Clinical Oral Investigations (2021) 25:5227–5238
https://doi.org/10.1007/s00784-021-03830-x

ORIGINAL ARTICLE

Analysis of facial features and prediction of lip position in skeletal class III malocclusion adult patients undergoing surgical-orthodontic treatment

Wenhsuan Lu[1,2] · Guangying Song[1] · Qiannan Sun[1] · Liying Peng[1] · Yunfan Zhang[1] · Yan Wei[3] · Bing Han[1] · Jiuxiang Lin[1]

Received: 21 May 2020 / Accepted: 5 February 2021 / Published online: 15 February 2021

Abstract

Objectives This study presents a retrospective study aimed to analyze the facial features at each stage of surgical-orthodontic treatment for skeletal class III malocclusion, and predict the changes in the lips after treatment.

Materials and methods There were 49 skeletal class III malocclusion patients treated with bimaxillary surgery and orthodontic treatment enrolled in this study. Lateral cephalograms were obtained before treatment (T0), 1 month before surgery (T1), 1 month after surgery (T2), and after debonding (T3) for cephalometric measurements. After the measurement of the required variables, paired *t*-test, Pearson's correlation analysis, and multiple linear regression were performed using SPSS 19.0.

Results The main factors associated with changes in the upper lip included ΔUIE-V, ΔA-V, ΔU1A-V, and ΔL1A-V, and those associated with changes in the lower lip included ΔLIE-V, ΔL1A-V, ΔB-V, ΔPog-V, and Δfacial angle. The predicted regression equation for the horizontal change in the upper lip was represented as ΔUL-vertical reference line (VRL) = 9.430 + 0.779 (ΔUIE-VRL) − 0.542(VULT) ($P < 0.05$) with a mean error of 1.04 mm; the corresponding equation for the lower lip was ΔLL-VRL = −1.670 + 0.530 (ΔB-VRL) + 0.360 (Ls-E) + 0.393 (ΔLIE-VRL) ($P < 0.05$), with a mean error of 1.51 mm.

Conclusions This study explored the relationship between orthognathic surgery and changes in the lips and obtained the predictive equations of lip position after treatment by using multiple linear regression, which likely offers a reference for prediction of soft tissue changes before surgical-orthodontic treatment in patients with skeletal class III malocclusion.

Clinical relevance The findings can help dentists to rapidly predict the lip changes after surgical-orthodontic treatment in patients with skeletal class III malocclusion. The study has been registered with the Chinese Clinical Trial Registration (No: ChiCTR1800017694).

Keywords Skeletal class III malocclusion · Orthognathic surgery · Multiple linear regression · Cephalometric analyses · Lip morphology

Wenhsuan Lu and Guangying Songare the first authors who contributed equally to this work.

✉ Yan Wei
kqweiyan@bjmu.edu.cn

✉ Bing Han
kqbinghan@bjmu.edu.cn

[1] Department of Orthodontics, Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Peking University School and Hospital of Stomatology, 22 Zhongguancun South Avenue, Haidian District, Beijing, People's Republic of China

[2] The Third Dental Clinic, Engineering Laboratory for Digital and Material Technology of Stomatology, Beijing Key Laboratory of Digital Stomatology, Peking University School and Hospital of Stomatology, Beijing, People's Republic of China

[3] Beijing Laboratory of Biomedical Materials, Department of Geriatric Dentistry, Peking University School and Hospital of Stomatology, 22 Zhongguancun South Avenue, Haidian District, Beijing 100081, People's Republic of China

Introduction

Skeletal class III malocclusion is a common type of malocclusion in the Chinese population, and the etiology includes maxillary retrusion, mandibular protrusion, or both [1, 2]. Severe skeletal deformity can lead to masticatory impairment, a bad occlusal relationship, and even psychological barriers due to its negative effect on facial beauty [3]. Since the twenty-first century, the willingness of patients with skeletal class III malocclusion to undergo orthognathic surgery has increased; in fact, patients with this type of malocclusion are the most likely to agree to surgery [4]. Studies have found that these patients are more concerned about soft tissue changes, rather than functional recovery after treatment [3]. Thus, due to the enhancement of aesthetic consciousness, the prediction of soft tissue changes after surgical-orthodontic treatment has become increasingly important.

The facial profile is not only determined by jaw position but also by the soft tissue morphology. Due to the physiological characteristics of facial soft tissue, the changes in soft and hard tissue do not completely follow the 1:1 ratio; instead, the changes between regions affect each other. Although the changes are the greatest in regions where the jaws had been moved, they were observed over the entire face, regardless of the type of surgery performed [5]. Changes in the lip regions were particularly large and complex, and the change rule was less apparent. Accordingly, the change prediction error was also large [6, 7]. Current studies have shown that the soft and hard tissue changes of the lower lip are strongly correlated in both the horizontal and vertical directions, and that the associated factors may be varied; the ratio of changes in the soft and hard tissues of the lower lip in each study ranged from 0.55:1 to 1.03:1 [2, 8, 9]. In contrast, the change ratio of the upper lip was greater in the horizontal direction, but weaker in the vertical direction. Some studies suggest that the main factor influencing the position change of the upper lip includes the change at point A and the incisal edge of the upper central incisor (UIE) [10], whereas that for the lower lip includes the change in the incisal edge of the lower central incisor (LIE) [11]. In general, some changes beyond the surgical region are also noted, such as changes in the nose. In previous studies, the changes in pronasale (Prn) have differed and remain controversial [10, 12–15].

