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RESEARCH

Assessment of condylar positional changes in severe skeletal class II malocclusion after surgical-orthodontic treatment

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Abstract

Objectives This study aimed to determine the positional changes in the condyle in the temporomandibular joint (TMJ) of severe skeletal class II malocclusion patients treated with surgical-orthodontics.

Materials and methods The measurements of TMJ space in 97 severe skeletal class II malocclusion patients (20 males, 77 females, mean age, 24.8 years, mean ANB = 7.41°) were assessed using limited cone-beam computed tomography (LCBCT) images acquired before orthodontics (T0) and 12 months after surgery (T1). 3D remodeling of the TMJ and measurements of the anterior space (AS), superior space (SS), and posterior space (PS) were performed to determine the position of the condyle for each joint. All data were analyzed by *t* test, correlation analysis, and Pearson correlation coefficient.

Results The mean AS, SS, and PS values after the therapy changed from 1.684 to 1.680 mm (0.24%), 3.086 to 2.748 mm (10.968%), and 2.873 to 2.155 mm (24.985%), respectively. The decreases in SS and PS were statistically significant. Positive correlations were found in the mean AS, SS, and PS values between the right and left sides.

Conclusions The combination of orthodontic and surgical treatment makes the condyle move counterclockwise in the TMJ in severe skeletal class II patients.

Clinical relevance Studies of temporomandibular joint (TMJ) intervals changes in patients with severe skeletal class II after sagittal split ramus osteotomy (SSRO) are limited. The postoperative joint remodeling, resorption, and related complications remain unstudied.

Keywords Orthognathic surgery · Mandibular condyle · Orthodontics · Cone-beam computed Tomography · Temporomandibular joint

Introduction

Skeletal class II malocclusion is characterized by mandibular retrusion or maxillary prognathism, which is associated with various clinical manifestations, including anterior deep overbite, overjet, retrusion of the chin, and even upper airway obstruction in severe cases [1–3].

The main characteristic of patients with severe skeletal class II malocclusion is mandibular retrusion, which moves the condyle within the articular fossa. Surgical-orthodontic treatment is considered the most effective method for correcting malocclusion and improve the shape of face. The condylar positional and functional changes after therapy thereby improve the stability of the TMJ and patients' quality of life, which is clinically important [4–8].

Limited cone-beam computed tomography (LCBCT) is a highly accurate method that can be used to examine the 3D structure of the TMJ during therapy [9, 10].

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Therefore, the changes of the TMJ can be measured via LCBCT before and after treatment.

Based on an assessment of 57 class II malocclusion patients, Da Silva RJ [11], from the University of Campinas, found that the superior and medial joint spaces were significantly reduced after orthognathic surgery. The authors also reported positive correlations in the mean changes in the anterior space (AS), superior space (SS), and posterior space (PS) between the left and right condyles.

Researchers at the Centre of Medical Specialties of the State of Veracruz (CEMEV) reported a case of skeletal class II malocclusion. They found a forwards movement of the mandible after surgical-orthodontic treatment [12]. A Jäger et al. [13] also reached a similar conclusion and found that the entire mandible rotated counterclockwise and that the gonial angle was increased.

It is important to note that previous clinical trials, except for the trial conducted at the University of Campinas [11], only consisted of small sample sizes of less than 30 patients or only reported a single case. Although the University of Campinas study included 57 patients, these patients were aged from 18 to 64, which is an excessive age range for studies of condylar positional changes. In addition, the previous studies prioritized on "average" class II patients, but surgical-orthodontic treatment is the only choice for individuals with severe dentofacial deformities [2, 6, 14]. Their conclusions, therefore, cannot be extended to patients with severe class II skeletal discrepancies.

In a recent study, Junho Jung et al. [15] found that rotation of the proximal segment could riskily affect condylar resorption. In addition to TMJ morphologic changes, stable ramus height, stable occlusion, and normal growth, functional remodeling of the condyle is considered as a kind of physiological morphologic change. Mild compression of the TMJ such as via a normal bite force and routine occlusal correction within a certain range can result in functional remodeling, while other external factors such as orthognathic surgery and fracture may cause dysfunctional remodeling [16]. Condylar resorption, as a kind of dysfunctional remodeling, is considered one of the most common complications seen in the TMJ region after orthognathic surgery. However, none of the present studies on condylar positional changes mentioned the functional changes of the condyle and glenoid fossa.

The therapeutic effect on the condyles of severe skeletal class II patients after orthodontic and surgical treatment remains controversial. Factors such as remodeling of the condyle, mandibular relapse, condylar positioning in the articular fossa, and joint stability must be considered. These complex factors cannot be easily understood because of the multifactorial nature of different malocclusions, as well as the difficulty of observing the TMJ [10, 17–20].

Referencing a cranial base coordinate system, M. Z. Miao et al. [21] reported that the mandible moved backwards in patients who underwent orthognathic and orthodontic treatment, and C. Dolce et al. [22] described consistent findings. However, N. Eggensperger et al. [23] disagreed and found that the mandible moved forwards after treatment. A limitation of all of these studies is that the position of the condyle was not assessed using 3D imaging [24].

