpha = 0.05$. Descriptive data are expressed as mean (SD), with all values rounded to two decimal places.

Paired samples t-tests compared left and right condylar changes within patients according to rotation direction. One-way ANOVA assessed the effect of rotation direction on condylar morphometric changes and surface-based metrics. ANCOVA models were used to control for preoperative morphometric variables and sex when appropriate, with Bonferroni-corrected post hoc tests applied for multiple comparisons.

Dice, Jaccard, Hausdorff distance, HD95, and ICP-based RMSE values were compared across rotation groups using one-way ANOVA. Pearson correlation analyses evaluated associations between condylar volume changes, mandibular movement magnitude, and preoperative morphometric measurements, stratified by rotation direction.

Results

A total of 100 condyles from 50 skeletal Class III patients were analysed. Fifteen patients showed right mandibular rotation, 17 left rotation, and 18 no rotation. Regional patterns of condylar surface changes are illustrated in Supplementary Material 1.

Segmentation performance was high (Dice: mandible 0.98, condyle 0.99). Descriptive data are presented in Table 1.

Overall, changes in condylar volume were small but showed a clear pattern related to mandibular rotation. In rotation groups, volume reduction was greater on one side, whereas in the non-rotation group, changes were minimal and symmetrical. The side showing greater reduction corresponded to the direction of mandibular rotation. In the right rotation group, the left condyle showed greater reduction (-12.28 mm^3; -5.16%) than the right side (-3.24 mm^3; -1.38%). In the left rotation group, the right condyle was more affected (-11.29 mm^3; -4.92%) than the left (-1.45 mm^3; -0.64%). In the non-rotation group, changes were minimal on both sides ($\leq 0.5\%$) (Table 1).

These inter-side differences were statistically significant in the rotation groups (left rotation $p = 0.003$; right rotation $p = 0.002$), but not in the non-rotation group ($p = 0.442$) (Table 2).

Rotation direction was significantly associated with change in condylar volume on both sides (left $p = 0.016$; right $p = 0.039$), while sex had no effect (Tables 3 and 4). Preoperative condylar volume was also significantly associated with volume change ($p = 0.011$), with larger condyles showing greater reduction. Changes in condylar width and height were small. Change in width was associated with rotation only on the right side ($p = 0.023$), and change in height only on the left side ($p = 0.039$). Preoperative dimensions were strongly associated with their respective changes ($p < 0.001$) (Table 3).

Surface-based analyses indicated that remodelling was region-specific rather than uniform. Significant differences were observed among rotation groups for Dice and Jaccard indices ($p < 0.001$). Hausdorff distance was significant only for the right condyle ($p = 0.024$), while HD95 and ICP-RMSE were significant for both sides (Table 3). Importantly, no consistent anatomical subregion of the condyle was identified as the predominant site of remodelling. Instead, appositional and resorptive changes were distributed heterogeneously across the condylar surface, with patient-specific variation, as illustrated in Supplementary Material 1.

Post hoc comparisons confirmed differences between rotation groups (Supplementary Material 2). Correlation analyses showed significant bilateral associations and a negative correlation with preoperative volume, with no association with magnitude of mandibular movement (Supplementary Material 3). From a clinical perspective, the magnitude of these changes suggests mild, adaptive remodelling rather than clinically significant condylar resorption.

Discussion

The literature has demonstrated that condylar-level changes following mandibular setback surgery can be measurable and, in most cases, may coexist with clinical stability. For instance, Ha et al reported condylar head rotation, dimensional reduction, and remodelling (detected by CBCT superimposition) in skeletal Class III patients treated with mandibular setback via bilateral sagittal split ramus osteotomy (BSSRO) and rigid fixation, without leading to signs or symptoms of TMJ disorders.[1] This finding is consistent with our results, in which condylar changes were quantitatively detectable at 12–18 months of follow up, and in which volume changes showed significant differences according to direction of rotation (with associations observed between direction of rotation and change in volume in both left and right condyles). This may be explained by the fact that rotational mandibular movements induce asymmetrical loading within the TMJ, leading to localised stress distribution and region-specific remodelling. In contrast, anteroposterior movements are more translational and may result in more uniform biomechanical loading. Side-specific differences may further reflect variations in condylar positioning, individual biomechanical adaptation, or occlusal factors. In addition, the observed rotational patterns may be influenced by

Table 1
Descriptive statistics of demographic characteristics, preoperative and postoperative condylar morphometric measurements, and surface-based superimposition metrics according to rotation and condylar side.