Currently, digital solutions, such as digital preoperative planning and simulation [16–18], individual surgical guides [19, 20], and osteosynthesis plates [21, 22], are the focus of interest. Many researchers have also tried using digital method to predict postoperative soft tissue changes, but the research results found that these digital concepts have limitations regarding soft tissue simulations. Elshebiny et al. [18] found that the soft tissue prediction accuracy after double-jaw surgery using Dolphin 3D is limited in upper lip. Pektas et al. [23] evaluated the accuracy of a computer-assisted imaging system in predicting the soft tissue response following orthognathic surgery, and the results showed that the largest difference was shown in the upper lip in the sagittal plane. Nadjmi et al. [24] compared the soft tissue profiles in Le Fort I osteotomy patients with the Dolphin and Maxilim softwares, and found that the greatest errors were seen in the chin region. A systematic review suggested that the most significant area of error in prediction through the available computer prediction programs was the lower lip area [25]. Due to the uncertainty and complexity of soft tissue changes after surgery, the factors influencing the changes of soft tissue need to be explored further, and the accuracy of predicting treatment results should also be improved.

This present retrospective study aimed to examine the factors influencing the treatment outcome and explore the soft tissue changes in patients with skeletal class III malocclusion after the surgical-orthodontic treatment. The facial features at each stage of treatment were analyzed, and multiple regression equations predicting the changes in lip protrusion after treatment were obtained, which may offer a reference for predicting soft tissue changes before the start of treatment.

Materials and methods

There were 49 adult patients with skeletal class III malocclusion (24 men, 25 women; mean age, 20.61 ± 3.21 years; cervical vertebral maturation, stage 6) who underwent bimaxillary surgery (Le Fort I osteotomy and bilateral sagittal split ramus osteotomy) and orthodontic treatment enrolled in this study. Surgeons decided whether genioplasty should be performed based on the shape and position of the chin before surgery. The number of patients was referenced from previous studies [10, 11]. The patient data used in this study was recruited through a database comprising >11,000 patients who had malocclusion and had completed orthodontic treatment between 1997 and 2005 at the Peking University School and Hospital of Stomatology (PKUSS; Beijing, China). According to previous studies, the difference of magnification and distortion among X-ray machines may lead to variation of results in measurement [26–29]. In terms of that concern, the data included in the database was acquired from the X-ray machine used in hospital before 2006, at which the hospital began to use X-ray machine of different brands. The study protocol was approved by the ethics committee of PKUSS (PKUSSIRB - 201626016); and the study has been registered with the Chinese Clinical Trial Registration (No: ChiCTR1800017694).

Inclusion and exclusion criteria

The following patients were included. Those who had four stages of lateral cephalograms; bilateral class III molar relationships; ANB ≤0°; combined Le Fort I osteotomy and bilateral sagittal split ramus osteotomy; growth completion, confirmed by the cervical vertebral maturation status; and deviation of menton point <5 mm. The patients with cleft lip or palate or other craniofacial syndromes were excluded.

Data acquisition

Lateral cephalograms were obtained before treatment (T0), 1 month before surgery (T1), 1 month after surgery (T2), and after debonding (T3). All the lateral cephalograms were taken at departments of oral and maxillofacial radiology of PKUSS. Patients were asked to stand relaxed, with arms at their sides, feet together with heels, and toes about 45° apart. The patient's head was in a natural head position, looking forward with the teeth in the centric occlusion, and the upper and lower lips in relaxed position.

The pre-surgical and post-surgical cephalograms were calibrated using a length scale with a template, digitized using a scanner (Agfa T1200), and analyzed and measured using the CIS software (developed by Peking University School of Stomatology Department of Growth and Development Center and Peking University Department of Computer Science & Technology). All landmarks were identified by three senior doctoral candidates, who were professionally trained in the definition of each point and the method of calibrating these points using the rules of standardized cephalometry. Outliers, among the three residents' data were mostly caused by inadvertent clicking on the screen, could be automatically detected with a customized software and were checked by the same individual. The average of three landmarks was used for subsequent calculations.

Assessment of cephalograms

The definitions of landmarks and reference lines are described in Figs. 1a and b, and 2. The coordinate system in Fig. 2 was designed to accurately evaluate the absolute movement of each point before and after surgery. The horizontal reference line (HRL) was the plane parallel to the Frankfort Plane through point S, and the vertical reference line (VRL) was the plane perpendicular to the HRL plane through point S. For example, the distance from the labrale inferius (Li) to HRL was denoted as Li-HRL, which is the vertical coordinate of point Li. The distance from point Li to the VRL is denoted as Li-VRL, which is the horizontal coordinate of point Li. By calculating the change in the point, coordinates at each stage can be obtained.

Statistical methods

Statistical analysis was performed with Statistical Product and Service Solutions (SPSS) version 19.0 (IBM Corp., Armonk, NY, USA). To compare the changes in the variables before and after each treatment stage, a paired *t*-test was performed. To assess the relationship between radiographic measurements and the change in the lips before and after treatment, Pearson's correlation was used. A total of 96 predictor variables were entered into a multiple linear regression model, including 28 skeletal landmarks, 36 dental landmarks, and 32 soft tissue landmarks.