The purpose of the present study was to compare the pre- and postoperative condylar positions of severe skeletal class II patients using 3D imaging.

Materials and methods

This study was approved by the local ethics committee.

Patients

To identify class II subjects eligible for this study, the charts of patients treated by an experienced clinician from 2016 to 2020 at the were reviewed. Information such as age, sex, the start and end dates of treatment, the total treatment time, and the treatment mode was retrieved for each patient.

The inclusion criteria were as follows: severe skeletal class II malocclusion (ANB≥5°) [2, 6, 14]; orthodontic and orthognathic treatment; available of LCBCT data at the initial and follow-up examinations (10–18 months); procedures performed by the same team of surgeons using rigid fixation; and age older than 18 years at the time of the surgery.

The exclusion criteria were as follows: joint diseases, malocclusion such as cross bite or anterior open bite, facial asymmetry (distance from the median line of the maxillary incisors to the mandibular incisors more than 3 mm), the presence of syndromes or trauma in the head and neck region, a missing tooth other than the third molar, an embedded tooth, and a history of orthodontic treatment.

A total of 550 patients were initially selected because they were categorized as class II in the databases of . The LCBCT cephalograms of all 550 patients were digitized, and 280 patients met the selection criteria for a severe class II malocclusion (ANB≥5°; sample mean ANB = 6.4°). The final 97 patients were selected (mean ANB = 7.41°) solely based on the availability of the initial and final records.

Therapeutic procedures

All patients were routinely treated with fixed straight wires before orthognathic operation, the dentition was flattened, and the compensatory tilt of teeth was corrected to prepare for the surgery. Patients underwent sagittal split ramus osteotomy (BSSRO), Le Fort I osteotomy, and genioplasty by the same team of surgeons, using rigid fixation. Fixation of the maxillary segment was performed with L-shaped miniplates, and the mandibular osteotomy was fixed and stabilized using one plate and monocortical screws on each side. Finally, the proximal segment was lifted and fixed to one end of the plate, and then the condyle was manually repositioned. During this process, no fracture occurred in the proximal segment for any patient.

Orthodontic treatment began 4–5 weeks after the operation, to establish a good occlusal relationship.

Cephalometric evaluation

All scans were taken with the same LCBCT unit (Morita Corp, Japan), a high-frequency X-ray source with a constant potential (80 kV at 4.5-mA pulse operation) and cone-beam profile. The scanning interval was 23 s, and the scanning thickness was 0.125 mm. All pictures were taken with the patient seated upright in habitual occlusion with both eyes looking straight ahead. The head fixation device and cursor positioning system were used to ensure that the orbital ear plane was parallel to the ground, the scanning plane was parallel to the orbital ear plane, and the midline of the plane coincided with the midline of the equipment. All obtained Digital Imaging and Communications in Medicine (DICOM) image datasets were anonymized. LCBCT images were obtained before orthodontics (T0) and 10 to 18 months after the surgery (T1).

SNA, SNB, and ANB measurements were obtained for each patient. All lateral cephalometric tracings were digitized by the same examiner using Mimics 20.0 (interactive medical image control software, Materialize, USA) software. Ten randomly chosen lateral cephalograms were traced twice by the same examiner and measured separately to check the measurement error, which ranged from 0.05 to 0.2°.

3D measurements on LCBCT

Measurements were made by experienced examiners using LCBCT images. These files were reconstructed into 3D images (Fig. 1) with Mimics software.

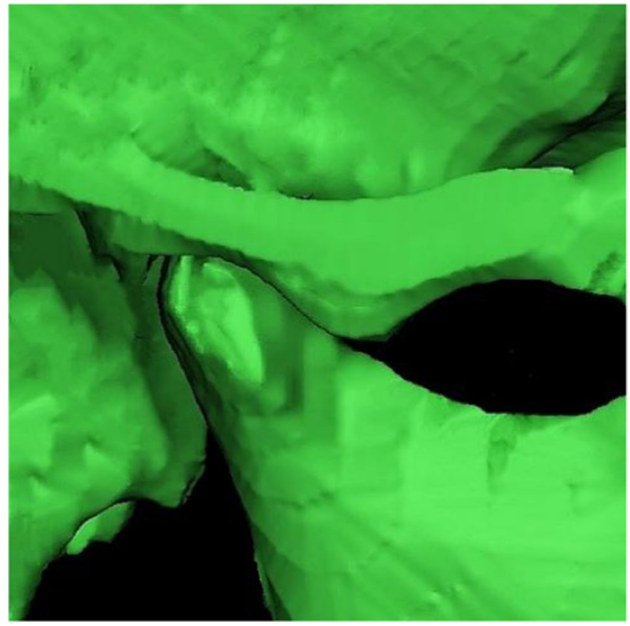

Fig. 1 3D reconstruction of the TMJ (lateral view)

The highest point of the articular fossa (H) and the most convex point of the condyle in the AS and PS were denoted using the reconstructed 3D image as the anterior-most condylar point (ACo) and posterior-most mandibular condyle point (PCo), respectively (Fig. 2). The plane determined by the three points was defined as the sagittal section (Fig. 3).