Parameter	Condylar side	Rotation side		
		Right (n = 15)	Left (n = 17)	No rotation (n = 18)
Age (years)		24.3 (2.19)	24.7 (3.04)	23.3 (2.80)
Gender:				
Female		7	11	10
Male		8	6	8
Preop volume (mm^3)	Left	237.83 (37.84)	226.29 (21.86)	212.30 (32.87)
	Right	234.66 (41.16)	229.41 (25.48)	221.83 (35.31)
Postop volume (mm^3)	Left	225.55 (33.29)	224.85 (19.98)	212.27 (32.62)
	Right	231.09 (33.22)	217.91 (27.02)	220.88 (38.84)
Volume difference (mm^3)	Left	−12.28 (6.19)	−1.45 (12.00)	−0.030 (11.13)
	Right	−3.24 (12.23)	−11.29 (10.73)	−0.953 (12.57)
Volume difference (%)	Left	−5.16	−0.64	−0.01
	Right	−1.38	−4.92	−0.43
Preop width (mm)	Left	19.34 (1.78)	19.76 (1.75)	20.03 (2.13)
	Right	20.11 (4.77)	20.06 (2.44)	20.91 (6.80)
Postop width (mm)	Left	19.68 (2.17)	19.99 (2.09)	18.58 (2.45)
	Right	20.99 (3.74)	20.23 (2.61)	18.37 (2.59)
Width difference (mm)	Left	0.34 (2.03)	0.24 (1.91)	−1.44 (2.99)
	Right	0.88 (3.08)	0.18 (0.41)	−2.54 (7.96)
Preop height (mm)	Left	24.37 (2.22)	24.11 (2.11)	23.80 (3.27)
	Right	22.48 (4.97)	24.05 (2.74)	25.09 (4.65)
Postop height (mm)	Left	24.41 (0.79)	23.33 (2.77)	24.73 (1.73)
	Right	23.65 (2.27)	23.41 (2.40)	25.25 (1.69)
Height difference (mm)	Left	0.04 (2.02)	−0.79 (1.81)	0.93 (3.00)
	Right	1.17 (5.25)	−0.64 (1.63)	0.16 (5.01)
Superimposition metrics:				
Dice	Left	0.14 (0.031)	0.10 (0.05)	0.07 (0.04)
	Right	0.12 (0.028)	0.12 (0.04)	0.07 (0.04)
Jaccard	Left	0.08 (0.018)	0.06 (0.03)	0.04 (0.02)
	Right	0.06 (0.016)	0.06 (0.02)	0.04 (0.02)
Hausdorff (mm)	Left	2.53 (1.198)	2.67 (1.32)	3.23 (1.78)
	Right	2.80 (1.024)	2.16 (1.41)	4.01 (2.81)
HD95 (mm)	Left	0.45 (0.228)	0.74 (0.46)	1.18 (1.05)
	Right	0.62 (0.559)	0.70 (0.62)	1.52 (1.63)
ICP RMSE (mm)	Left	0.29 (0.128)	0.388 (0.22)	0.63 (0.51)
	Right	0.35 (0.183)	0.33 (0.23)	0.78 (0.77)

HD95: 95th percentile Hausdorff distance; ICP: iterative closest point; RMSE: root mean square error.

Table 2
Paired samples t-test results comparing left and right condylar changes (volume, width, and height differences) within rotation-side groups.

Rotation side	Measure 1 (left)	Measure 2 (right)	t	df	p value
Left	Condylar volume difference	Condylar volume difference	3.574	16	0.003
	Condylar width difference	Condylar width difference	0.122	16	0.904
	Condylar height difference	Condylar height difference	−0.340	16	0.738
Right	Condylar volume difference	Condylar volume difference	−3.813	14	0.002
	Condylar width difference	Condylar width difference	−0.525	14	0.608
	Condylar height difference	Condylar height difference	−1.147	14	0.270
No rotation	Condylar volume difference	Condylar volume difference	0.787	17	0.442
	Condylar width difference	Condylar width difference	0.854	17	0.405
	Condylar height difference	Condylar height difference	0.753	17	0.462

multiple underlying factors, including dental midline discrepancies, occlusal conditions, or functional asymmetry, rather than intrinsic condylar pathology alone.

Although not specifically evaluated in this study, factors such as condylar repositioning and potential alterations in vascular supply may also contribute to remodelling patterns. Furthermore, clinical variables such as fixation technique and patient-specific functional conditions may affect condylar adaptation. As this study was primarily imaging-based, detailed clinical characterisation was beyond its scope; these aspects should therefore be considered when interpreting the findings and they warrant further investigation in future stud-

Table 3
Results of ANCOVA and one-way ANOVA evaluating the effects of rotation side on condylar morphometric changes and surface-based superimposition metrics.