Reliability analysis for the predictive equations

To test if the predictive equations could be generalized in the present cases, 15 additional patients between 2015 and 2018 were collected. The lateral cephalograms before and after treatment of these patients were taken using the latest X-ray machine of the hospital, and the inclusion and exclusion criteria for these patients were similar to those included in the experiment. The variables in the prediction equation were measured, and the predicted values for upper lip-VRL_P (UL-VRL_P) and lower lip-VRL_P (LL-VRL_P) were obtained by substituting them into the equation. The predicted values were compared with the actual UL-VRL and LL-VRL values. Intragroup correlation coefficients were used to assess the consistency between the predicted and actual values.

Results

Changes in facial features of patients with skeletal class III malocclusion at each treatment stage

Soft tissue is believed to recover from an edema state at least 6 months after surgery [30, 31]. Therefore, soft tissue measurements at T2 were not used. Soft tissue measurements were taken with T3, whose shooting time was more than 6 months after the surgery. The data in Table 1 show that the upper and lower incisors had decompensated at the pre-surgical stage (T0–T1), and the decompensation was greater in the lower incisors than in the upper incisors. The corresponding compensation of soft tissue after the pre-surgical-orthodontic treatment stage was similar; the thickness of the upper lip was greater than that of the lower lip. The sagittal skeletal landmarks significantly improved after surgery (T1–T2), and ANB recovered to within the normal range. With regard to the dental landmarks, compensation of the lower incisors was observed, and the upper incisors were compensated further by surgery. During the post-surgical-orthodontic treatment period (T2–T3), an increase in SNB and decrease in ANB were observed, indicating that a mandibular setback tended to recur after surgery. With regard to the total therapeutic effect (T0–T3), the skeletal landmarks were closer to normal, but still exhibited class III malocclusion. With regard to the dental landmarks, the upper and lower incisors were compensated

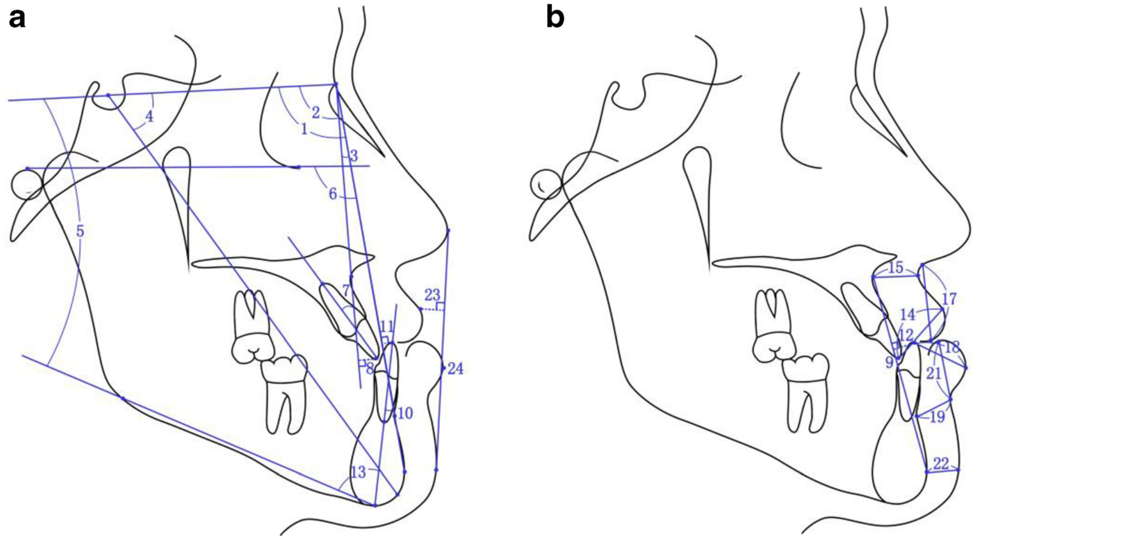

Fig. 1 **a**, **b** Cephalometry of the 49 patients 1. SNA, angle between the sella, nasion, and point A; 2. SNB, angle between the sella, nasion, and point B; 3. ANB, angle between point A, nasion, and point B; 4. Y axis, angle between the sella-nasion plane and sella-gnathion plane; 5. MPA, angle between the Frankfort plane and mandibular plane; 6. facial angle, angle between the Frankfort plane and the nasion-pogonion plane; 7. U1/NA, angle between the long axis of the most prominent maxillary incisor and the nasion-point A plane; 8. U1-NA, distance of the most prominent maxillary incisor in relation to the nasion-point A plane; 9. U1-AP, angle between the long axis of the most prominent maxillary incisor and the point A-pogonion plane; 10. L1/NB, angle between the long axis of the most prominent mandibular incisor and the nasion-point B plane; 11. L1-NB, distance of the most prominent mandibular incisor in relation to the nasion-point B plane; 12. L1-AP, angle between the long axis of the most prominent mandibular incisor and the point A-pogonion plane; 13. L1/MP, angle between the long axis of the most prominent mandibular incisor and the mandibular plane; 14. VULT, Vermillion upper lip thickness; 15. BULT, basic upper lip thickness; 16. ULT, upper lip taper; 17. ULlength, upper lip length; 18. VLLT, Vermillion lower lip thickness; 19. BLLT, basic lower lip thickness; 20. LLT, lower lip taper; 21. LLlength, lower lip length; 22. CT, chin thickness; 23. Ls-E, distance of the upper lip to the pronasale-pogonion plane; 24. Li-E, distance of the lower lip to the pronasale-pogonion plane; 25. Bs-E, distance of point B of soft tissue to the pronasale-pogonion plane; 26. NLA, nasolabial angle; 27. MLA, labiomental angle

before treatment and remained compensated relative to the normal value. With regard to soft tissue landmarks, the upper lip was thinner and longer, whereas the lower lip was thicker and shorter. In addition, the base of the lower lip appeared thinner, the nasolabial angle increased, and the labiomental angle decreased.

