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Factors affecting postoperative nasal morphology after Le Fort I osteotomy on multiple regression analysis

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Changes in external nasal morphology after Le Fort I osteotomy can lead to reduced patient satisfaction and diminished quality of life postoperatively. Despite various modifications such as alar cinch suture and subspinal osteotomy to overcome such changes, the external nasal morphology may vary unexpectedly on an individual basis. This report investigated the factors influencing the changes in external nasal morphology, by considering the patient's preoperative external nasal morphology as well as the surgical technique, and the direction of repositioning of maxilla. Multiple regression analysis identified the patient's preoperative nasal width as a factor that increased the alar base width of the nose, in addition to incision (oral vestibular incision) and the amount of anterior and superior movements at point A of the maxilla. The factors that caused the nasal tip to turn upward were the amount of anterior and superior movements at point A and the absence of subspinal osteotomy. The direction of surgical maxillary movement was influenced not only by anterior movement, but also by superior movement and surgical technique. The patient's preoperative nasal morphology should also be considered during the preoperative planning for orthognathic surgery to ensure optimal esthetic and functional outcomes.

Keywords Le Fort, Maxilla, Nose, Orthognathic surgery, Osteotomy, Regression analysis

Le Fort I osteotomy (LF1) is the most prevalent operative procedure to correct midfacial deformities such as maxillary protrusion, retrusion, and asymmetry[1,2]. An osteotomy of LF1 is performed horizontally from the piriform rim to the posterior part, and the maxilla is transected below the nasal cavity and fixed in a position appropriate for the facial profile. The goal of this procedure—often performed in conjunction with mandibular surgery—is to achieve preferable occlusion and improve facial harmony. Appropriate occlusal and intermaxillary relationships can greatly enhance the quality of life, including masticatory efficiency and positive thinking due to esthetic improvements. However, LF1 often results in undesirable nasolabial changes, particularly with anterior and/or superior repositioning of the maxilla[2,3]. Typically, an increase in the width of the alar base and upturning of the nasal tip are observed depending on the direction of movement of the maxilla. Various surgical techniques such as alar base cinch suture[2,4–10], subspinal osteotomy[11–14], V-Y closure[9,15,16], anterior nasal spine (ANS) reduction, and nasal floor base reduction have been applied to resolve these issues[17,18]. The alar base cinch suturing method is used to control excessive widening of the nasal alar by passing threads through the base tissue of the left and right nasal alar and suturing them together. Subspinal LF1 is performed to preserve perinasal insertions of the musculature and pre-existing positions of the ANS and nasal septum[19]. However, even with these techniques, the external nasal morphology can vary more than anticipated in some patients; changes in nasal wing morphology could be controlled despite the use of alar cinch sutures or V-Y closure[20,21]. Even with three-dimensional (3D) simulation, it is often difficult to predict changes in the external nasal shape after surgery[22]. Generally, if there is more forward movement of the maxilla, the nasal width is more likely to widen, leading to postoperative complications. Subspinal osteotomy may be effective, especially if there is a large

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amount of anterior displacement; however, this cannot completely prevent the complications. The external nose is generally shaped by the nasal cartilage, including the greater alar cartilage[23], but it varies from race to race and from individual to individual. We hypothesized that the patient's preoperative external nasal morphology may be a factor influencing the changes observed after LF1 surgery. Although many studies have shown the effectiveness of each technique such as subspinal osteotomy and cinch suture, few have included multiple factors using multiple regression analysis.

Postoperative nasal deformity is a complex issue, influenced by the mode of maxillary repositioning and surgical technique factors including the incision method, which can significantly impact the outcomes. The purpose of this retrospective study was to identify the factors that cause postoperative nasal deformity—from a variety of factors, including surgical technique and direction of maxillary repositioning as well as preoperative nasal morphology—using multiple regression analysis.

Results

Demographic characteristics of the patients

A total of 276 patients with complete data met the inclusion criteria. The median age of the patients was 24 years (interquartile range, 9 years). This study included 88 males and 188 females. According to Ballard's classification of skeletal patterns, 42 patients (15.2%) had skeletal Class I, 61 (22.1%) had skeletal Class II, and 173 (62.7%) had skeletal Class III pattern. In total, 50 asymmetrical cases (18.1%) were identified. Regarding the surgical technique, 56 patients (20.3%) underwent oral vestibular incision, and 220 (79.7%) underwent marginal gingival incision; further, 103 (37.3%) patients underwent a subspinal osteotomy, whereas 173 (62.7%) did not (Fig. 1). The amount of movement at point A was 2.19 ± 1.90 mm superiorly (maximum: 8.91 mm, minimum: -2.76 mm) and 1.73 ± 1.49 mm anteriorly (maximum: 6.21 mm, minimum: -5.48 mm), with an average anterior movement of 2.24 ± 1.60 mm for the right and left piriform aperture around the base of the nose (maximum: 6.71 mm, minimum: -4.26 mm).

As for the appropriateness of the sample size of this study, since it was a retrospective study, a sensitivity analysis was performed based on the results of multiple regression analysis. The results showed that the sample size of this study was adequate, with a power (1-β) of 0.99 for changes in nasal width and a power (1-β) of 0.99 for changes in angle of nasal tip.

Univariate and multiple regression analyses for each factor associated with changes in nasal width

Univariate analysis was performed for each factor associated with changes in the nasal width (Table 1). According to the Chi-square test, significant differences were found in preoperative nasal width and superior movement at point A of maxilla, with *P*-values of 0.033 and < 0.001, respectively. A comparison between the two groups using continuous variables also revealed significant differences in the same factors.