Parameter	Condylar side	Factor	df	F	p
Volume difference	Left	Rotation side	2	4.559	0.016
		Gender	1	0.663	0.419
		Left preop volume	1	7.056	0.011
	Right	Rotation side	2	3.492	0.039
		Gender	1	0.025	0.874
		Right preop volume	1	2.534	0.0118
Width difference	Left	Rotation side	2	2.661	0.081
		Gender	1	0.565	0.456
		Left preop width	1	13.041	<0.001
	Right	Rotation Side	2	4.074	0.023
		Gender	1	1.117	0.296
		Right preop width	1	99.085	<0.001
Height difference	Left	Rotation side	2	3.471	0.039
		Gender	1	4.978×10^{-5}	0.994
		Left preop height	1	42.275	<0.001
	Right	Rotation side	2	3.117	0.054
		Gender	1	2.121	0.152
		Right preop height	1	149.363	<0.001
Dice	Left	Rotation side	2	10.188	<0.001
	Right	Rotation side	2	9.419	<0.001
Jaccard	Left	Rotation side	2	9.810	<0.001
	Right	Rotation side	2	9.347	<0.001
Hausdorff	Left	Rotation side	2	1.089	0.345
	Right	Rotation side	2	4.035	0.024
HD95	Left	Rotation side	2	4.621	0.015
	Right	Rotation side	2	3.563	0.036
ICP RMSE	Left	Rotation side	2	4.638	0.015
	Right	Rotation side	2	4.646	0.014

HD95: 95th percentile Hausdorff distance; ICP: iterative closest point; RMSE: root mean square error.

Table 4
Estimated marginal means and 95% confidence intervals (95% CI) for condylar volume, width, and height differences according to rotation side and condylar side.

Parameter	Condylar side	Rotation side		
		Right	Left	No rotation
Volume difference (mm^3)	Left	−10.714 (−15.871 to −5.556)	−1.257 (−5.974 to 3.459)	−1.514 (−6.232 to 3.203)
	Right	−2.730 (−8.834 to 3.373)	−11.196 (−16.899 to −5.493)	−1.460 (−7.038 to 4.118)
Width difference (mm)	Left	0.111 (−1.003 to 1.226)	0.251 (−0.789 to 1.291)	−1.267 (−2.282 to −0.251)
	Right	0.655 (−0.847 to 2.158)	−0.089 (−1.501 to 1.323)	−2.098 (−3.472 to −0.724)
Height difference (mm)	Left	0.223 (−0.676 to 1.121)	−0.763 (−1.606 to 0.079)	0.759 (−0.061 to 1.579)
	Right	−0.136 (−1.244 to 0.973)	−0.555 (−1.576 to 0.467)	1.163 (0.156 to 2.170)

ies. The presence of significant inter-side differences in volume in the rotation groups supports the notion that condylar adaptation may be patient-specific and asymmetrical. Similar findings have been reported, showing changes in condylar position without compromising stability.[2]

Our findings further show that changes are not limited to net volumetric differences, but may also manifest as regional variations detectable through surface-based metrics and similarity indices. In this context, the recommendations highlighted in the systematic review by Verhelst et al (namely the standardisation of registration, segmentation, and analysis steps, and the combined reporting of volumetric and surface-based measurements in condylar remodelling analysis) directly align with the multimetric approach adopted in our workflow.[4] Furthermore, the work of Vinayahalingam et al, which demonstrates high-accuracy deep learning–based segmentation of TMJ components on CBCT, provides contemporary methodological support for the nnU-Net–based automation strategy employed in the present study.[6]

Studies focusing on quantitative evaluation of condylar changes after orthognathic surgery have reported that loss of volume is frequently observed, although its magnitude varies widely depending on surgical type, biomechanical loading, and patient-specific factors. In cases of mandibular advancement, Xi et al reported an average reduction in condylar volume of 105 mm^3 (6.1%) in 55% of condyles (n = 62/112), and identified a statistically significant association between the magnitude of volume lost and postoperative skeletal relapse. Losses in volume exceeding 17% were defined as a critical threshold associated with progressive condylar resorption and clinical instability.[10] These findings underscore the fact that condylar remodelling is not merely a localised bony adaptation but also an important biomechanical parameter influencing long-term surgical stability.

Recent advances in automatic and semi-automatic analysis methods have enabled more sensitive and reproducible quantification of condylar changes. Holte et al reported that a fully automated workflow for evaluating changes in condylar volume after bimaxillary surgery produced an average absolute difference of only 2.7% compared with semi-automatic methods, and achieved excellent agreement (ICC = 0.993).[11] These findings indicate that automatic segmentation-based and registration-based approaches are methodologically reliable for volumetric measurements and have reached precision levels suitable for clinical application.

The combined use of volumetric and surface-based metrics provides a multidimensional assessment of condylar remodelling, capturing both magnitude and spatial distribution. This approach enables the detection of regional and direction-dependent changes that may not be reflected by volumetric measures alone. Reduced Dice and Jaccard coefficients are likely to represent true morphological changes rather than segmentation error, whereas low Hausdorff distance, HD95, and ICP-RMSE values indicate accurate geometric alignment. The integration of deep learning–based segmentation with standardised registration improves reproducibility and reduces operator dependency. Overall, these findings support the fact that condylar adaptation after mandibular setback surgery is a non-uniform process that is influenced by the direction of rotation and preoperative morphology.