After surgical-orthodontic treatment, points UIA, U6, Prn, and Ls moved forward and downward; points B, LIE, ID, LIA, and L6 moved backward and upward; point Li moved backward and downward; points A, PNS, UIE, Prn, and Sn moved forward; points Bs and Pos moved backward; and point Pog moved upward (Table 2). The schematic diagram of each point movement is shown in Fig. 3. The maxillary landmarks generally tended to move forward and downward. In addition to point Li moving backward and downward, the other mandibular landmarks tended to move backward and upward.

Changes in the measured and actual change in lip protrusion and the extent of correlation

Among the significantly correlated landmarks listed in Table S1 (see Supplementary information), a strong correlation was observed between the measured landmarks and the changes in points Ls and Li in the sagittal direction before and after treatment. Based on the coefficient, a strong correlation was considered if $1 > |r| \geq 0.7$, moderate correlation was considered if $0.7 > |r| \geq 0.4$, and weak correlation was considered if $0.4 > |r|$. The measured landmarks strongly correlated with the upper lip changes included ΔA-V, ΔUIE-V, ΔU1A-V, and ΔL1A-V, whereas the landmarks strongly correlated with the lower lip changes included Δfacial, ΔB-V, ΔPog-V, ΔLIE-V, and ΔL1A-V.

Data analysis indicated that the factors influencing the change in lower lip protrusion were greater in number than those associated with the change in upper lip protrusion; the degree of correlation for the lower lip was also stronger. Moreover, the correlation for the measured landmarks and the changes in points Ls and Li in the sagittal direction were stronger than those in the vertical direction for both the upper and lower lips.

Predictive regression equations indicating the changes in the lip in the sagittal direction were obtained

Moreover, multiple linear regression equations were obtained which predicted change in the lips in the sagittal direction using the stepwise method (Table 3). For convenience of clinical application, the model that was within three variables

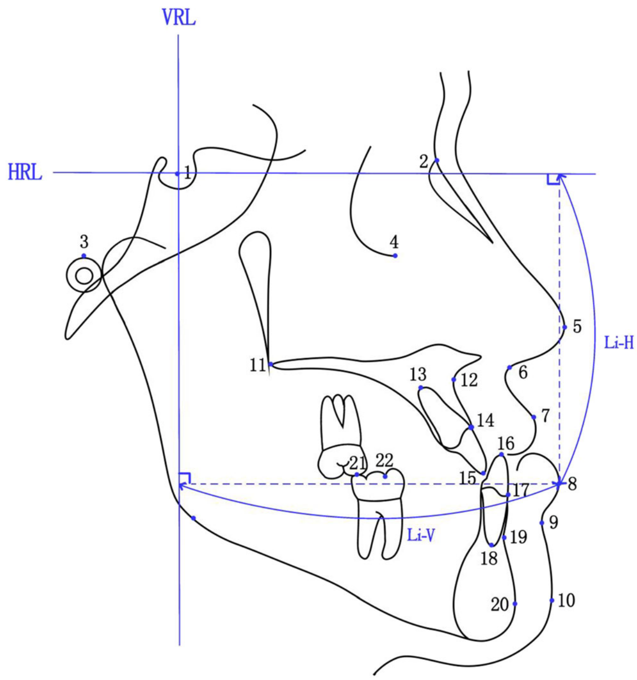

Fig. 2 Landmarks 1. S, sella; 2. N, nasion; 3. P, porion; 4. Or, orbitale; 5. Prn, pronasale; 6. Sn, subnasale; 7. UL, upper lip; 8. LL, lower lip; 9. Bs, point B in soft tissue; 10. Pos, Pogonion in soft tissue; 11. PNS, posterior nasal spine; 12. A, point A; 13. UIA, the root apex of the upper central incisor; 14. Pr, prosthion; 15. UIE, the incisal edge of the upper central incisor; 16. LIE, the incisal edge of the lower central incisor; 17. Id, infradentale; 18. LIA, the root apex of the lower central incisor; 19. B, point B; 20. Po, pogonion; 21. UMC, the mesiobuccal cusp tip of the upper first molar; 22. LMC, the mesiobuccal cusp tip of the lower first molar; horizontal reference plan (HRP): a line parallel to the Frankfort plane through point S; vertical reference plan (VRP): a line perpendicular to the HRP through point S

under the guarantee of goodness of fit among the multiple linear regression models was selected. The upper lip prediction equation incorporated 2 variables: ΔUIE-VRL and VULT. The equation was as follows: $\Delta UL - VRL = 9.430 + 0.779\ (\Delta UIE\text{-}VRL) - 0.542(VULT)$ ($P < 0.05$); the goodness of fit for the equation was 0.69. The lower lip prediction equation incorporated 3 variables: ΔB-VRL, Ls-E, and ΔLIE-VRL. The equation was as follows: $\Delta LL\text{-}VRL = -1.670 + 0.530\ (\Delta B\text{-}VRL) + 0.360(Ls\text{-}E) + 0.393(\Delta LIE\text{-}VRL)$ ($P < 0.05$); the goodness of fit was 0.84. Figure 4a–e are scatter diagrams of sagittal variation between the partial variables and changes in lip.