Multiple regression analysis showed significant differences in the incision method (oral vestibular incision) in addition to the superior and anterior movements at point A, and preoperative nasal width with *P*-values of 0.041, < 0.001, 0.006, and < 0.001, respectively (Table 2). The variance inflation factor (VIF) was less than 10 for all factors and there were no problems with multicollinearity.

Correlations were also checked for continuous variables for which significant differences were found using multiple regression analyses. The factors that increased nose width were preoperative nasal width: -0.348 ($P < 0.001$), amount of superior movement at point A: 0.353 ($P < 0.001$), and amount of anterior movement at point A: 0.129 ($P = 0.032$) (Fig. 2).

Univariate and multiple regression analyses for each factor associated with changes in the nasal tip

Univariate analysis was performed for each factor associated with changes in the nasal tip (Table 3). According to the Chi-square test, significant differences were found in the presence of subspinal osteotomy and incision method, with *P*-values of 0.016 and 0.025, respectively. According to comparison between the two groups using continuous variables, significant differences were found in superior and anterior movements at point A, with *P*-values of 0.024 and 0.003, respectively.

Multiple regression analysis showed significant differences in the presence of subspinal osteotomy, and superior and anterior movements at point A, with *P*-values of 0.009, < 0.001, and 0.003, respectively (Table 4). VIF was less than 10 for all factors and there were no problems with multicollinearity.

Correlations for the factors of upturn of the nose tip were as follows: amount of superior movement at point A: 0.182 ($P = 0.002$) and amount of anterior movement at point A: 0.212 ($P < 0.001$) (Fig. 3).

Fig. 1. Photographs of each auxiliary technique in Le Fort I osteotomy. (**a**) Oral vestibular incision. (**b**) Marginal gingival incision. (**c**) Le Fort I osteotomy with subspinal osteotomy.

		Patients	Patients $N = 276$ (%)		
		$N = 276$ (%)	Nasal width: < 2 mm	Nasal width: ≥ 2 mm	*P*-value
Patient-specific factors					
Sex	Male	88 (31.9)	50 (18.1)	38 (13.8)	
	Female	188 (68.1)	116 (42.0)	72 (26.1)	0.522[a]
Age	years old: median (IQR)		24 (IQR: 9)	23 (IQR: 8)	0.126[b]
	< 25	152 (55.1)	89 (32.2)	63 (22.8)	
	≥ 25, < 40	96 (34.8)	58 (21.0)	38 (13.8)	
	≥ 40	28 (10.1)	19 (6.9)	9 (3.3)	0.651[a]
Skeletal pattern	Class I	42 (15.2)	27 (9.8)	15 (5.4)	
	Class II	61 (22.1)	34 (12.3)	27 (9.8)	
	Class III	173 (62.7)	105 (38.0)	68 (24.6)	0.665[a]
Asymmetry	Yes	50 (18.1)	29 (10.5)	21 (7.6)	
	No	226 (81.9)	137 (49.6)	89 (32.2)	0.855[a]
Pre nasal width	mm: mean ± SD		37.6 ± 2.47	36.3 ± 2.83	< 0.001[c]***
	< 37.5	163 (59.1)	89 (32.2)	74 (26.8)	
	≥ 37.5	113 (40.9)	77 (27.9)	36 (13.0)	0.033[a]*
Pre nasal frontal angle	Degree, median (IQR)		144.9 (IQR: 8.7)	144.9 (IQR: 9.4)	0.778[b]
	< 146	155 (56.2)	95 (34.4)	60 (21.7)	
	≥ 146	121 (43.8)	71 (25.7)	50 (18.1)	0.752[a]
Pre nasal tip angle	Degree, mean ± SD		100.6 ± 5.45	101.2 ± 5.41	0.438[c]
	< 101	149 (54.0)	90 (32.6)	59 (21.4)	
	≥ 101	127 (46.0)	76 (27.5)	51 (18.5)	1.000[a]
Pre nasal tip projection	mm, median (IQR)		14.6 (IQR: 2.2)	14.7 (IQR: 1.8)	0.729[b]
	< 14.3	118 (42.8)	74 (26.8)	44 (15.9)	
	≥ 14.3	158 (57.2)	92 (33.3)	66 (23.9)	0.530[a]
Pre nasolabial angle	Degree, mean ± SD		94.9 ± 11.8	97.9 ± 12.4	0.052[c]
	< 97	143 (51.8)	92 (33.3)	51 (18.5)	
	≥ 97	133 (48.2)	74 (26.8)	59 (21.4)	0.177[a]
Surgical procedure factors					
Incision method	Oral vestibular incision	220 (79.7)	137 (49.6)	83 (30.1)	
	Marginal gingival incision	56 (20.3)	29 (10.5)	27 (9.8)	0.201[a]
Subspinal osteotomy	Yes	103 (37.3)	60 (21.7)	43 (15.6)	
	No	173 (62.7)	106 (38.4)	67 (24.3)	0.713[a]
Amount of superior movement at point A	mm, median (IQR)		1.53 (IQR: 2.00)	2.61 (IQR: 2.56)	< 0.001[b]***
	< 2.2	147 (53.3)	104 (37.7)	43 (15.6)	
	≥ 2.2	129 (46.7)	62 (22.5)	67 (24.3)	< 0.001[a]***
Amount of anterior movement at point A	mm, median (IQR)		1.76 (IQR: 1.60)	1.97 (IQR: 1.95)	0.112[b]
	< 3.0	229 (83.0)	144 (52.2)	85 (30.8)	
	≧ 3.0	47 (17.0)	22 (8.0)	25 (9.1)	0.060[a]
Amount of anterior movement around nasal base (mean value of left and right)	mm, median (IQR)		2.28 (IQR: 2.05)	2.33 (IQR: 2.23)	0.679[b]
	< 3.0	190 (68.8)	117 (42.4)	73 (26.4)	
	≥ 3.0	86 (31.2)	49 (17.8)	37 (13.4)	0.555[a]