Using the plane as a reference, the joint spaces were measured by performing the following steps [25]: (1) A horizontal reference plane defined by a line tangent to the superior glenoid fossa was drawn parallel to the superior film border. (2) A line perpendicular to the horizontal tangent line was drawn to divide the joint space into anterior and posterior halves. (3) Anterior and posterior condylar tangent lines were drawn to intersect with the perpendicular line. (4) The joint space width was measured by the lines perpendicular to the condylar tangent lines. In this manner, the linear joint spaces were defined as the PS, SS, and AS (Fig. 4).

The measurement of the condyle included the length, width, height, and volume, and the length of the condyle was calculated as the distance between the PCo and ACo (Fig. 5A). The superior-most portion of the mandibular condyle was denoted as the superior mandibular condyle (SCo). The height of the condyle was calculated as the perpendicular distance from the SCo to the inferior-most point of the sigmoid notch (Inf Sig), which was between the mandibular condyle and the coronoid process (Fig. 5B). In the coronal section, two points were chosen as the medial condyle (MCo) and lateral condyle (LCo), and the condylar width was measured as the linear distance between the MCo and LCo (Fig. 5C).

On the axial view, the upper extent of the condylar head was determined when the first radiopaque point appeared in the joint space while scrolling the axial images from the upper to the lower regions of the joint space; the lower extent was determined when the sigmoid notch disappeared. Subsequently, we separated the condylar part from the mandible and reconstructed its 3D model, from which we assessed the surface area and volume using Mimics software (Fig. 6) [26, 27].

To analyze the thickness of the roof of the glenoid fossa (RGF), the images were reconstructed based on the individual condylar head angulation (Fig. 7A). Coronal sections

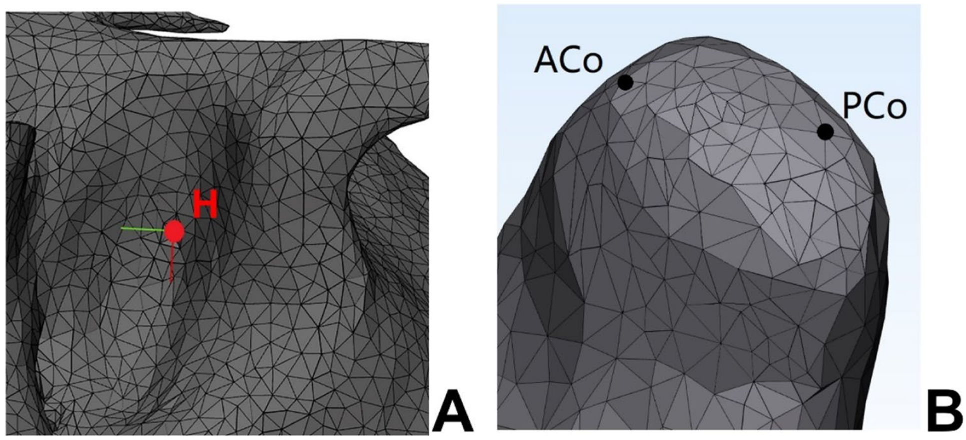

Fig. 2 Grid stereogram of a single bone: **A** articular fossa of the temporal bone, with the most concave point (H) marked in red; **B** lateral view of the condyle, with the most convex point marked in black; ACo, anterior-most condylar point; PCo, posterior-most mandibular condyle point

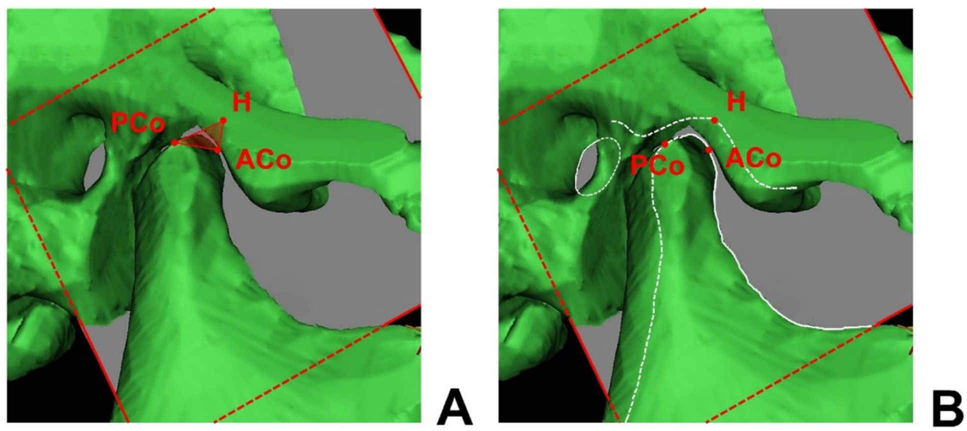

Fig. 3 Orientation of the planes of the 3D model. ACo, anterior-most condylar point; PCo, posterior-most mandibular condyle point; H, the highest point of glenoid fossa

were obtained parallel to the horizontal axis of the condylar head, and sagittal sections were reconstructed parallel to the line connecting the center point of the condylar head with the coronoid process. The distance between the inferior and superior cortices of the glenoid fossa was registered as the thickness of the RGF (Fig. 7B) [28, 29].