Prediction accuracy

The accuracy of the prediction equations was verified using cephalometric data collected from 15 other patients. The differences between the predicted value of $\Delta UL\text{-}VRL_P$ and $\Delta LL\text{-}VRL_P$ and the actual value (ΔUL-VRL and ΔLL-VRL) were obtained. The average error for the upper lip was 1.04 mm, and that of the lower lip was 1.51 mm. Figure 5a shows the prediction error curve for the upper and lower lips.

The intra-group correlation coefficient (ICC) was used to test the consistency between the predicted and actual values; the ICC for the upper lip was estimated as 0.835, whereas that for the lower lip was estimated as 0.895 ($P < 0.01$). The upper and lower lips showed strong consistency in terms of the predicted and actual value, and the predicted value of the lower lip was more consistent with the actual value, indicating that the accuracy of the lower lip prediction equation was better than that of the upper lip prediction equation.

Discussion

Research background and measurement method used in current studies

As physical and cosmetic appearance is becoming increasingly important, the focus of predicting surgical-orthodontic treatment outcomes has gradually shifted from changes in hard tissue to changes in soft tissue. With the development of cone beam computed tomography (CBCT) technology and the increasingly widespread use of three-dimensional photography, the method for outcome prediction from soft tissue has changed from two-dimensional to three-dimensional. Some studies have found that three-dimensional methods are more advantageous in the prediction of asymmetric occlusion, facial asymmetry, and facial features. However, the prediction accuracy does not differ between two-dimensional and three-dimensional methods [32, 33]. This present study aimed to predict the sagittal changes in soft tissue of the lip, which makes it feasible to predict the outcome using cephalograms. In addition, the three-dimensional technical capabilities such as CBCT and 3D photography have not yet been widely used in orthodontic patients. Therefore, lateral cephalograms offer valuable benchmarks that should not be underestimated.

Variation in cephalogram landmarks at each stage

It can be seen from Table 1 that the original concave facial type could be improved significantly in patients with skeletal class III malocclusion through surgical-orthodontic treatment, although the SNA and SNB angles did not return to normal, consistent with previous findings [13, 34, 35]. Ghassemi et al. [13] believed that although the SNA and SNB angles were not in the normal range after treatment, good outcomes were still possible. The reason for this lack of effect may be that the jaws are more consistent with each other in the sagittal orientation after surgery. Moreover, the decompensation of the lower incisors is greater than that of the upper incisors; the upper incisors are mainly compensated through surgery. Although recurrence is commonly observed after surgery in these cases, the compensation in the upper and lower incisors was maintained after treatment, consistent with the findings of Troy

Table 1 Cephalometry of the 49 patients at each treatment stage of surgical-orthodontic treatment in skeletal Class III malocclusion

	Before treatment (T0)	T0-T1	1 month before surgery (T1)	T1-T2	1 month after surgery (T2)	T2-T3	After debonding (T3)	T0-T3
∠SNA	81.76 ± 4.05		81.57 ± 3.95	$P < 0.01$	84.81 ± 4.25		84.55 ± 4.53	$P < 0.01$
∠SNB	85.10 ± 4.84	$P < 0.05$	84.67 ± 4.94	$P < 0.01$	81.74 ± 4.24	$P < 0.01$	82.60 ± 4.65	$P < 0.01$
∠ANB	−3.34 ± 3.18		−3.10 ± 3.18	$P < 0.01$	3.07 ± 2.63	$P < 0.01$	1.95 ± 2.53	$P < 0.01$
∠Y axis	67.84 ± 4.89	$P < 0.01$	68.43 ± 5.17	$P < 0.05$	69.13 ± 4.19	$P < 0.01$	68.09 ± 4.40	
MPA	39.53 ± 7.69	$P < 0.05$	40.14 ± 7.93	$P < 0.01$	38.20 ± 6.62		37.64 ± 6.53	$P < 0.01$
Facial angle	89.55 ± 4.77		89.55 ± 4.94	$P < 0.01$	91.74 ± 4.38	$P < 0.01$	90.43 ± 4.48	$P < 0.05$
U1/NA	32.38 ± 7.51	$P < 0.05$	29.93 ± 8.66	$P < 0.01$	23.93 ± 9.58	$P < 0.01$	27.76 ± 9.23	$P < 0.01$
U1-NA	7.26 ± 3.08	$P < 0.05$	6.45 ± 3.05	$P < 0.01$	4.78 ± 3.01	$P < 0.01$	6.07 ± 2.79	$P < 0.01$
U1-AP	4.16 ± 3.07		3.83 ± 2.84	$P < 0.01$	5.20 ± 2.38	$P < 0.01$	5.79 ± 2.36	$P < 0.01$
L1/NB	20.16 ± 8.31	$P < 0.01$	30.84 ± 7.20	$P < 0.01$	25.44 ± 6.37	$P < 0.01$	23.36 ± 6.84	$P < 0.01$
L1-NB	5.39 ± 3.57	$P < 0.01$	8.25 ± 3.21	$P < 0.01$	6.39 ± 2.62	$P < 0.01$	5.85 ± 3.05	
L1-AP	7.23 ± 3.62	$P < 0.01$	9.85 ± 3.13	$P < 0.01$	2.46 ± 1.97		2.78 ± 2.14	$P < 0.01$
L1/MP	76.95 ± 9.02	$P < 0.01$	87.50 ± 7.54		87.46 ± 7.55	$P < 0.01$	85.00 ± 7.83	$P < 0.01$
VULT	18.13 ± 2.78	$P < 0.05$	18.89 ± 2.85	–	–	–	16.3 ± 3.09	$P < 0.01$
BULT	14.89 ± 2.65		14.95 ± 2.68	–	–	–	14.04 ± 2.44	$P < 0.05$
ULT	−3.24 ± 2.82		−3.94 ± 3.24	–	–	–	−2.27 ± 3.07	
ULlength	24.11 ± 2.43		24.13 ± 2.41	–	–	–	26.30 ± 2.37	$P < 0.01$
VLLT	16.65 ± 2.86	$P < 0.01$	15.32 ± 3.27	–	–	–	17.71 ± 2.34	$P < 0.05$
BLLT	15.85 ± 3.41		15.34 ± 3.59	–	–	–	14.03 ± 2.18	$P < 0.01$
LLT	−0.80 ± 4.11		−0.03 ± 4.82	–	–	–	−3.68 ± 2.00	$P < 0.01$
LLlength	59.05 ± 4.12	$P < 0.01$	60.13 ± 4.22	–	–	–	56.39 ± 3.99	$P < 0.01$
CT	13.06 ± 2.62		12.76 ± 3.12	–	–	–	12.26 ± 2.62	$P < 0.01$
Ls-E	2.68 ± 2.27	$P < 0.01$	3.58 ± 2.50	–	–	–	2.02 ± 1.52	
Li-E	4.74 ± 2.67		5.09 ± 2.78	–	–	–	2.73 ± 1.84	$P < 0.01$
Bs-E	3.16 ± 1.83		3.17 ± 1.73	–	–	–	6.33 ± 1.41	$P < 0.01$
NLA	88.61 ± 11.28		89.78 ± 10.59	–	–	–	92.49 ± 9.14	$P < 0.01$
MLA	152.42 ± 12.18		149.21 ± 14.34	–	–	–	137.94 ± 9.61	$P < 0.01$