Table 1. Univariate analysis for changes in nasal width. N, number; SD, standard deviation; pre, preoperative; $*P < 0.05$, $**P < 0.01$, $***P < 0.001$; [a]Chi-square test, [b]Mann–Whitney U test, [c] Welch's t-test.

Discussion

Multiple regression analysis identified the patient's preoperative nasal width as a factor that increased the nasal width after LF1, in addition to the incision technique (oral vestibular incision) and the amount of anterior and superior movements at point A. Factors contributing to the upturning of the nasal tip were the amount of anterior and superior movements at point A and the absence of subspinal osteotomy.

Generally, an increase in the width of the alar base and upturning of the nasal tip are observed depending on the direction of movement of the maxilla. The present study showed that not only the anterior movement of the maxilla but also the vertical influence is significant. Superior movement of the maxilla causes the soft tissues of the lower nasal wing and subnasal area to be lifted upward, leading to expansion of the nasal wing area due to excess tissue volume. Postoperative changes in nasal shape may be more prominent in patients with short nasal profile[14]. The influence of nasal projection was less significant in the present study. If the nose is low, the development of the constituent nasal cartilages is also suspected; however, it may be easier to bring the

	B	SD	b	t value	*P*-value	95% confidence interval		VIF
						Lower limit	Upper limit	
(Constant)	8.850	3.260		2.715	0.007**	2.430	15.270	
Sex	-0.219	0.188	-0.072	-1.162	0.246	-0.589	0.152	1.427
Age (25–39)	0.049	0.166	0.017	0.297	0.767	-0.277	0.376	1.155
Age (≥ 40)	-0.135	0.283	-0.029	-0.476	0.634	-0.692	0.422	1.352
Skeletal class II	0.260	0.266	0.076	0.978	0.329	-0.264	0.784	2.257
Skeletal class III	0.223	0.231	0.076	0.964	0.336	-0.232	0.678	2.319
Asymmetry	0.324	0.212	0.088	1.526	0.128	-0.094	0.742	1.238
Pre nasal width	-0.196	0.033	-0.369	-6.016	< 0.001***	-0.260	-0.132	1.410
Pre nasal frontal angle	-0.017	0.012	-0.087	-1.382	0.168	-0.041	0.007	1.484
Pre nasal tip angle	0.015	0.020	0.059	0.757	0.450	-0.025	0.056	2.273
Pre nasal tip projection	0.016	0.068	0.017	0.233	0.816	-0.119	0.151	1.999
Pre nasolabial angle	-0.003	0.008	-0.027	-0.400	0.690	-0.019	0.012	1.675
Incision method (Oral vestibular incision)	0.410	0.200	0.116	2.051	0.041*	0.016	0.804	1.200
Subspinal osteotomy	-0.055	0.165	-0.019	-0.332	0.740	-0.380	0.270	1.180
Amount of superior movement at point A	0.257	0.044	0.344	5.790	< 0.001***	0.170	0.344	1.320
Amount of anterior movement at point A	0.231	0.083	0.241	2.771	0.006**	0.067	0.395	2.842
Amount of anterior movement around nasal base	0.029	0.076	0.033	0.383	0.702	-0.120	0.178	2.718

Table 2. Multiple regression analysis for changes in nasal width. B, partial regression coefficient; b, standardized partial regression coefficient; SD, standard deviation; pre, preoperative; VIF, variance inflation factor; R2: 0.312, adjusted R2: 0.270; ANOVA < 0.001***; *N* = 276; **P* < 0.05, ***P* < 0.01, ****P* < 0.001

tissues together tightly, e.g. with a cinch, and prevent the opening of the nasal wing area. In addition, forward movement of LF1 decreases nasal height, nasal tip projection, and nasal length, but superior movement of the maxilla decreases subalar width and increases nasolabial angle and columella inclination[24]. In this study, the results showed that the greater the amount of anterior movement of the maxilla, the greater the difference in the nasal frontal angle; however, the effect was greater at point A than that on the amount of anterior movement of the base of the nasal ala. Additionally, inferior maxillary repositioning is associated with an increase in the nasolabial angle[25]. Naturally, the movement of the incisal edges of the anterior teeth and point A—which forms the base of the upper lip—will result in changes in the nasolabial angle; however, the preoperative nasolabial angle did not influence the postoperative external nasal shape. In the posterior movement of the anterior maxillary segment after anterior segmental maxillary osteotomy, no significant differences were observed in the alar base width or nasal tip angles[26]. In addition, the nasolabial angle was more affected by incisal angular changes when the horizontal posterior movement was less than 4 mm[27]. Greater changes in the external nasal morphology, such as a more forward position of the nasal tip and increased alar base width, were observed with anterosuperior repositioning than with posterosuperior repositioning by two-dimensional analysis[28]. This supports the hypothesis that anterior migration of maxilla likely results in nasal deformity by pushing the soft tissues of the lower nose and nasal wings forward.

