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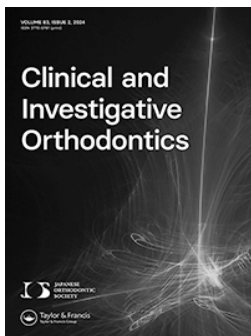
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Three-dimensional changes in the soft tissue chin after mandibular setback surgery in adult Japanese patients with skeletal class III malocclusion

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ABSTRACT

Purpose: The purpose of the present study is to improve the quality of prediction of soft tissue morphology by clarifying the relationship between the amount of three-dimensional (3-D) changes of hard tissue and the morphological differences of the soft tissue chin before and after orthognathic surgery in skeletal class III malocclusion.

Materials and methods: Preoperative and six-month postoperative CT was used to analyze the changes in 26 adult Japanese skeletal class III patients. The mean age was 25.5 years. Lateral cephalograms were analyzed to evaluate the initial antero-posterior jaw relationship and the changes before and after treatment. Three-D masks and bone structures were reconstructed using 3-D modelling software, and the final chin models were defined for further analysis following voxel-based registration. Correlation and linear regression analyses were performed to clarify the relationship between the movement of the soft tissue chin and the underlying bone.

Results: The soft tissue chin volume and surface area significantly increased after surgery. The thickness of the chin significantly increased only at pogonion and menton after surgery. Furthermore, a statistically significant correlation between the movement of soft tissue chin and underlying bone was found. Consequently, the regression model predicted the changes in soft tissue chin from the movement of the underlying bone.

Conclusion: Three-D analysis of the soft tissue chin revealed a significant change in response to surgical orthodontic treatment in skeletal class III adult patients, and soft tissue chin movement could be predicted by using 3-D CT data when planning orthognathic treatment.

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Soft tissue chin; orthognathic surgery; 3-D changes; volumetric analysis; chin prediction

Introduction

Combined orthodontic-orthognathic surgical treatment improves functional and aesthetic outcomes in patients with severe skeletal class III malocclusion [1]. Previous research has indicated the importance of evaluating soft tissue for facial attractiveness and beauty [2]. Many studies have demonstrated the changes and relationship between the surgical movement of maxillofacial bones and changes in soft tissue related to the facial profile using two-dimensional analysis for a long time [3–7]. Recently, methods for three-dimensional (3-D) analysis have been developed, and numerous investigators have focused on utilizing 3-D images to demonstrate the complexities of facial hard and soft tissue structures [8–10]. Some studies have examined the correlation between hard and soft tissues through symmetrical and asymmetrical changes resulting from either isolated mandibular setback surgery [11] or a combination of two jaw surgery [12]. In addition, some researchers have assessed changes in the midfacial area because these areas have complex concavity and convexity shapes [13–16]. However, they

did not thoroughly analyze the chin region, which is a prominent facial structure in the frontal and profile views that is crucial in facial aesthetic assessment, and changes in it are considered one of the main changes that may affect the aesthetics of the lower face after orthodontic-orthognathic surgery [17]. Hence, due to the importance of this region, other investigators have focused on evaluating chin thickness in relation to different skeletal malocclusions or vertical patterns [18–20]. Moreover, studies also evaluated the thickness following orthognathic surgery [21,22]. Yet, they did not analyze the real 3-D changes, such as volumetric changes, and the correlation between soft and hard tissue chin was studied only at unilateral points. Recent research examined 3-D chin among different types of skeletal malocclusion using different parameters. Nevertheless, it only investigated hard tissue chin without reflecting the soft tissue chin part [23].

Despite the increasing interest in the evaluation of facial soft tissue changes produced by orthognathic

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surgery, the current literature lacks a detailed 3-D analysis of the soft tissue chin after mandibular setback surgery with bilateral sagittal split ramus osteotomy (BSSO), which is crucial for determining facial attractiveness and establishing an appropriate orthognathic treatment plan. Understanding the correlation between changes in the soft tissue chin and underlying hard tissue is also essential for predicting the postoperative shape of the lower face.

Therefore, the present study aimed to evaluate 3-D changes in the soft tissue chin and to clarify the relationship between soft tissue and underlying hard tissue movement in the chin region after BSSO in adult Japanese patients with skeletal class III jaw deformities using 3-D computed tomography (CT). We hypothesized that the 3-D shape of the soft tissue chin might change significantly when the mandibular protrusion is surgically corrected, and the amount of the change in soft tissue is significantly correlated with the amount of hard tissue movement.

Materials and methods

Participants

Three-dimensional CT images of 26 adult Japanese patients (18 females, and 8 males) taken before and after treatment were utilized in the present study. Participants were recruited from the patients at the Orthodontic Clinic, Kyushu University Hospital. The mean age was (25.5 years, range 18–51 years).

The inclusion criteria for the present study were as follows:

- (1) Adult Japanese patients with good general health and had no systemic diseases.
- (2) They had severe skeletal class III malocclusion with an ANB angle of less than 0°.
- (3) They were treated by orthognathic surgery using BSSO with presurgical orthodontic treatment performed without Lefort 1 osteotomy and/or additional aesthetic surgical procedures, such as genioplasty.

The exclusion criteria were as follows:

- (1) The patients who had a history of orthodontic treatment, orthognathic surgery, or maxillofacial trauma.
- (2) They had a menton deviation greater than 4 mm from the midline.
- (3) They had cleft lip and/or palate and craniofacial syndromes.
- (4) They had lost or incomplete series of identifiable CT records, technically aberrant CTs, and non-continuous soft tissue contour at the chin level indicating chin strain.