Although changes in condylar volume were statistically significant, their magnitude was limited and did not result in clinically evident dysfunction, suggesting that they are not clinically significant in this patient population. Furthermore, the absence of a significant association between condylar remodelling and the magnitude of mandibular movement indicates that the extent of surgical displacement alone does not predict postoperative condylar changes. Instead, the direction of movement, particularly rotational components, appears to play a more important role.

From a clinical perspective, the present findings provide several important insights into condylar adaptation after mandibular setback surgery. First, condylar remodelling was found to be significantly influenced by mandibular rotation, with asymmetrical and side-specific changes in volume observed in the rotation groups. This suggests that rotational surgical movements may lead to uneven biomechanical loading within the TMJ, highlighting the importance of careful intraoperative control of mandibular rotation, and precise condylar positioning.[12–14] Secondly, the magnitude of change in condylar volume was relatively small, corresponding to approximately a 4%–5% reduction on the rotation side and $\leq$1% on the contralateral or non-rotation side. Importantly, no clinical signs of temporomandibular dysfunction or postoperative relapse were observed, indicating that these changes most likely represent physiological adaptation rather than clinically significant condylar resorption. Thirdly, condylar remodelling was not localised to a single consistent anatomical region, but instead showed a heterogeneous and patient-specific distribution across the condylar surface. This suggests that postoperative adaptation is driven by individualised biomechanical and functional factors rather than a uniform structural response. Finally, the observed negative correlation between preoperative condylar volume and postoperative change in volume indicates that larger condyles may be more susceptible to volume reduction. This may have potential clinical relevance for the identification of patients who could benefit from closer postoperative monitoring.

Overall, these findings suggest that condylar remodelling after mandibular setback surgery is a mild, rotation-dependent, and heterogeneous process. The ability to detect these subtle patterns using an automated and standardised CBCT workflow may support improved surgical planning, intraoperative decision-making, and individualised follow-up strategies.[15]

The findings of this study should be interpreted considering several limitations. The retrospective design and moderate sample size, particularly within rotation-based subgroups, may have limited statistical power. As only skeletal Class III patients undergoing mandibular setback surgery were included, generalisability to other types of malocclusion and surgical movements is limited, particularly given that condylar remodelling may be more pronounced in skeletal Class II patients undergoing mandibular advancement procedures.[16]

Future studies including different patient groups and surgical modalities would provide a more comprehensive understanding of condylar adaptation patterns.[17] Nevertheless, focusing on a homogeneous Class III cohort improves internal consistency and allows a more controlled evaluation of rotation-related condylar changes. Although nnU-Net–based segmentation provides high reproducibility, minor uncertainties may persist in anatomically ambiguous regions, and only rigid registration was applied. Furthermore, the absence of a direct correlation between imaging findings and clinical outcomes limits the immediate clinical applicability of the results.[18] Future studies that integrate quantitative imaging data with clinical and functional assessments are warranted to better elucidate the clinical significance of condylar remodelling patterns and their potential impact on treatment planning and long-term stability.[14]

Conclusion

This study demonstrates that condylar remodelling after mandibular setback surgery is influenced by mandibular rotation and preoperative condylar morphology, with asymmetrical and region-specific changes observed across the condylar surface. Although these changes were statistically significant, their magnitude was limited and did not result in clinically evident instability or temporomandibular dysfunction, suggesting a predominantly adaptive remodelling process. Condylar changes were not confined to a single anatomical region but showed a heterogeneous and patient-specific distribution.

The proposed automated CBCT-based workflow enables objective and reproducible detection of these subtle remodelling patterns and may support improved surgical planning, intraoperative condylar management, and individualised postoperative monitoring.

CRediT authorship contribution statement

Yunus Balel: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft. **Nihat Akbulut:** Conceptualization, Data curation, Methodology, Validation, Writing – review & editing. **Sibel Akbulut:** Data curation, Validation, Writing – review & editing.

Data availability

The data and materials used in the study can be obtained by contacting the corresponding author.

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Conflict of interest

We have no conflicts of interest.

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None.

Ethics statement/confirmation of patients permission

This study was approved by the Sivas Cumhuriyet University Health Sciences Research Ethics Committee under approval number 25_11_20_73. Following ethics committee approval, patient consent was not required for this study, which includes retrospective data.

Declaration of generative AI in scientific writing

During the preparation of this manuscript, the authors used ChatGPT as a language editing and style improvement tool. After using this service, the authors carefully reviewed and edited the content as needed, and take full responsibility for the final version of the manuscript.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bjoms.2026.04.009.

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