LF1 widens the upper philtrum width[29], and the forward movement of the maxilla has a significant effect on the lips and nose. Furthermore, in the short term, the alar base cinch suture increases nasal tip elevation and the overall nasolabial angle. In the long term, there was no significant difference, suggesting that the initial nasal tip elevation resolves over time and that the cinch suture may have a limited effect on nasal tip elevation in the longer term[8]. The balance of the soft tissue around the nose, such as the skin gathered by the cinch suture, is expected to improve as it settles over time postoperatively. In the present study, the patients were evaluated 1 year postoperatively, which suggests that the soft tissue condition was almost fixed. It is believed that the anterosuperior movement of the maxilla is likely to affect the external nasal shape, and it is necessary to minimize the impact on the external nasal shape as much as possible using the surgical techniques described in the following discussion.

Alar cinch sutures significantly influence surgical techniques. The piriform ligament is easily identified during exposure of the maxilla and piriform aperture and can be used to control alar base widening after LF1[7]. Extraoral alar base cinch suture is more effective in maintaining preoperative alar and alar base widths than classic intraoral nasal sutures[30]. Since the intraoperative cinch suture is altered by postoperative swelling and other factors, administering dexamethasone or using bandages may be effective in reducing swelling as much as possible[31]. It is important to hook the thread to the piriform ligament to ensure that the tissue at the base of the nasal wing is pulled together securely. We also inserted the thread from outside the oral cavity using a needle and hooked it over the piriform ligament to make the alar cinch suture as full as possible; however, as in this study, changes occurred due to various factors.

Various incision methods have been used for LF1, such as oral vestibular and marginal gingival incisions. In oral vestibular incision, the increase in transverse nasal dimension is probably multifactorial primarily due to muscle shortening and lateral retraction associated with the transection of the perioral and perinasal musculature during surgery[32–35]. In contrast, marginal gingival incision can maintain tissue morphology such as

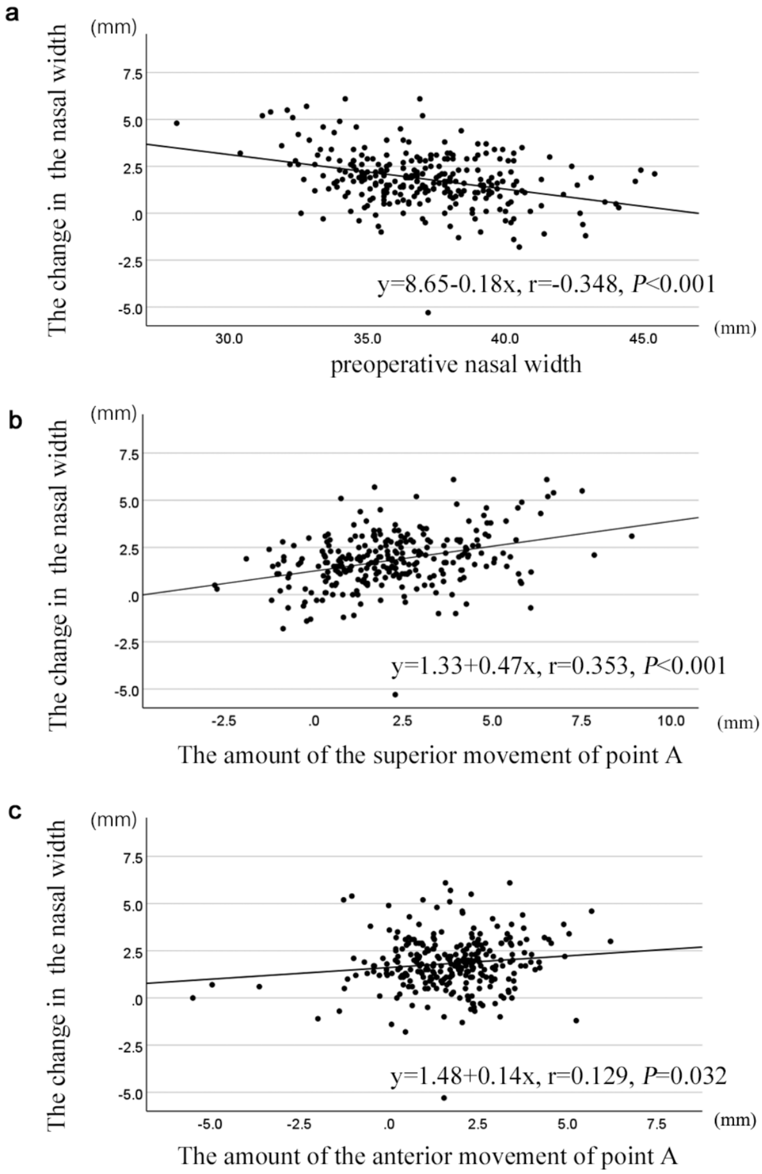

Fig. 2. Correlations between changes in nasal width and each of the factors. (**a**) Preoperative nasal width and amount of changes in the nasal width show weak negative correlation. (**b**) The amount of the superior movement at point A and the amount of changes in the nasal width show weak positive correlation. (**c**) The amount of the anterior movement at point A and the amount of changes in the nasal width show weak positive correlation.

the nasal muscles leading to maintenance of the external nasal morphology after surgery, which is substantially supported by the results of this study. However, the incision method should be considered based on patient conditions, including periodontal status and prosthetic condition, as it can also lead to various factors, including gingival retraction and black triangles at the interdental papillae.