This study was approved by the Ethics Committee of the Faculty of Dental Science of Kyushu University, Fukuoka, Japan (Approval no. 23182–00).

Image acquisition, segmentation, and registration

Each patient underwent CT scans before (T1) and six months after (T2) surgery. CT Images were acquired with the patient positioned supine on the CT couch, the head in a natural position, and relaxed facial musculature. During scanning, the patients were asked to bite with maximum intercuspation and not move their heads or tongues. CT scans were obtained using Aquilion (Toshiba Medical System Corporation, Tokyo, Japan). All patients had the following scan parameters: slice thickness, 0.5 mm; tube voltage, 120 kVp; tube current, 100 mA; image matrix size, 512 × 512; and field of view, 230 mm. Fifty-two CT scans were stored in Digital Imaging and Communications in Medicine (DICOM) format. DICOM data were imported into Mimics software (v.24.0, Materialise, Leuven, Belgium) to reconstruct the 3-D masks. A total of 104 hard and soft tissue 3-D models were reconstructed using a semi-automatic segmentation workflow function of grayscale thresholding with a range (–700–225) Hounsfield Units for soft tissue and (226–3071) for hard tissue [24]. Voxel-based automatic image registration was used to compare the 3-D masks between T1 and T2 images [25], as shown in (Figure 1).

Soft tissue chin analysis and measurements

The chin was defined by indicating four cephalometric landmarks in the 3-D soft tissue model: chelion right (ChR), chelion left (ChL), sublabial (Sl), and soft tissue menton (Me'). The final chin model was exported to the 3-D analytical and design software 3-Matic (v.16.0, Materialise, Leuven, Belgium) for further analysis and automatic computation of the volume and surface area of soft tissue chin. Mimics software was used to determine the distance between the soft and hard tissue landmarks (Figure 2). During this process, seven soft tissue and seven hard tissue landmarks were identified to determine soft-tissue chin thickness. In addition, anthropometric point changes were measured, the ratio and correlation of 3-D soft-to-hard tissue movement were implemented, and linear regression was performed to predict 3-D soft tissue chin movement from the underlying skeletal movement following BSSO. Table 1 presents the definitions of landmarks. Furthermore, Intraobserver reliability was determined by one examiner to reduce inexactness between the investigators. The measurements taken during the initial assessment were compared with those taken during repeated examinations after two-week intervals.

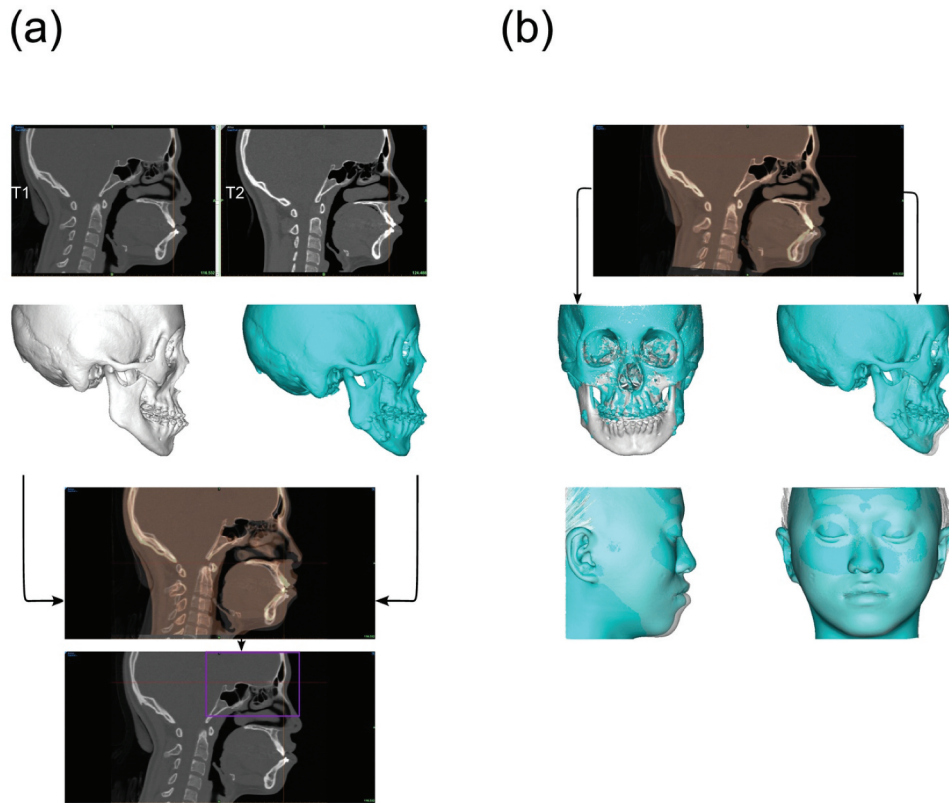


Figure 1. Image superimposition using voxel-based automatic registration. (a) Aligning the moving image (T2) and selecting the registration area for cranial base registration. (b) Image registration and superimposition of 3-D masks using transparency overlay tool.

