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Three-Dimensional Change of Lip after Two-Jaw Surgery in Facial Asymmetry Using Facial Scanner

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Abstract: A facial scanner and three-dimensional computed tomography (CT) were used to evaluate the three-dimensional change in lip asymmetry before and after two-jaw surgery for 22 patients with facial asymmetry (menton deviation > 3 mm). We used the labrale superius (Ls), deviated/non-deviated-side cheilions (Ch-D/Ch-ND), and labrale inferius (Li) to construct the upper and lower lip planes to evaluate the lip asymmetry. A correlation analysis was performed to determine the factors related to the vertical change in the cheilions (ΔChZ-D/ND). In the transverse axis, Ch-D and Li moved to improve the asymmetry after surgery. All landmarks, except the Ls, moved backward in the anteroposterior axis. In the vertical axis, significant upward movement was observed in all hard tissue landmarks; however, there were no significant changes in the soft tissue. In the lip plane, the difference in the height of Ch-D and Ch-ND was significantly reduced (1.38 mm vs. 0.72 mm). In the anteroposterior axis, the ΔChZ-D/ND showed significant correlations with the mandibular setback. In the vertical axis, the ΔCh-ND showed significant correlations with the maxillary impaction of the non-deviated side. The improvement in lip asymmetry post-surgery was mainly achieved by the movement of the lower lip and Ch-D rather than the upper lip and Ch-ND.

Keywords: lip asymmetry; two-jaw surgery; three-dimensional CT; facial scanner

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1. Introduction

A jaw deformity with facial asymmetry is frequently accompanied by asymmetry of the lips, which can affect patients' quality of life [1]. Lip asymmetry is a highly visible component of the facial configuration and is often a patient's major complaint [2]. Asymmetry of the lips is defined as the difference in height between the labial commissures on each side, with distorted vermilion borders of the upper and lower lips and deviations between the midlines of the mouth and face [3]. Wang et al. [4] found that patients were more sensitive to asymmetries of the eyelid, brow, and oral commissure than to nasal tip and chin deformities. Therefore, to restore facial symmetry, it is more effective to correct the eyelid, brow, and oral commissure. Although several studies have suggested that the lip cant can be corrected with orthognathic surgery [5–10], few researchers have evaluated the three-dimensional (3D) changes in lip asymmetry after two-jaw surgery.

Traditionally, a two-dimensional analysis with frontal photographs and posteroanterior (PA) cephalograms is used to evaluate cant corrections [5,9]. However, these methods have unavoidable projection errors, including magnification and distortion, and landmark identification errors due to the superimposition of dentofacial structures [11,12]. Over the years, 3D computed tomography (CT) has been used for the diagnosis and quantitative evaluation of hard and soft tissue changes in the face following orthognathic surgery [6,8,10,13]. However, soft tissue images obtained from CT imaging have a low resolution, a long scanning time, and lack skin color and texture, resulting in less than ideal accuracy [14].

Recently, some studies have merged 3D facial surface scans with CT images [6,13,15]. Using the structured light scanning system, texture and color information on the facial skin can be readily obtained at a high resolution without additional radiation hazards, together with advantages such as a short scan time and no hazard to the naked eye [16]. Considering these advantages, the use of a 3D facial scan in conjunction with a 3D CT can be an effective tool in evaluating hard and soft tissue changes after orthognathic surgery [6].

The purpose of this study was to evaluate the 3D change in lip asymmetry after two-jaw orthognathic surgery in patients with facial asymmetry using a facial scanner (FS) and 3D CT. The null hypothesis was that there would be no significant change in lip asymmetry after two-jaw orthognathic surgery in patients with facial asymmetry.

2. Materials and Methods

This retrospective study was approved by the regional Ethical Review Board of Yonsei Dental Hospital Institutional Review Board (IRB No.: 2-2022-0004). The study comprised 22 patients (10 men and 12 women, with a mean age of 23.8 ± 5.8 years) who underwent two-jaw orthognathic surgeries between 2018 and 2020 at the Department of Oral and Maxillofacial Surgery, Yonsei Dental Hospital. The inclusion criteria were as follows: patients diagnosed with skeletal class I or class III facial asymmetry (menton deviation > 3 mm) [17], patients with a menton deviation that coincided with the side of the upward maxillary occlusal plane cant (ipsilateral asymmetry) [18], patients who underwent two-jaw surgery (single-segment LeFort I osteotomy combined with bilateral intraoral vertical ramus osteotomy) performed by a single surgeon, and patients who underwent imaging using 3D CT and FS one month prior to (T1) and at least one month after (T2) orthognathic surgery (CT, mean 2.0 ± 0.9 month; FS, mean 3.1 ± 0.9 month) (Table 1). Patients with congenital craniofacial anomalies, such as cleft lip and palate, or with a missing maxillary canine or first molar were excluded.

Table 1. Patient characteristics.

	Class I (n = 8)	**Class III (n = 14)**
Age (y)	22.8 ± 4.8	24.4 ± 6.3
Sex, Male	3	8
Female	5	6
ANB (°)	2.4 ± 1.5	−2.1 ± 1.4
Me * (mm)	6.4 ± 5.4	4.7 ± 3.6

* The Mann–Whitney U test was performed. The menton deviation did not differ significantly between class I and class III patients ($p > 0.05$). Abbreviations: ANB, A point–nasion–B point; Me, menton.