Subspinal osteotomy is also effective because it can be performed without dissecting the surrounding nasal tissue or connecting to the ANS. Subspinal osteotomy can be effective when the roots of the maxillary incisors are not in close proximity. In close contact, it may cause pulp necrosis; therefore, caution should be exercised in its indications. Postoperative changes in nasal shape after subspinal LF1 and alar base cinch suture must be considered with anterior/vertical movements of the maxilla. Postoperative pronasale and subnasale can be estimable from the amount of downward advancement of the maxilla[14]. Yamashsita et al. applied subspinal osteotomy with LF1 to prevent postoperative nasal deformation[13]. Their study involved 39 patients who underwent bilateral sagittal ramus osteotomy and LF1 with maxillary advancement along with alar base cinch suture, V-Y closure, and reduction of the piriform aperture. A comparison of the two groups at 1 year postoperatively revealed that nasal width and alar base width differed significantly between the groups, with an increase of 0.81 mm nasal width in subspinal LF1, and 1.46 mm nasal width in conventional LF1. Furthermore, the changes in alar width, alar base width, nasal length, and nasofrontal angle were significantly less after subspinal LF1 than those after

Factor		Patients N = 276 (%)	Patients N = 276 (%) Nasal frontal angle: < 1.6°	Nasal frontal angle: > 1.6°	P-value
Patient-specific factors					
Sex	Male	88 (31.9)	44 (15.9)	44 (15.9)	
	Female	188 (68.1)	79 (28.6)	109 (39.5)	0.266[a]
Age	Years old, median (IQR)		25 (IQR: 9)	23 (IQR: 7)	0.052[b]
	< 25	152 (55.1)	61 (22.1)	91 (33.0)	
	≥ 25, < 40	96 (34.8)	48 (17.4)	48 (17.4)	
	≥ 40	28 (10.1)	14 (5.1)	14 (5.1)	0.260[a]
Skeletal pattern	Class I	42 (15.2)	16 (5.8)	26 (9.4)	
	Class II	61 (22.1)	34 (12.3)	27 (9.8)	
	Class III	173 (62.7)	73 (26.4)	100 (36.2)	0.123[a]
Asymmetry	Yes	50 (18.1)	18 (6.5)	32 (11.6)	
	No	226 (81.9)	105 (38.0)	121 (43.8)	0.234[a]
Pre nasal width	mm, mean ± SD		37.1 ± 2.7	37.1 ± 2.7	0.942[c]
	< 37.5	163 (59.1)	75 (27.2)	88 (31.9)	
	≥ 37.5	113 (40.9)	48 (17.4)	65 (23.6)	0.647[a]
Pre nasal frontal angle	Degree, median (IQR)		145.0 (8.6)	144.6 (9.1)	0.845[b]
	< 146	155 (56.2)	69 (25.0)	86 (31.2)	
	≥ 146	121 (43.8)	54 (19.6)	67 (24.3)	1.000[a]
Pre nasal tip angle	Degree, mean ± SD		101.2 ± 5.5	100.6 ± 5.4	0.406[c]
	< 101	149 (54.0)	62 (22.5)	87 (31.5)	
	≥ 101	127 (46.0)	61 (22.1)	66 (23.9)	0.343[a]
Pre nasal tip projection	mm, median (IQR)		14.8 (IQR: 2.1)	14.5 (IQR: 1.9)	0.808[b]
	< 14.3	118 (42.8)	53 (19.2)	65 (23.6)	
	≥ 14.3	158 (57.2)	70 (25.4)	88 (31.8)	1.000[a]
Pre nasolabial angle	Degree, mean ± SD		97.3 ± 11.2	95.2 ± 12.8	0.157[c]
	< 97	143 (51.8)	60 (21.7)	83 (30.1)	
	≥ 97	133 (48.2)	63 (22.8)	70 (25.4)	0.434[a]
Surgical procedure factors					
Incision method	Oral vestibular incision	56 (20.3)	17 (6.2)	39 (14.1)	
	Marginal gingival incision	220 (79.7)	106 (38.4)	114 (41.3)	0.025[a]*
Subspinal osteotomy	Yes	103 (37.3)	56 (20.3)	47 (17.0)	
	No	173 (62.7)	67 (24.3)	106 (38.4)	0.016[a]*
Amount of superior movement at point A	mm, median (IQR)		1.71 (IQR: 2.32)	2.28 (IQR: 2.75)	0.024[b]*
	< 2.2	147 (53.3)	74 (26.8)	73 (26.4)	
	≥ 2.2	129 (46.7)	49 (17.6)	80 (29.0)	0.053[a]
Amount of anterior movement at point A	mm, median (IQR)		1.57 (IQR: 1.79)	2.09 (IQR: 1.69)	0.003[b]**
	< 3.0	229 (83.0)	108 (39.1)	121 (43.8)	
	≥ 3.0	47 (17.0)	15 (5.4)	32 (11.6)	0.079[a]
Amount of anterior movement around nasal base (mean value of left and right)	mm, median (IQR)		1.97 (IQR: 2.27)	2.44 (IQR: 2.1)	0.262[b]
	< 3.0	190 (68.8)	83 (30.1)	107 (38.8)	
	≥ 3.0	86 (31.2)	40 (14.5)	46 (16.7)	0.759[a]