Three experienced examiners measured every condyle and glenoid fossa three times each, and the mean value was used for statistical analysis. The examiners reassessed 20% of the sample after 1 month to calculate the intraobserver agreement. In addition, we performed a follow-up observation on the occlusion of these 97 patients after surgery.

Statistical analysis

Statistical analyses were performed with SPSS (version 25.0; SPSS, Chicago, IL). The Kolmogorov-Smirnov test was used to determine the normality of the data. A paired-samples *t* test was used to evaluate the differences between the data of the left and right joints in both groups pretreatment (T0) and posttreatment (T1). An independent-sample *t* test was used to compare the condylar data between groups at T0 and T1. P value < 0.05 was considered statistically significant. In addition, Pearson correlation coefficients were applied to compare the variables analyzed.

Twenty percent of the randomly selected images were reassessed after 1 month by the same investigator, and the systematic intraexaminer error between the two measurements was determined by calculating the intraclass correlation coefficients (ICCs). To evaluate the interexaminer reliability, the measurements were obtained from one of the authors (YAW), and the ICCs were calculated.

Results

A total of 97 patients (20 males and 77 females) aged between 18 and 34 years (mean age 24.82 years) met the inclusion and exclusion criteria. The follow-up results showed that none of the 97 patients had occlusal problems after treatment. The mean interval between the T0 and T1 LCBCT examinations was 11.49 months (range 10 to 18 months). The difference in the number of samples between the sexes was due to the desire of more female patients to improve their facial aesthetics through this treatment. The

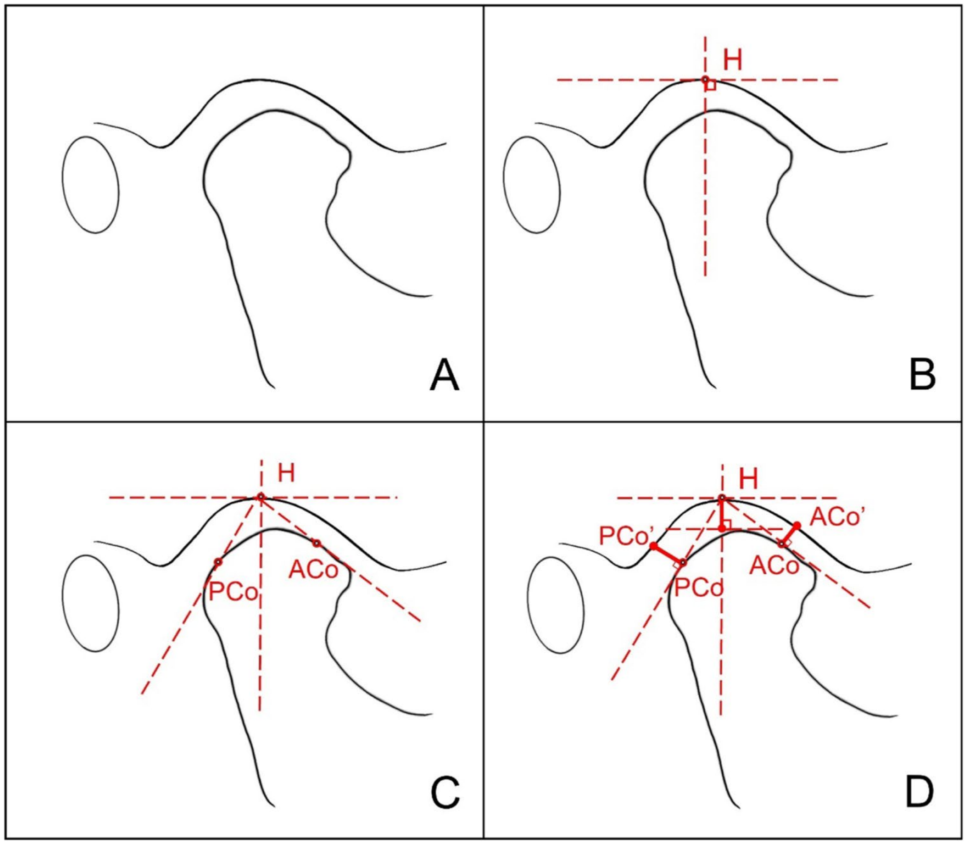

Fig. 4 Measurements of the AS, SS, and PS of each joint. **A** A cross-sectional view of the plane; **B** reference plane defined by the line tangent to the glenoid fossa; **C** anterior and posterior condylar tangent lines that intersected at the superior fossa; and **D** linear measurement perpendicular to the tangential intersections