2.1. Data Acquisition

The 3D CT image data were obtained with a High-Speed Advantage CT (512 × 512 matrix, 120 kV, and 200 mA; Milwaukee, WI, USA). The FS images were obtained using a white-structured light scanner, Morpheus 3D (scan time 0.8 s, scan accuracy 0.1 mm; Morpheus Co, Ltd., Seoul, Korea).

2.2. Landmarks and Coordinate System

In the CT images, three reference planes were constructed for a 3D coordinate system: the horizontal plane (Frankfort horizontal plane connecting both side orbitales and the right porion) [19], the midsagittal plane (a perpendicular plane passing through the nasion and the basion positioned perpendicular to the horizontal plane), and the coronal plane (perpendicular to the previous two planes and passing the nasion). The origin point (0, 0, 0) was set at the nasion point. A positive (+) sign indicated the menton-deviated side and the anterior and superior side of the patient. A negative (−) sign indicated the opposite side.

2.3. Superimposition Process

To use the same 3D coordinate system for the CT image, the preoperative (T1) FS image was registered on the CT image using Geomagic Design X software (3D Systems, Morrisville, NC, USA). For an initial register, seven landmarks (right and left exocanthions (Ex), right and left endocanthions (En), right and left nasal alas (Al), and soft tissue nasion (N′)) were used as reference points to superimpose the T1 CT and T1 FS images. Subsequently, the iterative closest point algorithm was used for fine registration with the seven reference points, the wide surface of the forehead, and the dorsum of the nose. Finally, the superimposed 3D images with the same coordinate system were imported into the Morpheus system (Figure 1) [20].

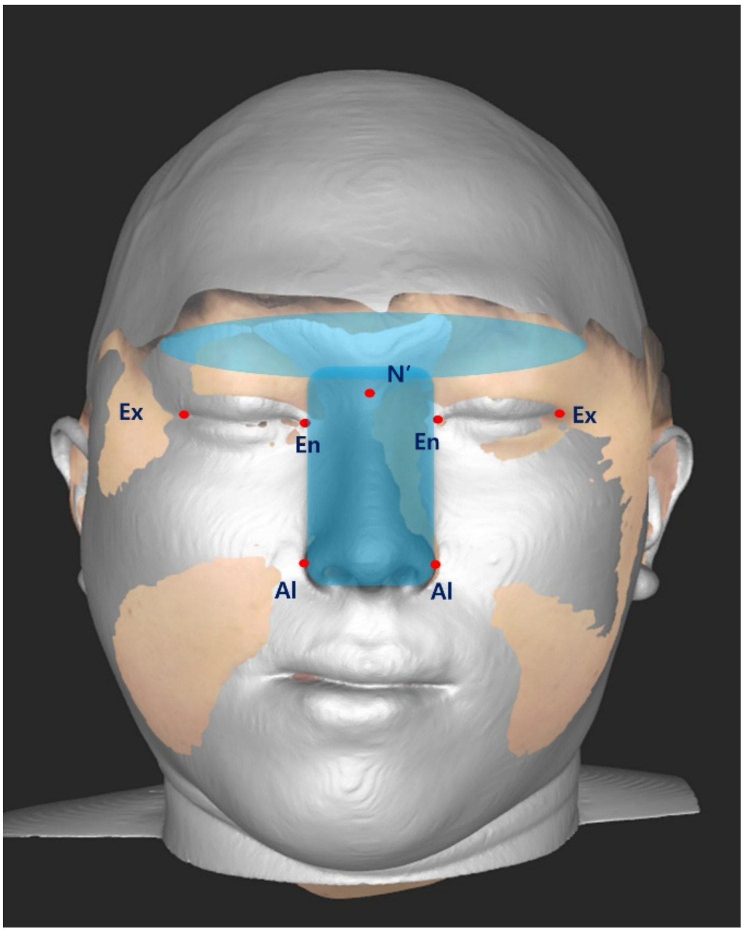

Figure 1. Registration of preoperative (T1) CT and FS images. The references used for superimposition were the forehead and the dorsum of the nose area (blue color), exocanthions, endocanthions, and nasal alas: N′, soft tissue nasion; Ex, exocanthion; En, endocanthion; Al, nasal ala; CT, computed tomography; and FS, facial scanner.

For hard tissue superimposition, the T1 and T2 Digital imaging and Communications in Medicine (DICOM) images of each patient were imported, and voxel-based registration was performed on the anterior cranial base to exclude the volume of the jaw affected by orthognathic surgery using Ondemand3D software (CyberMed Inc., Seoul, Korea). For soft tissue superimposition, the T1 and T2 FS images of each patient were imported, and the registration was carried out using Morpheus 3D (Morpheus, Seoul, Korea) software with five reference points (right and left Ex, right and left En, and N′) and the wide surface of the forehead and nasal bridge (Figure 2).