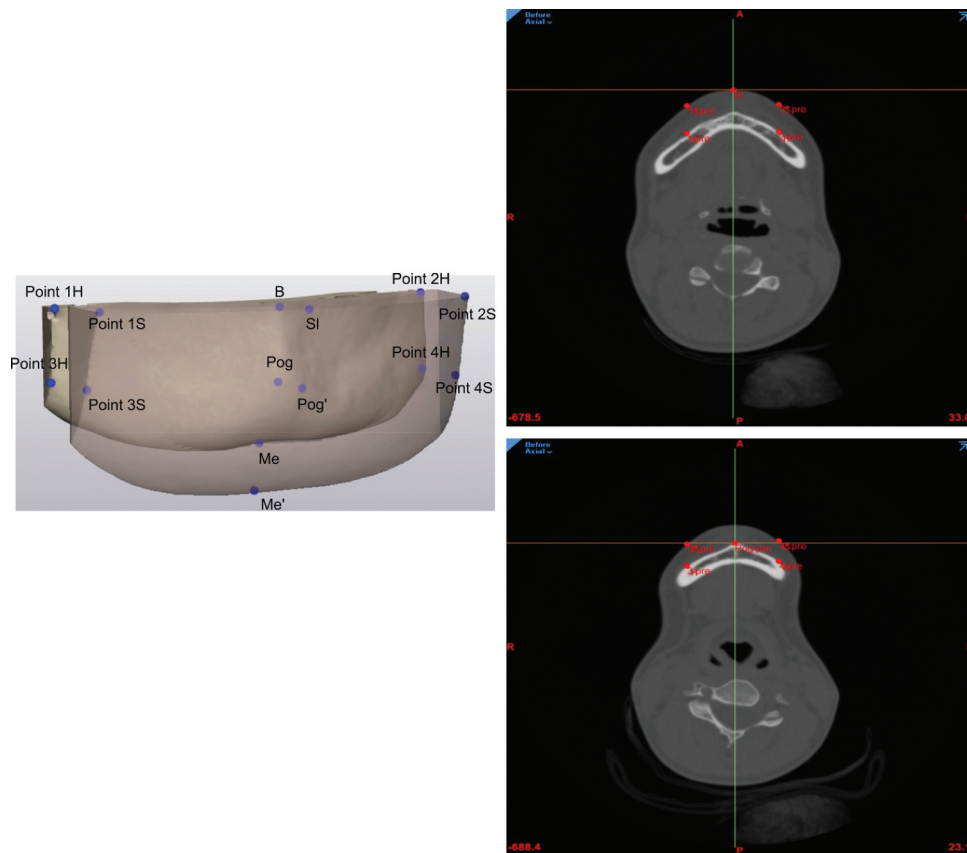


Figure 2. Three-D landmarks on the chin surface. To the left, 14 reproducible landmarks were plotted on the surface of the 3-D chin to perform the measurements. Six points on the midsagittal plane: Point B, hard tissue pogonion (Pog), hard tissue menton (Me), sublabial (SI), soft tissue pogonion (Pog'), and soft tissue menton (Me'). Eight points were plotted on the right and left lateral sides of the hard and soft tissue chin surface: points 1H and 1S, points 2H and 2S, points 3H and 3S, and points 4H and 4S. To the right axial view of the points.

Table 1. Description of chin landmarks used in this study.

Landmarks	Description
** Chelion	The point located at the right/left labial commissure.
*Point B	The point at the deepest concavity located between the infradentale and bony pogonion.
*Pogonion	The most anterior midpoint of the bony chin.
* Menton	The most inferior midpoint of the bony chin.
** Point 1H	Located on the external bony of the chin sharing the same vertical line of chelion right at the same level of point B.
** Point 2H	Located on the external bony of the chin sharing the same vertical line of chelion left at the same level of point B.
** Point 3H	located on the external bony of the chin sharing the same vertical line of Point 1H at the same level of pogonion.
** Point 4H	located on the external bony of the chin sharing the same vertical line of Point 2H at the same level of pogonion.
*Sublabiale	The point at the deepest concavity located between the lower vermilion border and the pogonion.
*Soft tissue pogonion	The most anterior midpoint of the soft tissue chin.
* Soft tissue Menton	The most inferior midpoint of the soft tissue chin.
** Point 1S	Extension of point 1H to the outermost soft tissue contour of chin at the same level of SI.
** Point 2S	Extension of point 2H to the outermost soft tissue contour of chin at the same level of SI.
** Point 3S	Extension of point 3H to the outermost soft tissue contour of chin at the same level of pogonion.
** Point 4S	Extension of point 4H to the outermost soft tissue contour of chin at the same level of pogonion.

*Midline point.**lateral point.

Cephalometric analysis

Cephalometric analysis was performed using lateral cephalograms taken before and after orthognathic surgery. The cephalometric parameters and their changes were analyzed, and the definition of the parameters is shown in Supplementary Table 1.

Statistical analysis

The Shapiro-Wilk test was used to check the normality of the data, as all tended to be normally distributed. A paired t-test was used to compare the soft tissue chin parameters between T1 and T2. The Pearson correlation coefficient was used to assess the relationship between the soft tissue chin and underlying hard tissue and to analyze the correlation between patient age

and soft tissue chin volume, surface area, and thickness changes. Regression analysis was performed to develop an equation to predict 3-D soft tissue chin movement after mandibular setback and to evaluate the impact of vertical characteristics on soft tissue changes. All data were statistically analyzed using JMP software (JMP® Pro Version 17.0.0 SAS Institute Inc., Cary, NC 2022). The results were presented as mean $\pm$ standard deviation and statistical significance was set at $p < 0.05$.

A sample size calculation was conducted using G*power 3.1.9 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). With reference to a previous study [26], a significant level of $\alpha = 0.05$, a power of 80% to detect a 1 mm difference (standard deviation = 1 mm) for the soft tissue thickness at pogonion between pre and post-surgical treatment. Consequently, the power analysis showed that 10 subjects would provide adequate statistical power for differences. Additionally, a power analysis for correlation was conducted based on a previous study [10] with an estimated correlation of $r = 0.55$, $\alpha = 0.05$, with 80% power. The analysis indicated that at least 23 samples would be required to achieve adequate statistical power for the correlation analysis.