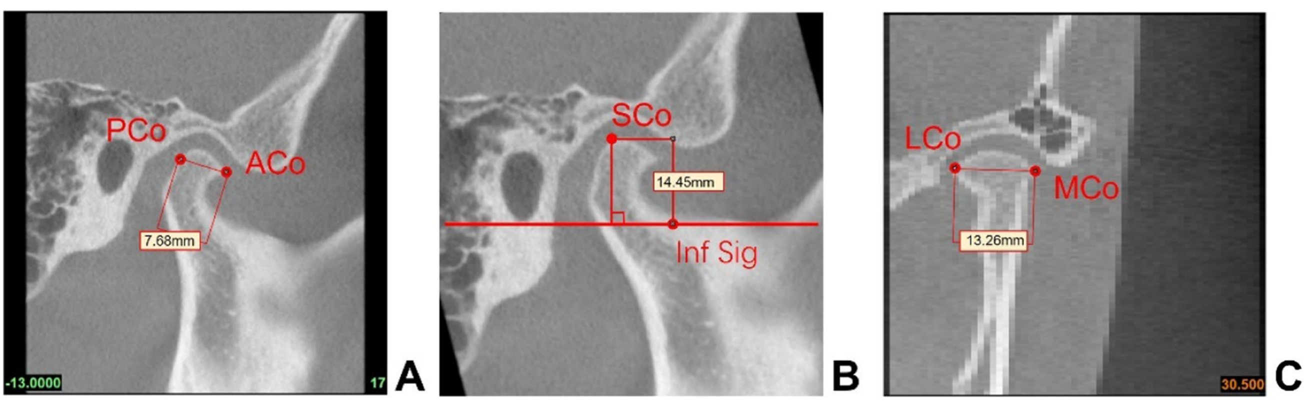

Fig. 5 Measurement of the length, width, and height of condyle. **A** Condylar length in the anteroposterior direction. ACo, anterior-most condylar point; PCo, posterior-most mandibular condyle point; **B** the sagittal view showing condylar height measurements. Inf Sig, inferior-most point of the sigmoid notch; SCo, superior mandibular condyle; **C** the coronal view showing condylar width measurement between the two poles. LCo, maximum convex curvature on the lateral aspect of the condyle; MCo, maximum convex curvature on the mesial aspect of the condyle

patient age and treatment time were similar for both sexes ($P > 0.05$).

At T0, the mean SNA was 86.66 ± 4.58°, the mean SNB was 76.27 ± 4.62°, and the mean ANB was 7.39 ± 1.03°. At T1, the mean SNA was 86.66 ± 4.27°, the mean SNB was 83.29 ± 4.29°, and the mean ANB was 3.37 ± 0.82°. The SNB and ANB showed significant differences between T0 and T1 ($P<0.05$), and the change in SNA was insignificant ($P>0.05$). The 3 measurements were similar for both sexes ($P>0.05$) (Table 1).

High ICCs (>0.9) were calculated, indicating excellent agreement between the different examiners, and between the first and second assessments of the same patient. The random error was less than 6.2% for the space changes.

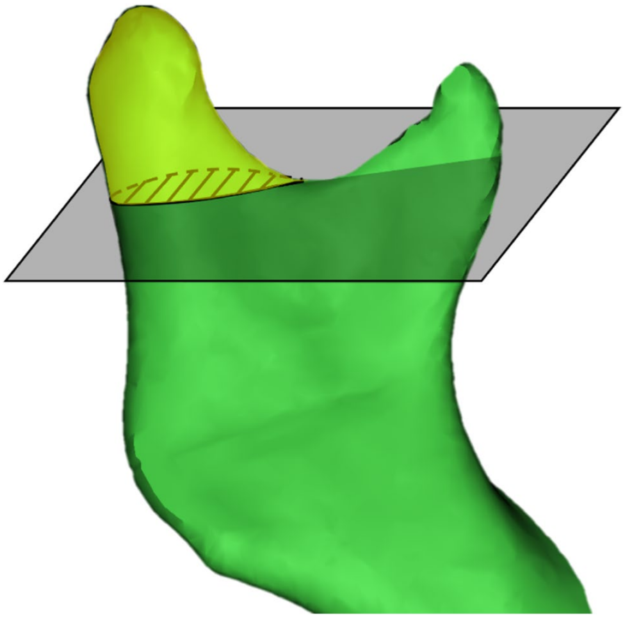

Fig. 6 Measurement of the surface area and volume of the condyle. The part of the condyle we measured has been marked in yellow

A small (0.24%) and statistically nonsignificant (P>0.05, Table 2) decrease in AS between the left and right condyles (0.058% and 0.625%, respectively) was observed, whereas significant changes were found in the SS and PS (P<0.05, Table 2). The mean PS decreased from 2.873 to 2.155 mm (24.985%, P = 0.000), and the mean SS decreased from 3.086 to 2.748 mm (10.968%, P = 0.047). The mean condylar positional change of 97 patients from T0 to T1 is illustrated in Fig. 8.

A moderate positive correlation (r>0.6) was found between the left and right condyles at the same observation period in each group, and the differences were small.