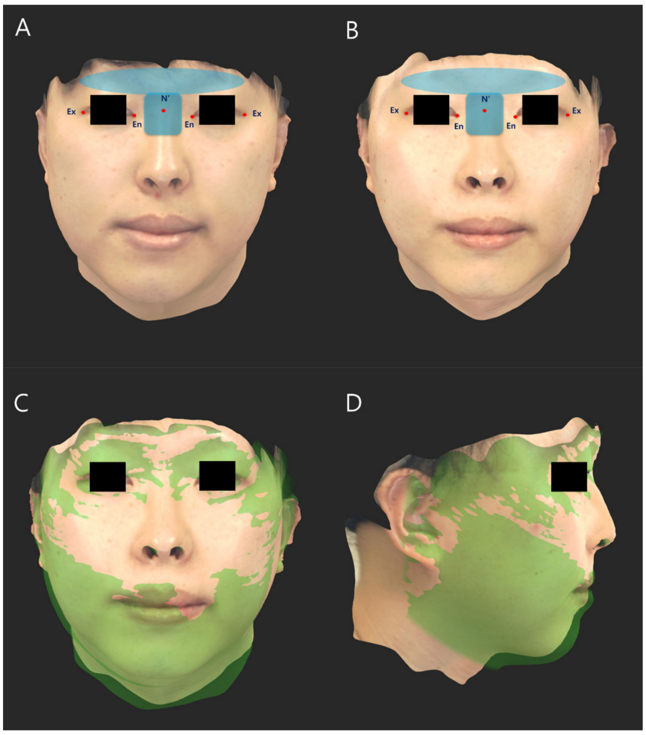

Figure 2. Superimposition of preoperative (T1) and postoperative (T2) images of the facial scanner. The references used for superimposition were the forehead and nasal bridge area (blue color), exocanthions, endocanthions, and nasal alas. (**A**) Preoperative FS image, (**B**) postoperative FS image, and (**C**,**D**) superimposed images. N′, soft tissue nasion; Ex, exocanthion; En, endocanthion; and Al, nasal ala.

A total of 11 landmarks were identified (Figure 3, Table 2) and measured in the 3D coordinate system before (T1) and after (T2) surgery using Ondemand3D and Morpheus 3D software. The changes in all landmarks were evaluated in the transverse (x), anteroposterior (y), and vertical axes (z).

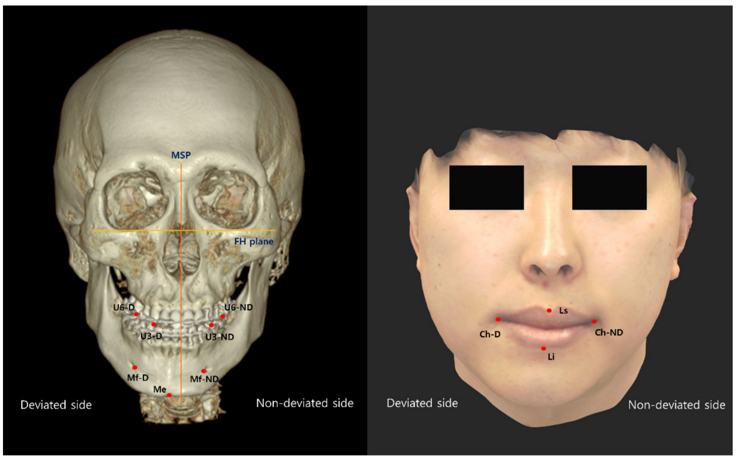

Figure 3. Hard tissue and soft tissue landmarks used in this study. MSP, midsagittal plane; U3-D/ND, maxillary canine cusp tip on the deviated side/non-deviated side; U6-D/ND, maxillary 1st molar mesiobuccal cusp tip on the deviated side/non-deviated side; Mf-D/ND, mental foramen on the deviated side/non-deviated side; Me, menton; Ls, labrale superius; Li, labrale inferius; and Ch-D/ND, cheilion on the deviated side/non-deviated side.

Table 2. Landmarks and reference planes used in this study.

Reference	Definition
Hard tissue landmarks	
Nasion (Na)	The most anterior point of the frontonasal suture in the midsagittal plane
Orbitale (Or)	The most inferior point of the lower margin of the bony orbit
Porion (Por)	The most superior point of the external auditory meatus
Upper canine (U3-D/ND)	Maxillary canine cusp tip on the deviated side (D)/non-deviated side (ND)
Upper 1st molar (U6-D/ND)	Maxillary 1st molar mesiobuccal cusp tip on the deviated side (D)/non-deviated side (ND)
Mental foramen (Mf-D/ND)	The most inferior point on the lower edge of the mental foramen on the deviated side (D)/non-deviated side (ND)
Menton (Me)	The most inferior point in the middle of the mandibular chin in the frontal plane
Soft tissue landmarks	
Cheilion (Ch-D/ND)	The most lateral extent of the outline of the lip in the deviated side (D)/non-deviated side (ND)
Labrale superius (Ls)	The midpoint of the upper vermilion line
Labrale inferius (Li)	The midpoint of the lower vermilion line
Reference planes	
Horizontal plane	A plane constructed with both side orbitales and right porion (Frankfort horizontal (FH) plane)
Midsagittal plane (MSP)	A plane passing through the nasion and the basion as well as positioned perpendicular to the horizontal plane
Coronal plane	A plane positioned perpendicular to the horizontal and midsagittal planes as well as passing the nasion

The lip planes were constructed to simplify and effectively evaluate their three-dimensional changes. The upper lip planes were established by connecting both sides of the cheilion (Ch) and labrale superius (Ls). The lower lip planes were also established by connecting both sides of the Ch and labrale inferius (Li). Three-dimensional changes in the lip planes before and after surgery were evaluated in the coronal, sagittal, and axial planes (Figure 4).