Results

Measurement's reliability

Intraexaminer agreement was high for the measurements, with intraclass correlation coefficients ranged from 0.84 to 0.99.

Changes in hard tissue before and after surgery

The cephalometric measurements of the samples before and after orthognathic surgery are indicated in Supplementary Table 2. The skeletal class III cephalometric characteristics of the patients were changed to skeletal class I.

Table 2 summarizes the changes in the 3-D hard tissue chin landmarks following BSSO. The average amount of mandibular setback surgery was 7.5 mm. The amount of

Table 2. Three-dimensional changes in chin hard tissue landmarks before and after surgery.

Hard tissue landmarks	Mediolateral (X-axis)		Anteroposterior (Y-axis)		Superoinferior (Z-axis)	
	T2–T1 differences	p value	T2–T1 differences	p value	T2–T1 differences	p value
B	-0.54 ± 1.94	0.16	5.97 ± 2.43	$<0.0001^*$	1.27 ± 1.86	0.0019*
Pog	-0.54 ± 1.93	0.15	5.70 ± 2.90	$<0.0001^*$	1.13 ± 1.19	$<0.0001^*$
Me	-0.54 ± 1.93	0.15	5.85 ± 2.84	$<0.0001^*$	0.91 ± 1.16	0.0005*
Point 1H	-0.16 ± 1.55	0.58	5.56 ± 3.15	$<0.0001^*$	1.26 ± 1.86	0.001*
Point 2H	-0.11 ± 1.38	0.67	5.74 ± 2.42	$<0.0001^*$	1.27 ± 1.86	0.001*
Point 3H	-0.19 ± 1.91	0.60	5.51 ± 3.51	$<0.0001^*$	1.13 ± 1.19	$<0.0001^*$
Point 4H	-0.49 ± 1.87	0.18	5.82 ± 3.13	$<0.0001^*$	1.13 ± 1.19	$<0.0001^*$

Data are presented as mean $\pm$ SD. Paired t-test was used for comparison between before and after surgery. X-axis refer to mediolateral, Y axis to Anteroposterior, and Z axis to Superoinferior. Positive values indicate left, posterior, and superior changes in the X, Y, and Z axis. Negative values indicate right, anterior, and inferior changes in the X, Y, and Z axis, respectively. $p < 0.05$ is considered statistically significant.

Table 3. Comparison of the soft tissue chin volume and surface area before and after surgery.

Chin Measurements	Before surgery (T1)	After surgery (T2)	T2-T1 differences	p value
Volume (mm ³)	12455.4 ± 2494.25	13273.3 ± 2483.10	817.93 ± 824.65	<0.0001*
Surface Area (mm ²)	3937.94 ± 476.75	4066.51 ± 498.12	128.57 ± 136.31	<0.0001*

Data are presented as mean ± SD. Paired t-test was used to compare chin volume and surface area before and after surgery. $p < 0.05$ is considered statistically significant.

posterior movement at points B, Pog, and Me was 5.97 ± 2.43 mm, 5.70 ± 2.90 mm, and 5.85 ± 2.84 mm, respectively. The amount of upward movement at points B, Pog, and Me was 1.27 ± 1.86 mm, 1.13 ± 1.19 mm, and 0.91 ± 1.16 mm, respectively. These three points after orthognathic surgery showed significant backward and upward positions compared with those before surgery. On the other hand, there were no significant differences in the mediolateral direction between the three points.

Changes in soft tissue chin volume, surface area, and thickness before and after surgery

Figure 3 shows the changes in soft tissue chin volume and surface area. Chin volume statistically

significantly increased at T2 (13273.3 ± 2483.10 mm³) compared to T1 (12455.4 ± 2494.25 mm³). The difference in chin volume was (817.93 ± 824.65 mm³, $p < 0.0001$). Similarly, the surface area of the chin demonstrated a statistically significant increase at T2, as the difference in surface area between T1 and T2 was (128.57 ± 136.31 mm², $p < 0.0001$). This is further illustrated in Table 3.

Furthermore, Table 4 shows the chin thickness between T1 and T2. We found that the thickness significantly increased after surgery at Pog (0.39 mm ± 0.79 mm, $p = 0.018$) and at Me (0.29 mm ± 0.58 mm, $p = 0.03$). The increase in chin thickness at the lateral points was not statistically significant ($p > 0.05$).