The pre- and postoperative cephalometric values and changes in the condyle are shown in Table 3. Small and statistically nonsignificant changes were found in the values of the condylar width and height, the mean width decreased from 16.682 mm to 16.543 mm (−0.840%, P = 0.625), and the mean height decreased from 18.921 mm to 18.877 mm (−0.233%, P = 0.537). The mean changes in condylar length, surface area, and volume were relatively larger (length, 2.821%; surface area, 3.659%; volume, 5.819%) but

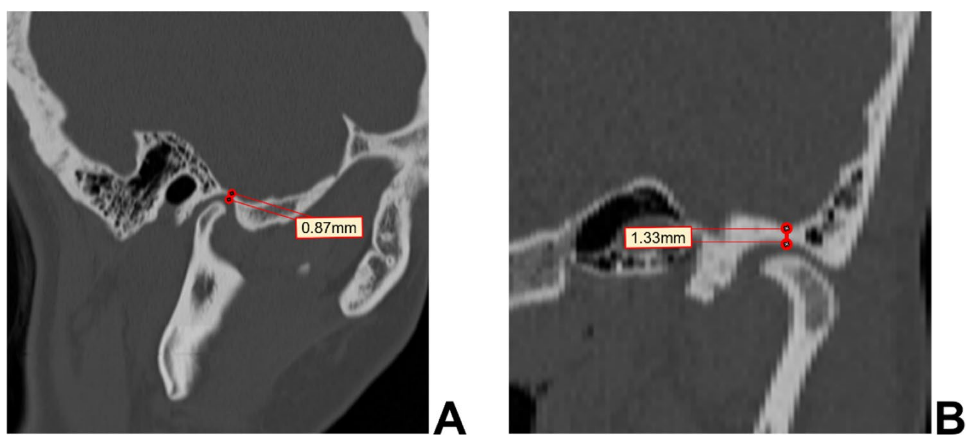

Fig. 7 Measurement of the glenoid fossa. **A** Para-sagittal section showing the thickness of the roof of the glenoid fossa on left side; **B** para-coronal section showing the thickness of the roof of the glenoid fossa on the right side

Table 1 Mean value of the cephalometric evaluation index at T0 and T1

		T0	T1	T0-T1	P (T0 vs T1)
SNA (°)	Mean	86.66 ± 4.58	86.66 ± 4.27	0.00 ± 3.23	0.99
	Male	86.96 ± 3.15	88.13 ± 3.37	−1.17 ± 2.64	0.26
	Female	86.58 ± 4.42	86.28 ± 4.42	0.30 ± 3.32	0.69
	P (male vs female)	0.75	0.09	0.07	
SNB (°)	Mean	76.27 ± 4.62	83.29 ± 4.29	−4.02 ± 3.54	0.00[a]
	Male	79.60 ± 3.07	84.68 ± 3.74	−5.08 ± 3.39	0.00[a]
	Female	79.1 ± 4.95	82.93 ± 4.38	−3.75 ± 3.55	0.00[a]
	P (male vs female)	0.72	0.11	0.14	
ANB (°)	Mean	7.39 ± 1.03	3.37 ± 0.82	4.002 ± 1.23	0.00[a]
	Male	7.35 ± 0.98	3.45 ± 1.07	3.91 ± 1.17	0.00[a]
	Female	7.41 ± 1.05	3.35 ± 0.75	4.05 ± 1.25	0.00[a]
	P (male vs female)	0.84	0.65	0.64	

[a]Statistically significant P value

Table 2 Mean spaces of the joints on the left and right side at T0 and T1

		T0		T1		T0-T1			*P**
		Mean	SD	Mean	SD	Mean	SD	T0-T1(%)	T0-T1
AS (mm)	Mean	1.684	0.591	1.680	0.644	−0.004	0.581	−0.237	0.964
	Left	1.830	0.596	1.820	0.666	−0.011	0.610	−0.058	0.907
	Right	1.542	0.590	1.533	0.634	−0.009	0.567	−0.625	0.913
	P (left vs right)	0.585		0.906		0.990			
SS (mm)	Mean	3.086	1.186	2.748	1.074	−0.339	1.185	−10.968	0.047[a]
	Left	2.875	1.264	2.546	1.113	−0.329	1.210	−11.445	0.049[a]
	Right	3.302	1.238	2.962	1.097	−0.339	1.178	−10.278	0.045[a]
	P (left vs right)	0.601		0.760		0.952			
PS (mm)	Mean	2.873	1.623	2.155	0.815	−0.718	1.640	−24.985	0.000[a]
	Left	3.135	1.612	2.475	0.853	−0.659	1.648	21.026	0.001[a]
	Right	2.541	1.632	1.827	0.817	−0.714	1.685	−28.092	0.000[a]
	P (left vs right)	0.857		0.509		0.819			

AS, anterior space; *SS*, superior space; *PS*, posterior space

[a]Statistically significant *P* value

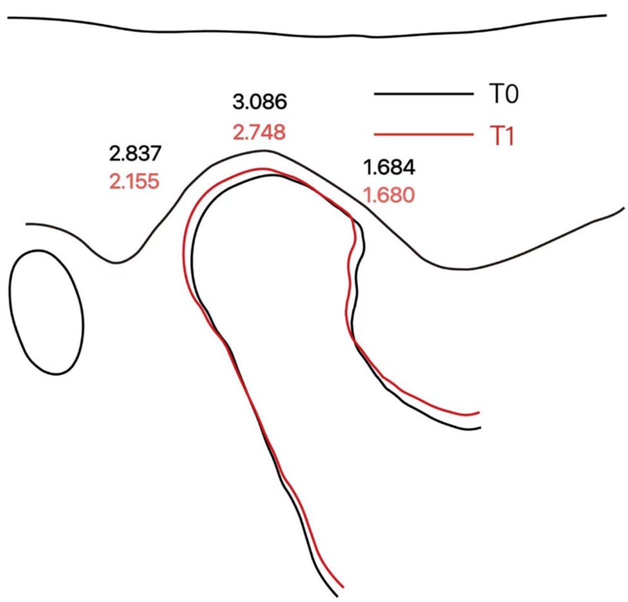

Fig. 8 Mean TMJ positional change in different therapeutic periods

still not statistically significant (length, $P = 0.143$; surface area, $P = 0.061$; volume, $P = 0.077$).