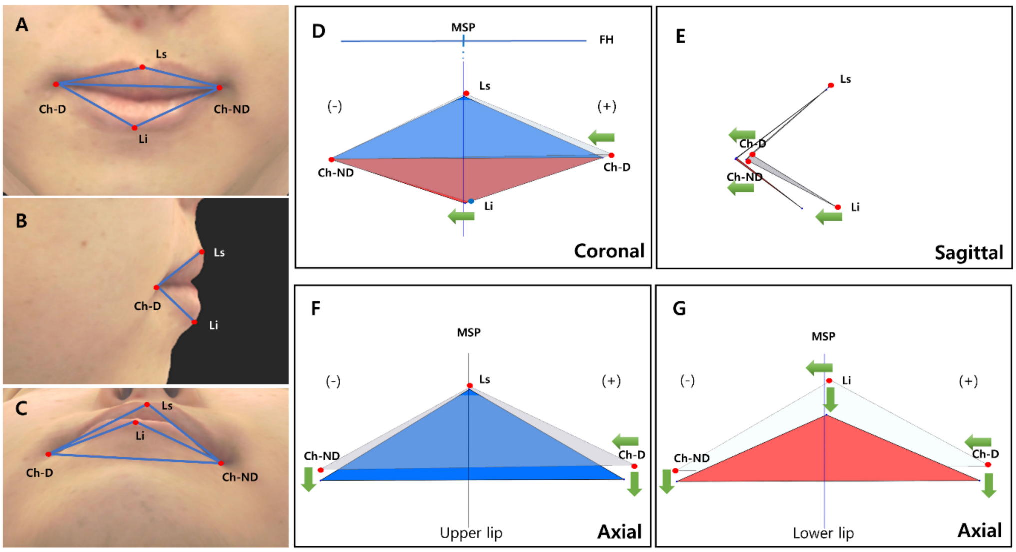

Figure 4. Changes in the upper and lower lip planes. The upper lip plane was established by connecting both sides of the Ch and Ls. The lower lip planes were also established by connecting both sides of the Ch and Li. (**A**–**C**) The lip planes on the FS images, (**D**) The coronal view of the lip planes, (**E**) The sagittal view of the lip planes, (**F**) The axial view of the upper lip plane, (**G**) The axial view of the lower lip plane. Green arrows indicate significant changes in the landmarks. MSP, midsagittal plane; FH, Frankfort horizontal plane; Ls, labrale superius; Ch-D/ND, cheilion on deviated side/non-deviated side; Li, labrale inferius; and Ls, labrale superius.

In addition, a correlation analysis was performed to ascertain the factors related to the vertical change in the corner of the mouth post-surgery. The correlation coefficients (p) between the vertical changes in both sides of the Ch and the changes in the hard tissue landmarks were evaluated in the transverse, anteroposterior, and vertical axes.

2.4. Statistical Analysis

For reproducibility, all the variables from ten randomly selected participants were reobtained by the same operator after two weeks, and the intraclass correlation coefficients (ICCs) were calculated. The ICCs of all the values indicated sufficient reproducibility (hard tissue, 0.966; soft tissue, 0.978); therefore, the first data set was used in the current study.

All statistical analyses were performed using SPSS (ver. 26.0; IBM Korea Inc, Seoul, Korea). The Mann–Whitney *U* test was performed for non-normally distributed data. After confirming the normality of the data distribution using the Shapiro–Wilk test, a paired *t*-test was used to evaluate the changes in landmarks before and after surgery for each patient. A Pearson's correlation analysis was also performed to determine the factors related to the vertical change of the cheilions. The level of significance was set at $p < 0.05$.

We used G*Power 3 (Heinrich Heine University, Dusseldorf, Germany) to calculate the sample size. Based on a preliminary study [21], we obtained a minimum sample size of 15 at a significance level of $p < 0.05$, power of 80%, and effect size of 0.8 to detect differences in hard and soft tissue landmark changes before and after surgery using a paired *t*-test. The retrospective data of all 22 patients who met the inclusion criteria were selected for analysis.

3. Results

There were no significant differences in the menton (Me) deviations between class I and class III patients (Table 1, $p > 0.05$).

3.1. Changes in Hard and Soft Tissue Variables between the T1 and T2 Stages

In the transverse axis, most of the hard tissue landmarks tended to move toward improving the asymmetry. Among the hard tissue landmarks, there were more significant changes in landmarks related to the mandible (Mf-D, Mf-ND, Me, all $p < 0.001$, Table 3) than in other landmarks. Among the soft tissue landmarks, Ch-D ($p < 0.01$) and Li ($p < 0.05$) moved toward the midsagittal plane (MSP), thus improving the asymmetry significantly (Table 3). There were significant changes in the hard and soft tissue landmarks in the anteroposterior axis. All landmarks, except for the Ls, moved backward following the surgery ($p < 0.05$, Table 3).

In the vertical axis, significant upward movement was observed in all hard tissue landmarks ($p < 0.05$, Table 3). The upward movement of the landmarks on the non-deviated side was greater than the upward movement on the deviated side in hard tissue. However, there were no significant changes in the soft tissue landmarks, although there was a tendency toward downward movement for the Ch-D and upward movement for the Ch-ND.