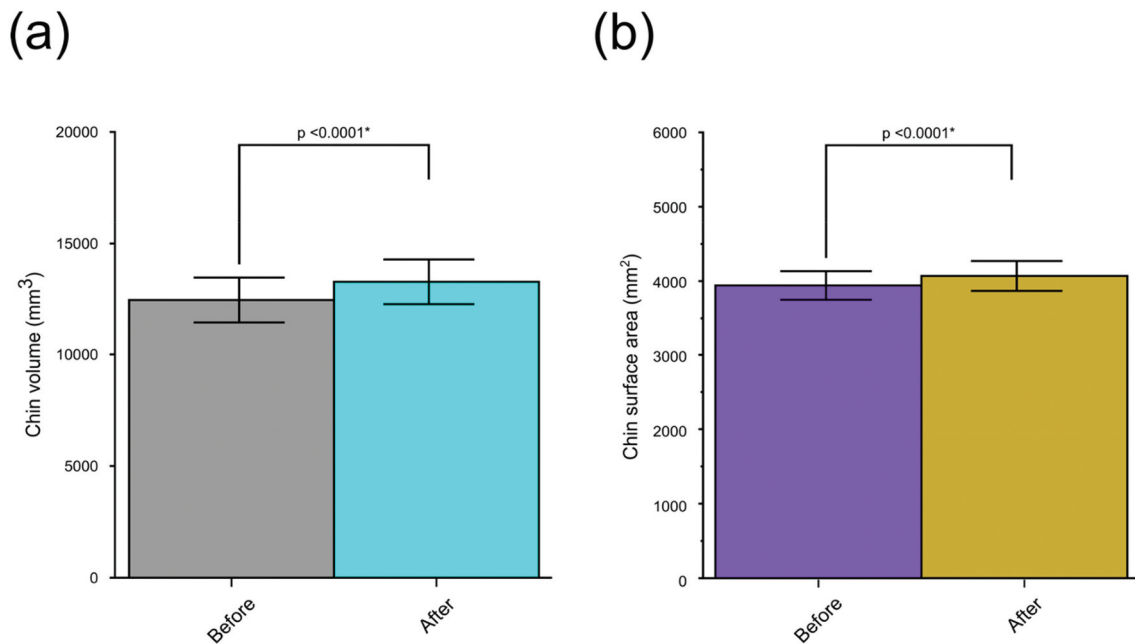


Figure 3. Soft tissue chin volume and surface area before and after surgery. (a) Changes in the soft-tissue chin volume before and after surgery. (b) Changes in soft tissue chin surface area before and after surgery. Each error bar is reconstructed using a 95% confidence interval. A paired t-test was used to compare the values before and after surgery. Statistical significance was set at $p < 0.05$.

Table 4. Chin soft tissue thickness changes before and after surgery.

Paired landmarks	Before surgery (T1) mm	After surgery (T2) mm	T2-T1 differences	p value
B-SI	11.82 ± 1.41	12.02 ± 1.15	0.20 ± 0.92	0.29
Pog-Pog'	10.58 ± 2.27	10.98 ± 1.94	0.39 ± 0.79	0.018*
Me-Me'	6.08 ± 1.66	6.36 ± 1.83	0.29 ± 0.58	0.03*
Point 1H-Point 1S	15.91 ± 2.11	16.51 ± 2.24	0.60 ± 1.47	0.051
Point 2H-Point 2S	16.46 ± 2.40	17.07 ± 2.70	0.61 ± 1.80	0.09
Point 3H-Point 3S	13.26 ± 2.14	13.58 ± 1.94	0.32 ± 1.21	0.18
Point 4H-Point 4S	13.76 ± 2.34	14.19 ± 2.43	0.42 ± 1.27	0.08

Data are presented as mean ± SD. Paired t-test was used to compare chin soft tissue thickness before and after surgery. Positive values indicate an increase in the chin soft tissue thickness. Negative values indicate a decrease in the chin soft tissue. $p < 0.05$ is considered statistically significant.

Table 5. Ratio of chin soft tissue to chin hard tissue movement.

Chin Landmarks	3-D movement (mm)		Ratio (%) S/H
	Hard tissue	Soft tissue	
B	6.76 ± 2.16	6.26 ± 2.10	92.6
Pog	6.39 ± 2.55	5.61 ± 2.40	87.8
Me	6.49 ± 2.49	6.13 ± 2.28	94.5
Point 1	6.33 ± 2.78	5.50 ± 2.32	86.9
Point 2	6.45 ± 1.97	5.93 ± 2.24	91.9
Point 3	6.18 ± 2.94	5.60 ± 2.64	90.6
Point 4	6.5 ± 2.61	5.89 ± 2.32	90.6

S/H: soft to hard tissue ratio. Data are presented as mean ± SD.

Correlation between chin hard and soft tissue following orthognathic surgery

Figure 4 shows the correlation between the soft tissue chin and the underlying bone. The average ratio was 0.90, ranged from 0.87 to 0.94 (Table 5). Consequently, we investigated the relationship between soft tissue chin movement and underlying hard tissue movement and found a high correlation for all landmarks, with an average correlation of 0.927 and ranged from 0.88 to 0.99.