Comparing the thickness of the glenoid fossa before and after the therapy, small differences were found, with the sagittal thickness decreasing from 1.011 to 0.996 mm (−1.506%, $P = 0.576$) and the coronal thickness increasing from 1.401 to 1.422 mm (1.499%, $P = 0.930$).

When the changes in the joint spaces between T0 and T1 were correlated among themselves, a moderate positive correlation (mean, $r = 0.650$; left condyles, $r = 0.676$; right condyles, $r = 0.652$) was found between the SS and PS on both sides and the mean space, and a weak negative correlation (mean, $r = -0.172$; left condyles, $r = -0.127$; right condyles, $r = -0.197$) was found between the AS and PS on both sides and the mean space. When comparing the mean joint spaces between T0 and T1, a moderate positive correlation (AS, $r = 0.560$; SS, $r = 0.493$) with the AS and SS values and a weak positive correlation ($r = 0.230$) with the PS values were observed (Table 4).

Discussion

The purpose of this study was to retrospectively evaluate the outcomes of the combination of orthodontic and surgical treatment in patients with severe skeletal class II malocclusion.

In this study, the changes from T0 to T1 were positively correlated between the left and right condyles. R.J. DaSilva et al. [11] and R. Kuehle et al. [30] reported that patients with class II malocclusion have nearly equal reductions in the condyles on the left and right sides after orthognathic surgery, which is consistent with the results of this study. Thus, surgical-orthodontic treatment for severe skeletal class II patients may not change the patients' facial symmetry.

Positional changes in the condyles are a common effect associated with surgical-orthodontic treatment. Overall, most studies indicate that the combination of orthodontic and surgical treatment leads to backwards movement of the condyles [7, 17–19, 21, 30, 31]. M. Z. Miao reported that the increases in AS and decreases in SS and PS were significant, leading to backwards movement of the condyle and mandible. Interestingly, they suggested that the final treatment result for class II malocclusion patients initially presenting with mandibular retraction was backwards movement of their mandibles. They observed an approximately 10%

Table 3 Measurement of the condyle on the left and right side at T0 and T1

	c	T0		T1		T0-T1			P*
		Mean	SD	Mean	SD	Mean	SD	T0-T1(%)	T0-T1
Length (PCo-ACo) (mm)	Mean	7.253	1.051	7.054	0.985	−0.199	0.185	−2.821	0.143
	Left	7.136	1.031	6.996	0.904	−0.140	0.163	−2.001	0.081
	Right	7.430	0.959	7.112	0.949	−0.318	0.190	−4.471	0.180
	P (left vs right)	0.282		0.334		0.571			
Width (MCo-LCo) (mm)	Mean	16.682	2.156	16.543	2.238	−0.139	0.431	−0.840	0.625
	Left	17.190	2.154	17.050	1.949	−0.140	0.357	−0.821	0.680
	Right	16.174	2.059	16.036	2.152	−0.138	0.429	−0.861	0.335
	P (left vs right)	0.995		0.531		0.870			
Height (SCo- InfSig) (mm)	Mean	18.921	3.984	18.877	4.001	−0.044	3.795	−0.233	0.537
	Left	16.934	3.672	17.012	3.627	0.078	2.574	0.458	0.431
	Right	20.908	3.961	20.742	3.726	−0.166	3.994	−0.800	0.872
	P (left vs right)	0.484		0.959		0.790			
Surface area (mm2)	Mean	968.375	187.620	934.197	177.289	−34.178	162.578	−3.659	0.061
	Left	984.043	176.811	932.841	167.419	−51.202	153.793	−5.489	0.085
	Right	988.707	185.771	935.553	167.525	−53.154	170.976	−5.682	0.054
	P (left vs right)	0.174		0.592		0.482			
Volume (mm3)	Mean	1643.382	418.555	1553.018	417.520	−90.364	417.781	−5.819	0.077
	Left	1884.849	411.341	1813.008	400.425	−71.841	399.432	−3.963	0.062
	Right	1402.015	394.298	1293.028	413.023	108.987	415.098	−8.429	0.097
	P (left vs right)	0.463		0.970		0.406			

ACo, anterior-most condylar point; *PCo*, posterior-most mandibular condyle point; *MCo*, medial condyle; *LCo*, lateral condyle; *Inf Sig*, inferior-most point of the sigmoid notch

[a]Statistically significant *P* value

Table 4 Correlations between the changes in joint spaces from T0 to T1 for the mean, right, and left condyles, and between the sides for each parameter; Pearson correlation coefficient