3.2. Changes in the Upper and Lower Lip Planes

In the coronal plane, as the Li moved significantly toward the MSP after surgery, the difference in the deviations of the Ls and Li from the MSP decreased. In the sagittal plane, the Ls did not show significant backward movement, whereas Ch-D, Ch-ND, and Li moved backward significantly, and there was more backward movement of Li than of Ch-D and Ch-ND. In the axial plane evaluation, the change in the lower labial plane was greater than that in the upper labial plane owing to the significant movement of the Li (Figure 4 and Table 3).

The lip asymmetry and width were evaluated in the transverse, vertical, and anteroposterior axes (Figure 5 and Table 4). In the transverse axis, the difference in distance from the MSP to the Ch-D and Ch-ND (transverse lip asymmetry) significantly decreased after surgery (2.72 mm vs. 1.19 mm, $p < 0.05$).

Table 3. Changes in hard and soft tissue landmarks on 3D CT and FS images between the T1 and T2 stages.

Landmarks	Δx (T2-T1)			Δy (T2-T1)			Δz (T2-T1)		
	Mean	SD	*p* Value	Mean	SD	*p* Value	Mean	SD	*p* Value
Hard tissue									
U3-D	−0.65	1.40	0.040 *	−1.82	2.11	0.001 **	0.93	1.72	0.020 *
U3-ND	−0.55	1.67	0.170	−1.4	2.23	0.008 **	1.65	1.94	0.001 **
U6-D	−0.35	1.65	0.338	−1.73	2.36	0.002 **	2.31	1.37	0.000 ***
U6-ND	−1.30	1.64	0.001 **	−1.03	2.30	0.048 *	3.17	1.35	0.000 ***
Mf-D	−3.19	2.76	0.000 ***	−6.14	4.76	0.000 ***	3.21	2.90	0.000 ***
Mf-ND	−3.28	2.74	0.000 ***	−7.25	4.88	0.000 ***	4.67	2.36	0.000 ***
Me	−3.69	3.14	0.000 ***	−6.20	4.76	0.000 ***	4.30	3.09	0.000 ***
Soft tissue									
Ls	−0.20	1.35	0.499	−0.36	1.55	0.286	−0.44	1.28	0.123
Ch-D	−1.68	2.40	0.004 **	−2.27	2.73	0.001 **	−0.57	1.93	0.178
Ch-ND	0.16	1.75	0.678	−1.69	2.72	0.008 **	0.09	2.38	0.864
Li	−0.72	1.48	0.032 *	−5.43	3.42	0.000 ***	0.25	2.13	0.590

The paired *t*-test was performed. SD indicates standard deviation. * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Δx, Δy, and Δz means changes in the transverse, anteroposterior, and vertical axes, respectively. Abbreviations: U3-D/ND, maxillary canine cusp tip on deviated side/non-deviated side; U6-D/ND, maxillary 1st molar mesiobuccal cusp tip on the deviated side/non-deviated side; Mf-D/ND, mental foramen on the deviated side/non-deviated side; Me, menton; Ls, labrale superius; Ch-D/ND, cheilion on the deviated side/non-deviated side; Li, labrale inferius; FS, facial scanner; CT, computed tomography; and 3D, three-dimensional.

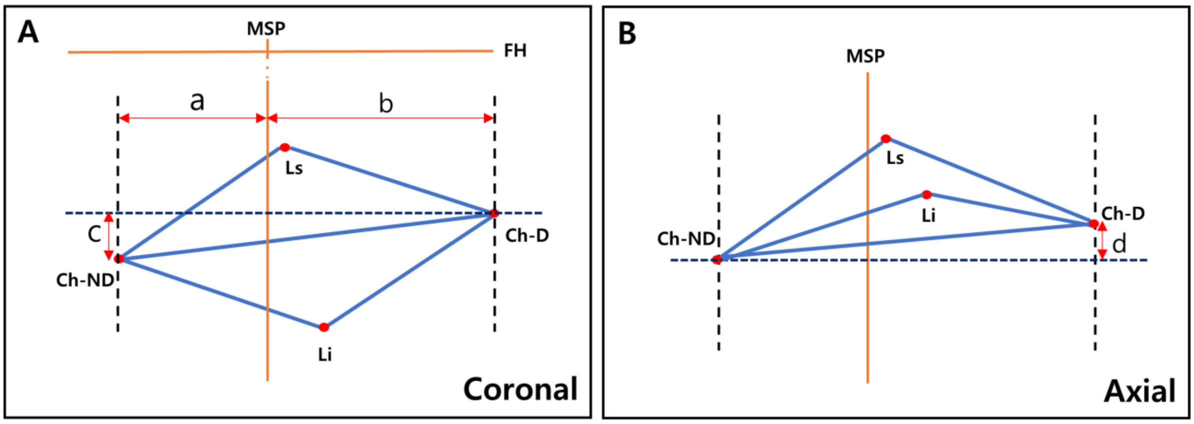

Figure 5. Schematic diagram of the upper and lower lip planes. (**A**) The coronal view of schematic diagram, (**B**) The axial view of schematic diagram. Abbreviations: MSP, midsagittal plane; FH, Frankfort horizontal plane; Ls, labrale superius; Ch-D/ND, cheilion on the deviated side/non-deviated side; Li, labrale inferius; b − a, transverse lip asymmetry; a + b, lip width; c, vertical lip asymmetry; and d, anteroposterior lip asymmetry.