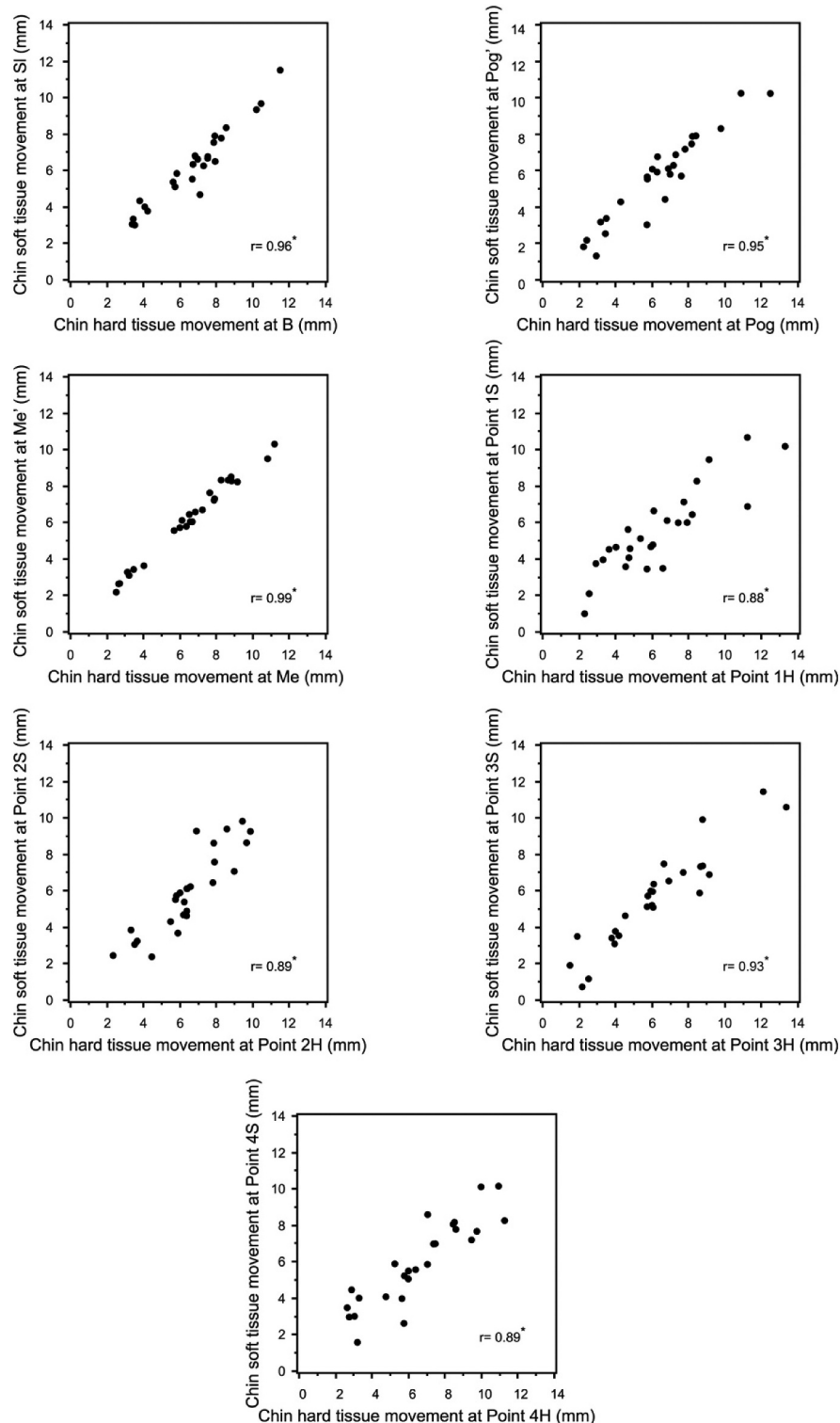


Figure 4. Correlation between 3-D chin soft tissue movements and underlying hard tissue movements, where r denotes the correlation coefficient of each plot. Statistical significance was set at $p < 0.05$.

Regression analysis

Table 6 presents the findings of the linear regression analysis. The R^2 value was high for SI, Pog', and Me' ranged from 0.9 to 0.98 ($p < 0.0001$) and medium to high R^2 values for the lateral points ranged from 0.77 to 0.87 ($p < 0.0001$).

Correlation between patient's age and soft tissue chin changes

No association exceeded $r > 0.5$ and no statistically significant correlation was observed between patient age and soft tissue chin changes including chin volume, chin surface area, and chin thicknesses at all points, as indicated in Table 7.

Effect of vertical characteristics on soft tissue chin changes

Based on the regression analysis (Table 8), the presurgical mandibular plane, occlusal plane, and lower facial height had no statistically significant relationship with soft tissue changes in chin volume, chin surface area, and chin thickness at the Pog and Me.

Discussion

The chin, a critical component of facial aesthetics, enormously affects facial harmony [27]. In addition, orthognathic surgery is a procedure that may alter the shape of soft tissue chin [28]. Therefore, investigating 3-D changes in the soft tissue chin after BSSO is essential for improving orthodontic treatment plans and patient-orthodontist communication.

The novel finding of the present study is that the chin volume and surface area are significantly increased after surgery. One possible explanation for this finding could be muscular relaxation in the strained mentalis and orbicularis oris after BSSO [29]. This may be explained by the fact that remained and loosened soft tissue on the bony chin could remain and accumulates in this area when the mandibular bone is set back [21]. A similar conclusion was reached by Filho et al. [28], who reported an average increase in the chin surface six months after two-jaw surgery.

We observed an increase in chin thickness at all points following surgery. However, only Pog' and Me' thicknesses were statistically significant. Previous investigations have been conducted to determine whether mandibular setback affects soft tissue thickness and have shown conflicting findings.

Table 6. Regression analysis predicting the 3-D movement of the soft tissue chin.

3-D soft chin region	Prediction formula	(R^2)	SE	t Ratio	p-value
SI	$Y = -0.05184 + 0.9340718 \times (X)$	0.92	0.053	17.50	<0.0001*
Pog	$Y = -0.09961 + 0.8941844 \times (X)$	0.90	0.06	14.59	<0.0001*
Me	$Y = 0.2465298 + 0.907086 \times (X)$	0.98	0.021	41.69	<0.0001*
Point 1S	$Y = 0.890264 + 0.7285782 \times (X)$	0.77	0.08	8.88	<0.0001*
Point 2S	$Y = -0.559161 + 1.005948 \times (X)$	0.78	0.10	9.38	<0.0001*
Point 3S	$Y = 0.419955 + 0.8377963 \times (X)$	0.87	0.065	12.74	<0.0001*
Point 4S	$Y = 0.7495606 + 0.7903777 \times (X)$	0.78	0.083	9.43	<0.0001*

Linear regression was calculated to predict the 3-D soft tissue chin movement according to its underlying hard tissue. Prediction formula: $Y = \beta_0 + \beta_1 \times (X)$. Y: represents the average of 3-D soft chin movement, (β_0): represents the intercept, (β_1): represents the regression coefficient, (X): represents the average of 3-D hard chin movement. R^2 : Coefficient of determination, Se: Standard Error. $p < 0.05$ is considered statistically significant.