Table 2 The movement of cephalometric landmarks in horizontal and vertical directions at each treatment stage of surgical-orthodontic treatment in skeletal class III malocclusion

(mm)	Pre-surgical treatment (T0–T1)	Orthognathic surgery (T1–T2)	Post-surgical treatment (T2–T3)	Treatment (T0–T3)
Skeletal landmarks				
A – V	0.67 ± 2.82	2.79 ± 3.51**	0.19 ± 2.42	3.66 ± 3.56**
– H	0.41 ± 1.93	0.06 ± 2.70	−0.40 ± 1.82	0.07 ± 2.40
B – V	0.37 ± 5.22	−7.67 ± 5.89**	2.82 ± 4.90**	−4.48 ± 5.00**
– H	0.88 ± 3.34	−2.09 ± 3.84**	−2.06 ± 3.15**	−3.27 ± 3.86**
Pog – V	0.39 ± 5.93	−4.87 ± 6.60**	2.81 ± 5.55**	−1.67 ± 5.90
– H	2.12 ± 3.36**	−1.44 ± 3.75*	−1.94 ± 2.67**	−1.26 ± 4.30*
PNS – V	0.28 ± 2.68	1.02 ± 3.16*	−0.14 ± 2.41	1.17 ± 2.56**
– H	0.65 ± 1.41**	−1.18 ± 1.91**	1.00 ± 1.58**	0.47 ± 1.71
Dental landmarks				
UIE – V	−0.07±3.87	1.64±4.07**	1.83 ± 3.50**	3.40 ± 4.17**
– H	1.02 ± 2.14**	0.74 ± 3.24	−0.98 ± 2.31**	0.78 ± 3.32
Pr – V	1.25 ± 2.87**	0.47 ± 4.13	−0.53 ± 2.27	1.20 ± 3.24**
– H	−1.20 ± 6.07	5.82 ± 6.81**	−1.30 ± 5.19	3.32 ± 4.52**
U1A – V	1.34 ± 3.24**	3.23 ± 4.00**	−0.23 ± 2.31	4.34 ± 4.31**
– H	1.16 ± 2.37**	0.06 ± 2.98	−0.41 ± 1.67	0.82 ± 3.02
LIE – V	3.25 ± 4.42**	−7.84 ± 4.91**	1.65 ± 3.59**	−2.94 ± 4.39**
– H	2.79 ± 3.28**	−2.54 ± 4.21**	−2.46 ± 2.51**	−2.21 ± 3.56**
Id – V	1.27 ± 4.53	−7.59 ± 5.31**	2.24 ± 4.20**	−4.08 ± 4.55**
– H	2.06 ± 3.07**	−2.06 ± 4.18**	−2.48 ± 2.92**	−2.49 ± 3.53**
L1A – V	−0.12 ± 5.11	−7.61 ± 6.10**	2.89 ± 4.93**	−4.84 ± 4.81**
– H	−0.17 ± 2.88	−1.82 ± 3.53**	−1.59 ± 2.27**	−3.58 ± 3.68**
U6 – V	0.75 ± 4.72	1.10 ± 3.88	1.62 ± 3.39**	3.48 ± 4.77**
– H	1.38 ± 1.91**	0.01 ± 2.07	−0.36 ± 1.81	1.02 ± 2.73**
L6 – V	1.42 ± 4.41*	−7.98 ± 5.19**	1.77 ± 3.99**	−4.79 ± 5.07**
– H	1.28 ± 2.49**	−1.63 ± 2.85**	−1.01 ± 1.96**	−1.36 ± 2.53**
Soft tissue landmarks				
Prn – V	1.14 ± 2.16**	-	-	2.08 ± 2.70**
– H	0.53 ± 2.66	-	-	0.02 ± 2.97
Sn – V	0.58 ± 2.48	-	-	2.47 ± 2.97**
– H	0.27 ± 2.22	-	-	–0.06 ± 2.61
Ls – V	0.49 ± 3.39	-	-	2.26 ± 4.10**
– H	0.64 ± 2.89	-	-	2.14 ± 2.96**
Li – V	2.13 ± 4.68**	-	-	−3.50 ± 4.90**
– H	1.94 ± 5.61*	-	-	1.21 ± 3.76*
Bs – V	0.53 ± 4.95	-	-	−4.94 ± 5.07**
– H	2.40 ± 5.18**	-	-	0.52 ± 4.17
Pos – V	−0.08 ± 5.77	-	-	−2.34 ± 5.52**
– H	1.95 ± 5.49*	-	-	0.38 ± 5.00