In the vertical axis, the difference in the height of the Ch-D and Ch-ND (vertical lip asymmetry) was significantly reduced after surgery (1.38 mm vs. 0.72 mm, $p < 0.01$). In the anteroposterior axis, as the mean backward movement of the Ch-D was larger than that of Ch-ND, there was a tendency for anteroposterior lip asymmetry to improve; however, this was not statistically significant. The lip width can be defined as the sum of the distances from the MSP to the Ch-D and from the MSP to the Ch-ND. Since there was no significant transverse movement of Ch-ND, while there was a significant movement of Ch-D toward the MSP (Table 3), the lip width was significantly decreased after surgery (49.71 mm vs. 47.87 mm, $p < 0.01$).

3.3. Correlation between the Vertical Changes in Cheilions and the Changes in Other Variables

In the transverse axis, there were no significant correlations between the vertical changes in the cheilions (ΔChZ-D/ND) and the changes in all the other landmarks ($p > 0.05$, Table 5). In the anteroposterior axis, ΔChZ-D/ND showed significant correlations with changes in the landmarks related to the mandible (MfY-ND, MeY, all $p < 0.05$, Table 6) and ΔU6Y-D ($p < 0.05$, Table 6). In the vertical axis, ΔChZ-ND showed significant correlations with ΔU3Z-ND ($p < 0.05$, Table 7) and ΔU6Z-ND ($p < 0.01$, Table 7).

Table 4. Changes in distance from the deviated side cheilion to the non-deviated side cheilion after surgery.

	T1		T2		
	Mean	**SD**	**Mean**	**SD**	***p* Value**
$\lvert ChX_D \rvert - \lvert ChX_{ND} \rvert$ (mm) (transverse asymmetry)	2.72	2.81	1.19	3.05	0.030 *
$\lvert ChX_D \rvert + \lvert ChX_{ND} \rvert$ (mm) (lip width)	49.71	4.41	47.87	3.78	0.007 **
$\lvert ChY_D \rvert - \lvert ChY_{ND} \rvert$ (mm) (anteroposterior asymmetry)	0.75	2.13	0.17	1.57	0.123
$\lvert ChZ_D \rvert - \lvert ChZ_{ND} \rvert$ (mm) (vertical asymmetry)	1.38	0.80	0.72	0.53	0.005 **

The paired *t*-test was performed. SD indicates standard deviation. * $p < 0.05$ and ** $p < 0.01$. Abbreviations: $\lvert ChX_{D/ND} \rvert$, distance from the midsagittal plane (MSP) to the cheilion on the deviated side/non-deviated side in the transverse axis; $\lvert ChY_{D/ND} \rvert$, distance from the MSP to the cheilion on the deviated side/non-deviated side in the anteroposterior axis; and $\lvert ChZ_{D/ND} \rvert$, distance from the MSP to the cheilion on the deviated side/non-deviated side in the vertical axis.

Table 5. Correlation between the vertical changes in the cheilions (ΔChZ-D/ND) and the changes in other variables in the transverse direction.

		ΔU3X-D	**ΔU3X-ND**	**ΔU6X-D**	**ΔU6X-ND**	**ΔMfX-D**	**ΔMfX-ND**	**ΔMeX**
ΔChZ-D	Pearson's correlation coefficient	−0.157	−0.160	−0.083	−0.252	−0.063	−0.026	−0.108
	p	0.485	0.476	0.714	0.258	0.780	0.909	0.634
ΔChZ-ND	Pearson's correlation coefficient	−0.132	−0.236	−0.165	−0.266	−0.170	−0.080	−0.247
	p	0.558	0.291	0.462	0.232	0.449	0.723	0.268

Pearson's correlation test was performed. X, transverse axis coordinate value; Z, vertical axis coordinate value. Abbreviations: U3X-D/ND, maxillary canine cusp tip on the deviated side/non-deviated side; U6X-D/ND, maxillary 1st molar mesiobuccal cusp tip on the deviated side/non-deviated side; MfX-D/ND, mental foramen on the deviated side/non-deviated side; MeX, menton; and ChZ-D/ND, cheilion on the deviated side/non-deviated side.

Table 6. Correlation between the vertical changes in the cheilions (ΔChZ-D/ND) and the changes in other variables in the anteroposterior direction.

		ΔU3Y-D	**ΔU3Y-ND**	**ΔU6Y-D**	**ΔU6Y-ND**	**ΔMfY-D**	**ΔMfY-ND**	**ΔMeY**
ΔChZ-D	Pearson's correlation coefficient	0.377	0.343	0.555	0.311	0.404	0.440	0.433
	p	0.080	0.070	0.007 **	0.159	0.062	0.040 *	0.044 *
ΔChZ-ND	Pearson's correlation coefficient	0.319	0.319	0.464	0.268	0.405	0.438	0.452
	p	0.148	0.148	0.030 *	0.197	0.061	0.041 *	0.035 *

Pearson's correlation test was performed. * $p < 0.05$ and ** $p < 0.01$. Y, anteroposterior axis coordinate value; Z, vertical axis coordinate value. Abbreviations: U3Y-D/ND, maxillary canine cusp tip on the deviated side/non-deviated side; U6Y-D/ND, maxillary 1st molar mesiobuccal cusp tip on the deviated side/non-deviated side; MfY-D/ND, mental foramen on the deviated side/non-deviated side; MeY, menton; and ChZ-D/ND, cheilion on the deviated side/non-deviated side.