Table 7. Pearson correlation analysis for age and soft tissue changes.

Variable	Soft tissue chin changes								
	Volume	Surface Area	Thick at B	Thick at Pog	Thick at Me	Thick at Point 1S	Thick at Point 2S	Thick at Point 3S	Thick at Point 4S
Age									
r	-0.13	-0.06	0.3	-0.04	-0.29	-0.01	-0.08	-0.03	-0.07
p	0.49	0.76	0.12	0.84	0.14	0.92	0.68	0.86	0.7

Pearson correlation analysis was used to evaluate the relationship between patient age and soft tissue chin change parameters used in the study. Thick: thickness, r denotes the correlation coefficient, and p denotes the correlation probability. Statistical significance was set at $p < 0.05$.

Table 8. Impact of vertical characteristics on changes of soft tissue chin.

Soft tissue chin changes	Variables Before Surgery								
	Mandibular plane			Occlusal plane			Lower facial height		
	R^2	SE	p	R^2	SE	p	R^2	SE	p
Volume (mm^3)	0.003	32.7	0.76	0.05	45.4	0.27	0.02	32.5	0.47
Surface Area (mm^2)	0.00	5.4	0.97	0.009	7.65	0.63	0.079	5.21	0.16
Thickness at Pog (mm)	0.11	0.02	0.09	0.07	0.04	0.17	0.08	0.03	0.14
Thickness at Me (mm)	0.03	0.02	0.34	0.06	0.03	0.20	0.01	0.02	0.56

Regression analysis was used to evaluate the relationship between the mandibular plane angle, occlusal plane, and lower facial height with soft tissue chin changes in volume, surface area, and thickness at the pogonion and menton. R^2 : Coefficient of determination; SE: standard error; p: correlation probability. $p < 0.05$ is considered statistically significant.

Our results are in line with those of Choi et al. [21], who showed that the thickness at the Pog increased significantly following bimaxillary surgery in high-angle groups. In contrast, point B' exhibited an average increase in thickness, which was not statistically significant. Ho et al. [29] remarked a significant increase in chin thickness not only at Pog' and Me' but also at B' following orthognathic surgery. This may be because their samples underwent a combination of mandibular setback surgery and vertical chin reduction genioplasty. In contrast, Naoumova et al. and Peng et al. [26,30] reported a decrease in point B thickness, accompanied by slight changes at Pog. These dissimilarities could result from the different methods of analysis and intergroup differences. In the present study, we found no significant difference in thickness between lateral landmarks. Moreover, the midpoints were thinner than the lateral points, which can be explained by differences in the chin level and location. As points approach the lateral region, which is known to be loose and thick, adhesion to the underlying bone stiffens and becomes less flexible [10]. This highlights the need to investigate the chin points at different levels.

The current study investigated the relationship between the soft tissue chin and its underlying hard tissue in 3-D following BSSO for mandibular setback. We found that changes in the soft tissue chin had a high positive correlation (0.90) with the underlying hard tissue at all points. The ratio of points B, Pog, and Me yielded a value of 0.91 (Table 5). Previous research has shown the same ratio at the same points [9]. However, another study indicated an almost 1:1 horizontal ratio for points B and Pog [7]. In contrast, other studies found a ratio of (0.73:1) for point B' [14,15,31], and a ratio of (0.69:1) for Pog' [15]. Pog in our study tends to display 0.87 to the corresponding hard tissue; This finding is consistent with that of a three-dimensional study conducted by Shi et al. [32] who reported that soft tissue changes relative to hard tissue in Pog were 86% following mandibular setback. These differences might be due to variations in the chin shape among the investigations.

Table 6 illustrates the outcome of the linear regression analysis, which was significant across all points. However, R^2 gained a greater value ($R^2 \geq 0.9$) for the central points compared to lateral points ($R^2 < 0.87$). Lo et al. [10] evaluated the correlation between soft and hard tissue and found that as the proportion of soft tissue changes relative to hard tissue movements gradually decreased towards the lateral side following surgical correction of class III jaw deformity. Koerich et al. [33] found that subchelion had smaller advancement when compared to soft tissue pogonion. The reason for this might be that the semicircular shape of the mandible causes soft tissue changes that tend to become smaller as it is farther from the midline [34].

Upon analyzing the influence of age on chin soft tissue changes, we found no significant relationship or good correlation coefficient between age and chin soft tissue parameters (Table 7). This outcome aligns with that of Jokic et al. [35], who found no correlation between patient age and soft tissue changes following orthognathic surgery.

Regression analysis indicated no significant impact of presurgical vertical characteristics on soft tissue chin changes after surgery (Table 8). These results may have been influenced by the population's biocharacteristics and sample size.

The main strength of this study was the use of 3-D evaluation that precisely determined and analyzed the shape and volume of the soft tissue chin in patients with skeletal class III malocclusion who underwent surgical orthodontic treatment with isolated mandibular setback surgery.