*$P < 0.05$

**$P < 0.01$

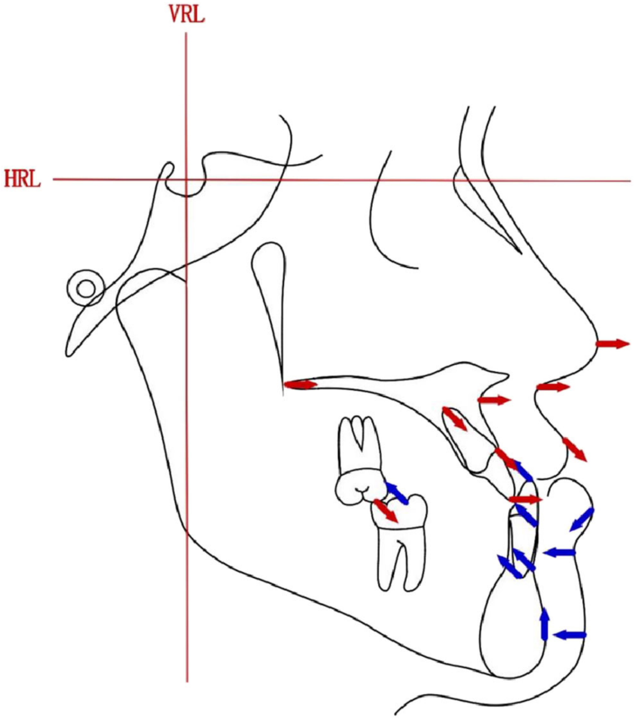

Fig. 3 The schematic diagram indicating movement of each point in patients with skeletal class III malocclusion after the surgical-orthodontic treatment

et al. and Mcneil [36, 37]. Moreover, Johnston [35] believed that compensation of the lower incisors was more difficult, which may be due to the inclusion of mandibular tooth extraction in the procedural design, as the inclusion of mandibular tooth extraction makes compensation of the lower incisors more difficult. Compensation of the lip soft tissue was observed, wherein the upper lip of patients with skeletal class III malocclusion was thicker and the lower lip was thinner before treatment, relative to the usual values before treatment. After the pre-surgical-orthodontic treatment stage, the upper lip was found to be thicker and the lower lip appeared thinner due to the decompensation of the incisors. After surgery, the upper lip appeared thinner and the lower lip appeared thicker due to the forward maxillary movement and mandibular setback. The results of this study suggest that orthognathic surgery can help patients obtain a good facial shape, even if the skeletal deformity is not completely corrected. Orthodontists should also anticipate postoperative recurrence.

Correlation between lip protrusion changes and cephalogram measurements

As noted in Table S1, the correlation between sagittal lip changes in the mandible was greater than in the maxilla, and mandibular soft and hard tissue movements showed a stronger correlation in the horizontal direction than in the vertical direction, consistent with the findings of Chew and Becker [2, 38]. However, the soft tissue was not only affected by the changes in hard tissue of the same area. In the present study, it was found that the changes of upper lip position were also correlated with the changes of point B, Pog, and lower incisors; these results suggest that soft tissue change is an overall occurrence, and future studies should carefully consider the integrity of change. A study by Verdenik [5] using three-dimensional photographs also supported this view, and found that the soft tissue changes were not only greatest in the in the surgical sites after surgical-orthodontic treatment in patients with skeletal Class III malocclusion but were also marked in the regions beyond the surgical site. In fact, the nose, cheek, and upper lip can all be affected by mandibular surgery; in particular, lower lip and mandibular changes are clearly visible after Lefort I surgery. These findings suggest that different algorithms should be adopted for single and bilateral jaw surgery for predicting treatment outcome.