Table 7. Correlation between the vertical changes in the cheilions (ΔChZ-D/ND) and the changes in other variables in the vertical direction.

		ΔU3Z-D	ΔU3Z-ND	ΔU6Z-D	ΔU6Z-ND	ΔMfZ-D	ΔMfZ-ND	ΔMeZ
ΔChZ-D	Pearson's correlation coefficient	0.298	0.343	0.073	0.337	−0.095	0.083	0.071
	p	0.178	0.118	0.748	0.125	0.673	0.715	0.752
ΔChZ-ND	Pearson's correlation coefficient	0.309	0.488	−0.015	0.550	−0.128	0.014	0.144
	p	0.162	0.021 *	0.949	0.008 **	0.571	0.951	0.522

Pearson's correlation test was performed. * $p < 0.05$ and ** $p < 0.01$. Z, vertical axis coordinate value. Abbreviations: U3Z-D/ND, maxillary canine cusp tip on the deviated side/non-deviated side; U6Z-D/ND, maxillary 1st molar mesiobuccal cusp tip on the deviated side/non-deviated side; MfZ-D/ND, mental foramen on the deviated side/non-deviated side; MeZ, menton; and ChZ-D/ND, cheilion on the deviated side/non-deviated side.

4. Discussion

The purpose of the present study was to evaluate the 3D changes in lip asymmetry after two-jaw surgery in patients with facial asymmetry using FS and three-dimensional CT. We found that, in the transverse axes, most hard tissue landmarks, especially those related to the mandible (Mf-D, Mf-ND, and Me), and the soft tissue landmarks Ch-D and Li moved toward significantly improving asymmetry after surgery (Figure 4 and Table 3); that the anteroposterior movements of the landmarks related to the mandible (MfY-ND and MeY) and the ΔU6Y-D correlated with the ΔChZ-D/ND; and in the vertical axis, the ΔChZ-ND showed significant correlations with the ΔU3Z-ND and ΔU6Z-ND (Tables 6 and 7). These results demonstrated that lip asymmetry can be improved by two-jaw surgery, and the null hypothesis was rejected.

To evaluate the changes in the hard tissue after orthodontic surgery, several researchers have analyzed the changes in the landmarks on teeth or orthodontic brackets by superimposing CT images [6–8,10,13,22]. Some of these studies used CT images taken six months after surgery to evaluate the changes in both hard and soft tissues [10,13,22]. In general, post-surgical orthodontic treatment begins 2–6 weeks after surgery; therefore, the changes in these landmarks could also be affected by orthodontic treatment. According to our protocol, the evaluation of post-operative hard tissue stabilization began 4 weeks after orthognathic surgery, and facial scanning was performed to evaluate soft tissue changes in consideration of individual differences in each patient. Several studies reported that facial morphology recovers to approximately 83~90% within 3 months following surgery [23,24], although many studies suggest that the soft tissues stabilize 6 months after surgery [25]. The timing of the soft tissue evaluation remains controversial. In this study, we intended to evaluate the changes in the hard tissue landmarks by orthognathic surgery rather than the change caused by orthodontic treatment. For this reason, the amount of change in the hard tissue was evaluated using CT images at least one month (mean 2.0 $\pm$ 0.9 months) after surgery, and the amount of change in the soft tissue was evaluated using FS images approximately three months (mean 3.1 $\pm$ 0.9 months) after surgery. To reduce patient radiation exposure, it is recommended to avoid using CT on patients to obtain data that can be provided by alternate non-ionizing modalities [26]; therefore, this method using CT and FS can be utilized to evaluate hard and soft tissues before and after orthognathic surgery.

Lip asymmetry in patients with facial asymmetry appears as a 3D distortion in the shape of the lips. However, the evaluation of changes in the lips after orthognathic surgery has mainly focused on the correction of the lip cant [6,8,22]. In this study, we analyzed the lip planes in the coronal, sagittal, and axial views to evaluate the 3D changes in the lips.

Regarding changes in the coronal plane of the lip, as Ch-D moved toward the MSP, the difference in the distance from the MSP to the Ch-D and Ch-ND significantly decreased post-surgery, which is consistent with the findings of Kwon et al. [8]. As a result of these differential movements of Ch-D/ND, the lip width was reduced, which is consistent with the findings reported by Xu et al. [27]. Assuming that transverse lip asymmetry is the difference in the distance from the MSP to the Ch-D and Ch-ND in the transverse axis, the difference was significantly reduced after surgery, indicating that the asymmetry had improved (Table 4).