	Mean		Left condyles		Right condyles	
	R	*P* value	*R*	*P* value	*R*	*P* value
AS vs SS	−0.062	0.631	−0.062	0.680	−0.059	0.586
SS vs PS	0.650[b]	<0.001	0.676[b]	<0.001	0.652[b]	<0.001
PS vs AS	−0.172[a]	0.047	−0.127[a]	0.155	−0.197[a]	0.021
	P value					
AS	<0.001					
SS	<0.001					
PS	0.003					

AS, anterior space; *SS*, superior space; *PS*, posterior space

[a]Weak correlation

[b]Moderate correlation

increase in AS and an approximately 30% decrease in SS and PS; however, the change in the spacing of the condyles was inconsistent in our patient sample, with the AS changing little, the SS decreasing by approximately 11%, and the PS distance decreasing by approximately 25%. Other authors have also described the positional changes of condyles after treatment of class II patients [11], and found a significant decrease in SS. These differences are difficult to explain. However, it is important to note that the previous studies only consisted of patient samples of less than 60, and here we studied a total of 97 patients.

Adaptive changes in the TMJ may also have an impact on changes in joint space, such as hyperplasia, remodeling, and absorption of the condyle and glenoid fossa. In the measurement of the condyle itself, we found that the mean value of the volume change in the condyle was approaching 6%, while the right side changed up to approximately 8%. Jung et al. [15] classified condylar heads with over 6% volume reduction as the resorption group. In conjunction with their study, we infer that the condylar changes in our experimental subjects were at the threshold where absorption was about to be defined as occurring or there was a tendency of absorption. Considering the measurements of the condylar width and height, the value changes were far less than 1%, and we can assume that the condyles experience little significant dysfunctional changes in the coronal plane, so the volumetric change in the condyle may mainly be caused by the decrease in the condylar length. Although the length, surface area, and volume of the condylar head decreased and there was a risk of resorption, the changes were not statistically significant in the present study, and no postoperative complications of joint resorption were observed during the follow-up visits.

Mandibular condylar remodeling after orthognathic surgery has been widely reported for decades [32]. The common interpretation of condylar resorption is that, the relative positional change of the condyle to the glenoid fossa causes compression of the condyle, resulting in a cellular response [33]. Jung et al. reported that the greatest resorption after SSRO was in the posterior segment of the condyle [15], which could explain why the AS has changed the most in the present study.

It has been reported that surgical procedures such as detachment of the masticatory muscles could cause enlargement of the glenoid fossa after SSRO, which returns to normal after a period of time [12]. By comparing the thickness of the sagittal and coronal surfaces of the glenoid fossa pretherapy and 1 year after surgery, we excluded the effect of changes in the glenoid fossa on the measurement of joint space. This might mean that the articular fossa and condyle have adapted to each other.

Cha et al. [14] reported backwards mandibular rotation in severe class II malocclusion patients, which might be a side effect of orthodontic treatment. However, recent studies have indicated that orthognathic surgery can also lead to mandibular rotation. Hoon Joo Yang [34] studied the position of the mandible and found that clockwise rotation is associated with advancement of the mandible. In our sample of patients with class II malocclusion who underwent surgical-orthodontic treatment, we can speculate that the condyle and mandible rotated during the therapy according to the almost unchanged AS and decreased SS and PS found in our study. During the course of treatment, the chins of patients moved forwards to correct the class II malocclusion, while the condyles had a tendency to move backwards. We can conjecture that there might be a center of rotation on the mandible and that the mandibles of class II patients rotated around this point or shaft during surgical-orthodontic treatment [35].

Accurate measurement of the linear changes is a requirement for evaluation of the condylar positional differences before and after surgery. In contrast to other studies in which the condylar space was measured on sagittal plane CT images [11, 14, 21, 30], we utilized pre- and posttreatment LCBCT for 3D remodeling and assessed condylar displacement during surgical-orthodontic treatment. Two-dimensional measurements are not accurate and might lead to identification errors associated with the imaging modality.

Given the incidence of condylar positional changes in this study, surgical-orthodontic treatment appears to let the condylar head rotate counterclockwise, which may lead to condylar absorption. We can reduce the complications of condylar resorption by personalizing the surgical plan for each patient and controlling the biological response by precisely locating the postoperative condylar position. Future studies on surgical-orthodontic treatment need to focus more on the alterations of the TMJ intervals and analysis of the risk factors for the related postoperative complications. Compared with controversial analyses, the present study analyzed the changes in the joint space, joint fossa, and condylar head itself in 3D models, counting for the deficiencies of previous work that only measured the joint space in 2D or focused only on the volume of each part of the joint. Therefore, the experimental results were more reliable.

Conclusions

- Surgical-orthodontic treatment moves the condyle counterclockwise in severe skeletal class II malocclusion patients.
- The positional changes in condyles were proportionally related between left and right sides.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Wen Yang, Yanbin Chen, Jiaxuan Li, and Nan Jiang. The first draft of the manuscript was written by Wen Yang, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

This retrospective chart review study involving human participants was in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The Human Investigation Committee (IRB) of Sichuan University approved this study (IRB Reference number: WCHS-IRB-CT-2019-221).

Competing interests The authors declare no competing interests.

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