Table 3. Univariate analysis for changes in angle of nasal tip. N, number; SD, standard deviation; pre, preoperative; *$P < 0.05$, **$P < 0.01$, ***$P < 0.001$. [a]Chi-square test, [b]Mann–Whitney U test, [c]Welch's t-test.

conventional LF1, although there were no significant differences in nasal projection, nasal tip angle, or nasolabial angle between the two procedures[13]. Therefore, they demonstrated the effectiveness of subspinal osteotomy during anterior maxillary movement, which differed from this study in that the subspinal osteotomy could not be identified as a factor that gives rise to changes in nasal width. This may be due to differences in the design of the present study, which included various directions of repositioning of the maxilla. Notably, Mommaerts et al. showed that subspinal osteotomy is not superior to the conventional LF1 in regard to minimizing nasal tip changes and obtaining control over the columello-labial angle, and that the advancing piriform aperture pushing on the alae—and not the nasal spine—is responsible for the increase in nasal tip projection[19]. In this study, the anterior and superior movements of the maxilla affected the angle of the nasal tip, whereas the amount of anterior movement of the base of the nasal wing did not. Overall, this study suggests that subspinal osteotomy is more effective in controlling nasal tip orientation than in controlling nasal width.

	B	SD	b	t value	*P*-value	95% confidence interval		VIF
						Lower limit	Upper limit	
(Constant)	5.676	3.585		1.584	0.115	-1.382	12.735	
Sex	0.311	0.207	0.099	1.502	0.134	-0.097	0.718	1.427
Age (25–39)	-0.412	0.182	-0.135	-2.263	0.054	-0.771	-0.054	1.155
Age (≥ 40)	-0.288	0.311	-0.060	-0.925	0.356	-0.900	0.325	1.352
Skeletal class II	-0.572	0.292	-0.163	-1.957	0.051	-1.148	0.004	2.257
Skeletal class III	-0.132	0.254	-0.044	-0.517	0.605	-0.632	0.369	2.319
Asymmetry	0.280	0.233	0.074	1.199	0.232	-0.180	0.739	1.238
Pre nasal width	-0.023	0.036	-0.043	-0.657	0.512	-0.094	0.047	1.410
Pre nasal frontal angle	-0.012	0.014	-0.061	-0.907	0.365	-0.039	0.014	1.484
Pre nasal tip angle	-0.014	0.022	-0.051	-0.604	0.546	-0.058	0.031	2.273
Pre nasal tip projection	-0.025	0.075	-0.026	-0.328	0.743	-0.173	0.124	1.999
Pre nasolabial angle	-0.002	0.009	-0.020	-0.282	0.778	-0.019	0.015	1.675
Incision method (Oral vestibular incision)	0.434	0.220	0.120	1.971	0.052	0.000	0.867	1.200
Subspinal osteotomy	-0.475	0.181	-0.158	-2.618	0.009**	-0.832	-0.118	1.180
Amount of superior movement at point A	0.201	0.049	0.262	4.113	< 0.001***	0.105	0.297	1.320
Amount of anterior movement at point A	0.278	0.092	0.284	3.042	0.003**	0.098	0.459	2.842
Amount of anterior movement around nasal base	-0.017	0.083	-0.019	-0.207	0.836	-0.181	0.147	2.718

Table 4. Multiple regression analysis for changes in angle of nasal tip. B, partial regression coefficient; b, standardized partial regression coefficient; SD, standard deviation; pre, preoperative; VIF, variance inflation factor; R2: 0.205, adjusted R2: 0.155; ANOVA, < 0.001***; *N* = 276; **P* < 0.05, ***P* < 0.01, ****P* < 0.001

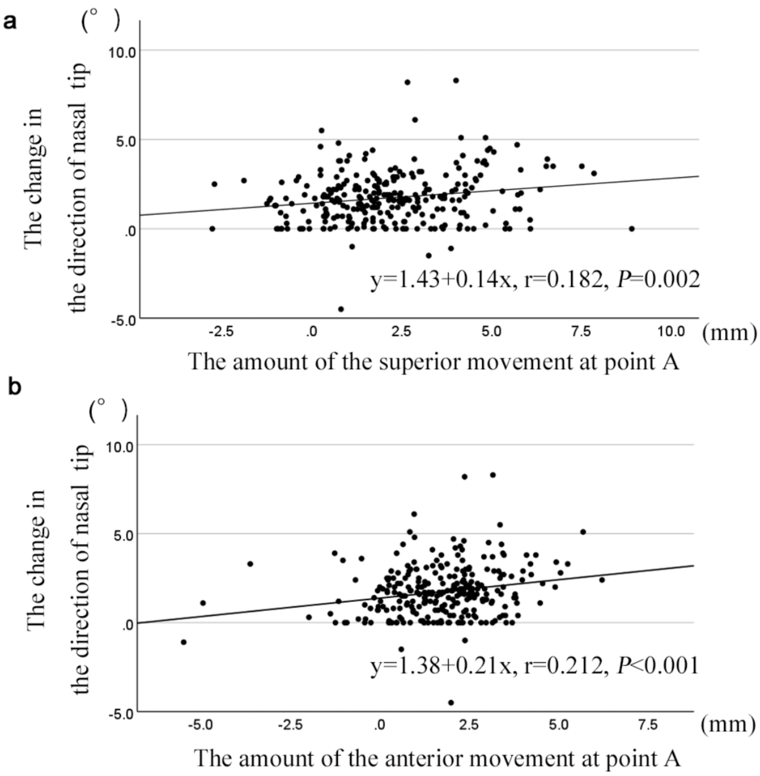

Fig. 3. Correlations between changes in the direction of the nasal tip and each of the factors. The amount of the superior (**a**)/anterior (**b**) movements at point A and the amount of change in the direction of the nasal tip show weak positive correlation.