Assuming that vertical lip asymmetry is the difference in the height of the Ch-D and Ch-ND in the vertical axis, this means that lip canting improved significantly after surgery (Table 4). One of the study methods to evaluate the change in lip cant after orthognathic surgery was to analyze the correlation between the amount of lip cant before and after surgery (e.g., the lip line cant changed from 3.18°, 1.91 mm to 0.75°, −0.25 mm after surgery) [8,22,28]. However, in these studies, it was difficult to evaluate whether the correction of the lip cant was due to the downward movement of the deviated-side cheilion or the upward movement of the non-deviated-side cheilion. Another method used to evaluate the change in lip cant was to analyze the change in the distance from the reference plane to the deviated- and non-deviated-side cheilions after orthognathic surgery [6,10,20]. In this study, the evaluation was performed according to this method. To investigate the factors affecting the vertical position of the cheilion (ΔChZ-D/ND) after orthognathic surgery, a correlation analysis was performed with the change in the hard tissue landmarks in each direction (transverse, anteroposterior, and vertical). As a result, it was found that there was no correlation between the transverse movement of the hard tissue and the ΔChZ-D/ND; there was a significant correlation between the mandibular differential setback and the downward movement of the cheilions; and there was a significant correlation between the impaction of the non-deviated side of the maxilla and the upward movement of the non-deviated side of the cheilion (Tables 6 and 7).

Several studies evaluating the vertical movement of the cheilion after orthognathic surgery in patients with class III skeletal asymmetry showed that the cheilion moved downward according to the setback of the mandible [20,29,30]. In addition, Ko et al. and Jung et al. reported that there was significant downward movement of the deviated-side cheilion after orthognathic surgery in patients with class III facial asymmetry [6,10].

This study was conducted on patients diagnosed with skeletal class I or class III facial asymmetry who had a maxillary occlusal plane cant. To improve facial asymmetry, the impaction of the non-deviated side of the maxilla and the differential setback of the mandible were commonly performed; thus, the patients were analyzed together without dividing them into class I and class III groups. In this study, although there was a significant correction of the lip cant due to the decrease in the vertical difference between the deviated- and non-deviated-side cheilions after surgery, the average vertical change of the cheilion on each side was not statistically significant (Tables 3 and 4). It seems that these results might be reflective of the present study cohort, which comprised patients with both class I and class III asymmetry (Table 1). Although the downward movement of the cheilions was more pronounced in class III patients because of the mandibular setback, in class I patients, the amount of maxillary impaction, including the non-deviated side, was relatively higher than the amount of mandibular setback. Accordingly, there was a tendency toward upward movement in the cheilions of some class I patients.

In the current study, there were significant correlations between the backward movement of U6-D and the downward movement of the cheilions (Table 6). In terms of surgical movement of the maxilla in patients with facial asymmetry, the cant correction was performed by impaction of the non-deviated side more than that of the deviated side. According to this differential impaction of the maxilla, the upper dental midline could be shifted to the non-deviated side, and it can be considered that the yawing of the maxilla was planned to compensate for this shift and to establish symmetry. As a result, U6-D moved backward more than U6-ND, suggesting that there were significant correlations.

The orbicularis oris muscle itself is not connected to the jawbone, instead displaying a structure resembling a rubber band [31]. Muscles originating from the maxilla and mandible adhere to the skin of the lips, resulting in changes in the orientation of those muscle fibers in cases with deviations of the mandible and maxilla [32]. Therefore, these muscles appear to pull the orbicularis oris muscle and the skin of the lips, changing the morphology of the upper and lower lips [33]. Due to these characteristics of the orbicularis muscle, not only the vertical movement of the hard tissue but also the 3D movement, including in the anteroposterior and horizontal directions, could affect the vertical position of the cheilion.

Despite the greater amount of setback on the non-deviated side in the mandible during orthognathic surgery (Table 3; Mf-ND, −7.25 mm > Mf-D, −6.14 mm), the backward movement of the Ch-D exceeded that of the Ch-ND (Table 3, Ch-D, −2.27 mm > Ch-ND, −1.69 mm). As a result, there was a tendency for improvement of the anterior–posterior lip asymmetry, although the change was not statistically significant (Table 4; 0.75 mm vs. 0.17 mm). These results appear to stem from the characteristics of the soft tissue. When the differential setback of the mandible is performed in patients with class III skeletal asymmetry, the perioral soft tissues on the non-deviated side can be more redundant, and consequently, Ch-D moves more backward than Ch-ND.

The present study has some limitations. The position of the cheilions was influenced not only by the hard tissue position but also by soft tissue factors, such as muscle tonicity and tissue thickness. The soft tissue changes after orthognathic surgery could be diverse owing to the biologic differences in these factors. In this study, to evaluate the 3D change in lip asymmetry after two-jaw surgery, FS and 3D CT were used. When taking 3D images with an FS, errors may occur due to the scanning ability of the equipment, and there is a possibility that the scanning accuracy may be further reduced in tissues with complex geometric curvature, such as around the nostrils. In addition, in this study, the areas and landmarks selected as references in the process for soft tissue superposition may cause more errors, because they have insufficient constraints, especially in the axial plane direction. Furthermore, there could be a slight registration error between the FS and CT images due to patients' facial expression, posture, or motion. In addition, the limited number of patients included in the study should be considered. Further studies of different skeletal patterns would illuminate the effects of two-jaw surgery on the correction of lip asymmetry.

5. Conclusions

The improvement in 3D lip asymmetry after surgery was mainly achieved by the movement of the lower lip rather than that of the upper lip and the movement of Ch-D rather than that of Ch-ND. To improve lip asymmetry, it is necessary to establish a surgical plan that considers not only the vertical movement of the hard tissue but also the 3D movement of the hard tissue, including in the anteroposterior direction, which could affect the vertical position of the cheilion.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy issue.

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