The present study has certain limitations that should be considered when interpreting the results. Because of the small sample size and the gender imbalance, we combined males and females in our analysis, which might impact the research outcome. Accordingly, it is crucial to conduct future research with a balanced male-female study and a larger sample size. It is imperative to conduct further research utilizing the current methodology in different populations to generalize the results, as our study was mainly conducted on the Japanese population. While CT scans are a valuable tool for 3-D evaluation even while the patients are in the natural position in the supine position. The difference between natural head posture in cephalograms and supine natural posture in 3-D CT would cause some misunderstanding.

Conclusion

Three-dimensional soft tissue chin showed a significant change in response to surgical orthodontic treatment in skeletal class III adult patients. These changes include soft tissue chin volume, surface area, and thickness of the pogonion and menton. The effects of age on soft tissue changes were not significant, and vertical characteristics before surgery did not significantly influence the changes in soft tissue. On this basis, creating a 3-D chin model using CT scans can be effectively applied as an evaluation procedure, and in the future, it would be useful for predicting the postoperative outcomes of orthognathic treatment.

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Disclosure statement

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Authors' contributions

Author 1 contributed to experimental investigation, methodology, data acquisition, statistics, original draft writing, conceptualization, review, and editing. Author 2,3,4,5 contributed to data acquisition and reviewed the final version before submission. Author 6 contributed to the conceptualization, project administration, methodology, writing, review, editing, and final approval of the manuscript. All authors read and approved the final manuscript.

Ethical approval

This study was approved by the Ethics Review Committee of the Faculty of Dental Science, Kyushu University, Fukuoka, Japan (Approval number: 23182–00).

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Supplementary Table 1. Cephalometric parameters used in the study.

Cephalometric parameters	Definition
Facial angle	The angle between Nasion-Pogonion line and Frankfurt Horizontal plane.
Convexity	The angle between Nasion-point A line and Pogonion-point A line.
A-B plane	The angle between Nasion-Pogonion line and point A- point B line.
Y-axis	The angle between Frankfurt Horizontal plane and Sella-Gnathion line.
SNA	The angle between Sella-Nasion line and Nasion-point A line.
SNB	The angle between Sella-Nasion line and Nasion-point B line.
ANB	The angle between Nasion-point A line and Nasion-point B line.
N-Pog to SN	The angle formed by Line passing through Sella Nasion to Nasion-Pogonion line.
Mandibular plane	The angle between Frankfurt horizontal plane and mandibular plane.
Occlusal plane	The angle formed by occlusal plane to Frankfurt Horizontal plane.
Gonial angle	The angle formed by the intersection of line tangent to the posterior border of the ramus and the mandibular plane.
U1 to SN	The angle between the long axis of upper incisor and Sella-Nasion line.
L1 to mandibular pl.	The angle between the long axis of lower incisor and the mandibular plane angle.
Interincisal angle	The angle formed by the long axis of the upper and lower incisors.
Wits	Line drawn perpendicular from points A and B into the occlusal plane and measured the distance between these two points.
Lower facial height	The distance between Anterior Nasal Spine and menton measured perpendicular to Frankfurt horizontal plane.
(Cd-Gn)-(Cd-A)	The differences between Condylion-Gnathion and Condylion-point A.

Supplementary Table 2. Cephalometric findings before and after surgery.

Cephalometric parameters	T1 (Mean ± SD)	T2 (Mean ± SD)	(T2-T1) differences	p value	Japanese Standard (Mean ± SD)
Facial angle	91.2 ± 3.1	87.7 ± 2.7	-3.5	<0.0001*	84.8 ± 3.1
Convexity	-4.4 ± 4.6	3.1 ± 4.3	7.6	<0.0001*	7.6 ± 5
A-B plane	3.2 ± 2.1	-3.3 ± 2.1	-6.6	<0.0001*	-4.8 ± 3.5
Y-axis	60.7 ± 3.2	63.4 ± 3.0	2.6	<0.0001*	65.4 ± 5.6
SNA	81.3 ± 3.5	81.4 ± 3.7	0.1	0.07	82.3 ± 3.5
SNB	83.5 ± 3.4	79.4 ± 3.0	-4.1	<0.0001*	78.9 ± 3.5
ANB	-2.2 ± 1.5	2.0 ± 1.4	4.2	<0.0001*	3.4 ± 1.8
N-Pog to SN	83.5 ± 3.4	79.8 ± 3.2	-3.6	<0.0001*	77.0 ± 3.6
Mandibular plane	27.7 ± 5.1	28.5 ± 4.3	0.7	0.1	28.8 ± 5.2
Occlusal plane	9.8 ± 3.6	9.48 ± 2.8	-0.3	0.4	9.5 ± 4
Gonial angle	127.0 ± 6.2	125.0 ± 7.1	-2.0	0.06	131.0 ± 5.6
U1 to SN	108.2 ± 5.0	107.8 ± 5.2	-0.3	0.6	104.5 ± 5.6
L1 to mandibular pl.	93.1 ± 4.6	90.6 ± 5.3	-2.5	0.002*	96.3 ± 5.8
Interincisal angle	123.0 ± 6.1	125.0 ± 6.8	2.0	0.1	124.1 ± 7.6
Wits, mm	-11.4 ± 2.3	-2.9 ± 2.6	8.5	<0.0001*	-5~0
Lower facial height	73.5 ± 5.1	73.2 ± 5.6	-0.3	0.6	72.2 ± 3.7
(Cd-Gn)-(Cd-A), mm	42.2 ± 4.6	36.8 ± 4.9	-5.3	<0.0001*	25~30

Data are presented as mean ± SD. Paired t-test was used to compare cephalometric values before and after surgery. p<0.05 is considered statistically significant.