Modified alar cinch suture and V-Y closure have a beneficial effect on the labial shape and prevent excessive upward rotation of the nasal tip[9,15,16]. The few cases of V-Y closure in this study suggest that the effect on the lips is stronger than that on the nose, and this is a topic for future studies.

Regarding the patient's preoperative nasal morphology, the preoperative width of the nose influenced the postoperative width of the external nose but not the postoperative orientation of the nasal tip. Not only the surgical technique (incision method or subspinal osteotomy), but also the patient's preoperative nasal morphology was also considered to be a factor in determining the preoperative migration style.

A limitation of this study is that it dealt with all orthognathic surgery patients, which is good for identifying trends; however, it is also important to examine subgroups of patients separately to compare detailed factors, and this is an issue to be considered for future investigations. In the future, technological advances in image analysis may make it possible to conduct more detailed studies by taking into account the orientation of the muscles around the patient's nose, shape and thickness of the nasal cartilage, and other factors. In addition, we hope that the accumulation of data from this study and others will lead to the development of more precise prediction tools for 3D simulation of facial appearance, especially nasal morphology.

Conclusion
The alterations in external nasal morphology after LF1 is influenced not only by the surgical technique and movement, but also by the preoperative nasal width; therefore, individual factors should be carefully considered before surgery. Furthermore, in orthognathic surgery, techniques such as subspinal osteotomy and gingival margin incision are effective in preventing postoperative deterioration of the external nasal morphology.

Materials and methods
Patient criteria
The inclusion criteria for this retrospective study included patients who underwent: (1) LF1 with/without bilateral sagittal split ramus osteotomy at the Department of Oral and Maxillofacial Surgery of Institute of Science Tokyo Hospital (Tokyo Medical and Dental University Hospital) between April 2019 and March 2023, (2) computed tomography (CT) preoperatively (1 month before surgery) and postoperatively (1 year after surgery) under the same conditions, and (3) surgery by three surgeons with experience in more than 100 cases of orthognathic surgery. The exclusion criteria included patients: (1) whose data were not well-documented, and (2) those with congenital anomalies such as cleft lip and palate. This study was approved by the Institutional Review Board (IRB) of Institute of Science Tokyo (Tokyo Medical and Dental University) (approval number: D2014-018). All methods were performed in accordance with relevant guidelines and regulations. This study was conducted in accordance with the ethical standards of the Institutional and/or National Research Committee and the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Informed consent for participation was obtained in the form of opt-out on the web site.

Surgical procedure
All orthognathic surgeries were performed by oral surgeons within the same team. The plate (titanium or absorbable) used for maxillary fixation depended on the case. For the oral vestibular incision, a horizontal incision was made across the mucosa and the surgical field was developed by cutting the nasal muscles. Muscle layer sutures were used at the time of suturing (Fig. 1a). For the marginal gingival incision, an incision was made at the gingival margin of the maxillary anterior teeth, and a vertical incision was made in the premolar area to develop the operative area (Fig. 1b). All patients underwent modified alar base-cinch suturing and reduction of the piriform aperture and ANS as needed. Depending on the case, subspinal osteotomy to retain the nasolabial muscle origin was performed as a V-shaped osteotomy at the base of the ANS through a circumventricular incision (Fig. 1c), and a hole for the alar base cinch suture was drilled at point A. A 3 – 0 nonabsorbable suture was placed using a modification of Rauso et al.'s alar base cinch suture technique[5], in which the suture was passed through both nasalis muscles, fibrous connective tissue, lesser alar cartilage, and hole in the ANS. If no subspinal osteotomy was performed, a hole was drilled in the ANS for the alar base cinch suture. The nasal septum cartilage was fixed through the hole with a 3 – 0 thread, and the thread of the alar base cinch suture was fixed through the hole in the ANS. The actual nasal width was overcorrected as much as possible through this procedure.

Computed tomographic data processing and analysis methods
All computed tomographic (CT) examinations were performed using a 64-slice multi-detector CT scanner (SOMATOM Sensation 64; Siemens AG, Erlangen, Germany). The scanning parameters were set as previously described[36,37]. The 3D objects of the maxilla, skull base, and face including external nose were created using PROPLAN CMF 3.0 software (Materialise, Leuven, Belgium). As the threshold value for clarifying the boundary between the bone and soft tissue was 280 Hounsfield units (HU), the maxilla and skull base were identified by extracting the visualized area higher than 280 HU. Similarly, the face was identified by extracting visualized areas higher than − 300 HU and lower than + 750 HU. The CT data obtained preoperatively and 1 year postoperatively were aligned by surface superimposition with a virtual skull, with no change in position on the software. The preoperative maxillary fragment was matched to the 1-year postoperative maxillary fragment by surface superimposition with the palatal portion (oral side) of the maxillary bone, which was separated from the teeth, and the amount of change from preoperatively to 1 year postoperatively was measured (Fig. 4a). This step eliminates tooth movement due to postoperative orthodontic correction and bone remodeling to accurately assess the stability of the maxilla after LF1 osteotomy. Three points (point A, near the lower part of the osteotomy

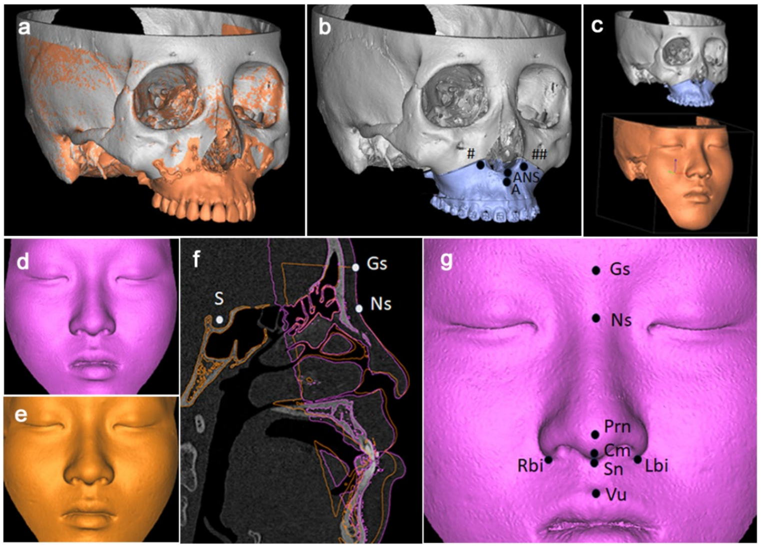

Fig. 4. Three-dimensional object of face is extracted and analyzed by PROPLAN CMF. (**a**) Preoperative and 1 year postoperative three-dimensional (3D) objects are aligned by surface superimposition with a virtual skull with no change in position. (**b**) Superimposition of 3D skull objects with combined facial objects 1 year after surgery. (**c**) Measurement point of maxillary reposition. ANS: anterior nasal spine, point A, #: near the lower part of the osteotomy at the right piriform foramen. ##: near the lower part of the osteotomy at the left piriform foramen. (**d**) Measurements of external nose morphology preoperatively. (**e**) Measurements of external nose morphology at 1 year postoperatively. (**f**) There is no positional deviation in Gs, Ns, and cranium, and an accurate measurement is possible. (**g**) Measurement points for the external nose morphology. Gs: glabellare in the soft tissue, Ns: nasion in soft tissue, Prn: most anterior point on the nose, Rbi: nasal alar on right side, Lbi: nasal alar on left side, Cm: most anterior point on the columella of the nose, Sn: most posterior superior point on the nasolabial curvature, Vu: most anterior point on the convexity of the upper lip.

site at the left and right piriform aperture) were measured for bone variation in location using 3D CT images preoperatively and 1 year after surgery (Fig. 4b).

A 3D object of the soft tissue morphology of the face was created and combined with the cranial maxilla to superimpose the pre- and postoperative soft tissue CT images by matching the pre- and postoperative images with the skull (Fig. 4c). The glabellare (Gs) and nasion in the soft tissues (Ns), and sella (S) were matched preoperatively and postoperatively to accurately measure differences in the nasal frontal angles.

The points used for soft tissue measurement before and after surgery were taken from the most inferior points on the nasal alar (LBi, RBi) on both sides, the most anterior point on the nose (Prn), the most anterior point on the columella of the nose (Cm), the most posterosuperior point on the nasolabial curvature (Sn), the most anterior point on the convexity of the upper lip (Vu), and Gs and Ns as soft tissue measurement points (Fig. 4d–g). Using these points, distances and angles were calculated as follows: nasal width (mm), distance between RBi and LBi; nasal frontal angle, angle of Gs-Ns-Prn; nasal tip angle, angle of Ns-Prn-Sn; nasal tip projection (perpendicular distance, mm), Ns-Prn; and nasolabial angle, angle of Cm-Sn-Vu. Anterior and superior movements were considered positive.

The two endpoints of this study were changes in the nasal width and upturning of the nasal tip. The respective cut-off values were set as 2.0 mm for changes in the nasal width and 1.6° for upturning of the nasal tip, by referring to Yamashita et al.[13].

Statistical analyses

Continuous variables (normal distribution) are presented as means with standard deviations, and continuous variables (non-normal distribution) are presented as median with interquartile range (IQR). Categorical variables are summarized as numbers and percentages. Univariate analysis was performed for each factor using the Chi-square test. Multiple regression analysis was used to analyze the factors associated with wide nasal width and upturned nasal tip. The factors considered were sex, age, skeletal pattern, asymmetry, preoperative external nasal morphology (nasal width, nasal frontal angle, nasal tip angle and projection, nasolabial angle), incision method, subspinal osteotomy, amount of superior/anterior movement at point A, and amount of anterior movement around the nose base. Age was grouped into three and analyzed as three categorical variables. To avoid multicollinearity, multiple regression analysis was performed with two factors each for age—"age (25–39 years)" and "age (≥ 40 years)"—and skeletal pattern classification—"skeletal Class II" and "skeletal Class III." Differences were considered statistically significant at $P < 0.05$. Statistical analyses were performed using SPSS Statistics software version 27.0 J (IBM Corp., Armonk, NY, USA).

Data availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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Author contributions
Statistical data analysis was performed by N.T. and Y.S. Study design and data interpretation was conducted by N.T., T.N., S.M. N.T. and K.N. conceived the idea of the study. T.Y. supervised the conduct of this study. All the authors agreed to the submission of the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

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