Furthermore, the results of this study suggest that the changes in upper and lower lip protrusion were slightly negatively related to the initial lip thickness in the maxillary region; i.e., a thicker initial upper lip protrusion was associated with a smaller post-treatment lip protrusion change, primarily as a result of the better compensatory ability of thicker lip soft tissue. Freihofer [39] and Jokic [40] also reported that the different thickness of soft tissue before treatment could significantly affect the movement ratio of soft and hard tissue after treatment, and a thinner initial lip thickness was associated with a greater change relative to hard tissue. In the latter study, the initial thickness of the lip protrusion was strongly negatively correlated with the change in lip protrusion after treatment, and lower lip thickness was significantly correlated with the extent of change in the soft and hard tissue of the upper and lower lip. Our results suggest that for patients with thick lips, the change in the position of lips after surgery is relatively

Table 3 Predictive multiple linear regression equations for change of upper and lower lip after the surgical-orthodontic treatment in skeletal class III malocclusion

Dependent variable	Evaluation indicators			Regression equation = constant + variable 1 + variable 2 + variable 3 +…			
	R^2	R	Adj R^2	Constant	Variable 1	Variable 2	Variable 3
ΔUL-VRL	0.705	0.839	0.692	9.430	0.779 (ΔUIE-VRL)	−0.542 (VULT)	
ΔLL-VRL	0.837	0.915	0.826	−1.670	0.530 (ΔB-VRL)	0.360 (Ls-E)	0.393 (ΔLIE-VRL)

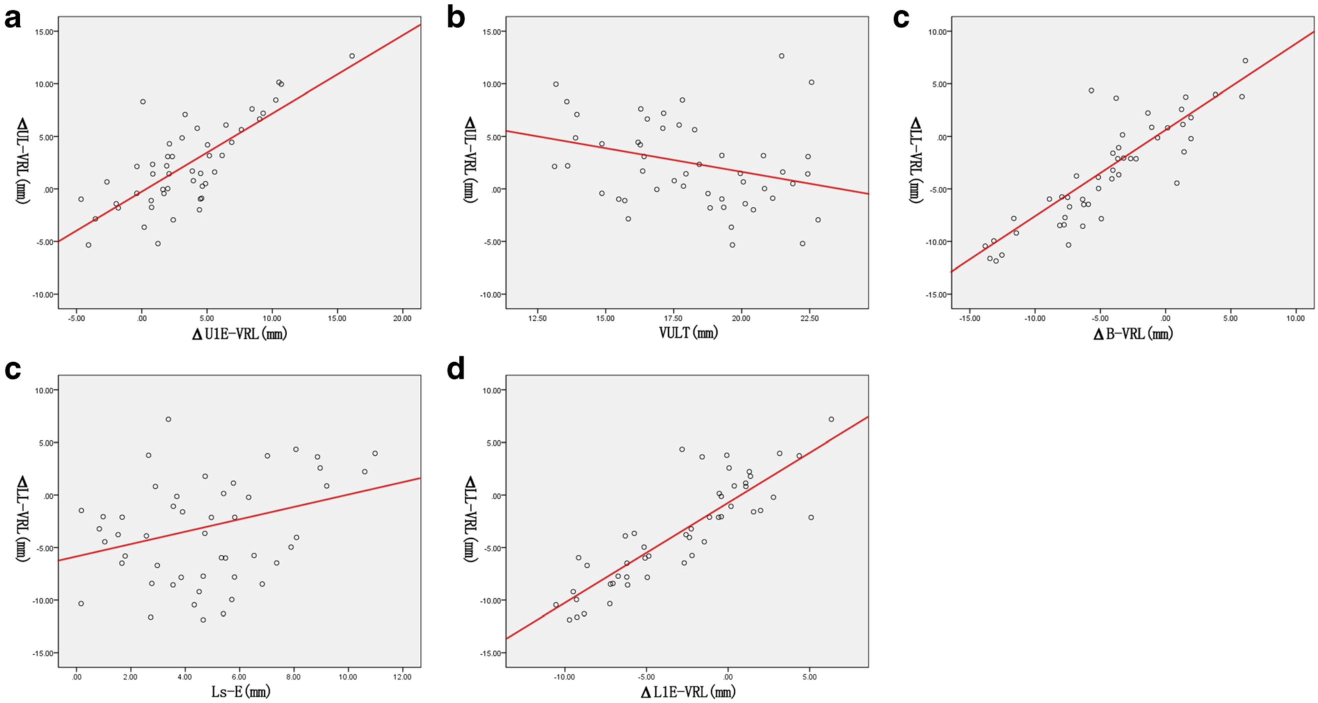

Fig. 4 **a**–**e** Scatter diagrams of sagittal variation between partial variables and the change of the lip

small, which should still be taken into account when making preoperative predictions.

Analysis of the protrusion of the lips, as noted in Table S1, showed that the landmarks with a strong correlation with the change in upper lip protrusion included ΔUIE-V, ΔA-V, ΔU1A-V, and ΔL1A-V, whereas those correlating with lower lip protrusion included ΔLIE-V, ΔL1A-V, ΔB-V, ΔPog-V, and Δfacial. This is generally consistent with previous studies. In the study by Jeon [10], upper lip changes were moderately correlated with ΔA-V and ΔUIE-V, whereas lower lip changes were moderately to strongly correlated with ΔB-V, ΔPog-V, ΔGn-V, ΔMe-V, ΔA-H, ΔUIE-H, and ΔGn-H. Becker also reported that upper lip changes were moderately correlated with Δ UIE-V, whereas lower lip changes moderately correlated with ΔLIE-V, ΔB-V, and ΔPog-V. As the measured values differed from those considered in the present study, the conclusions were inconsistent, although the main factors affecting the change in upper and lower lip protrusion were found to be similar.

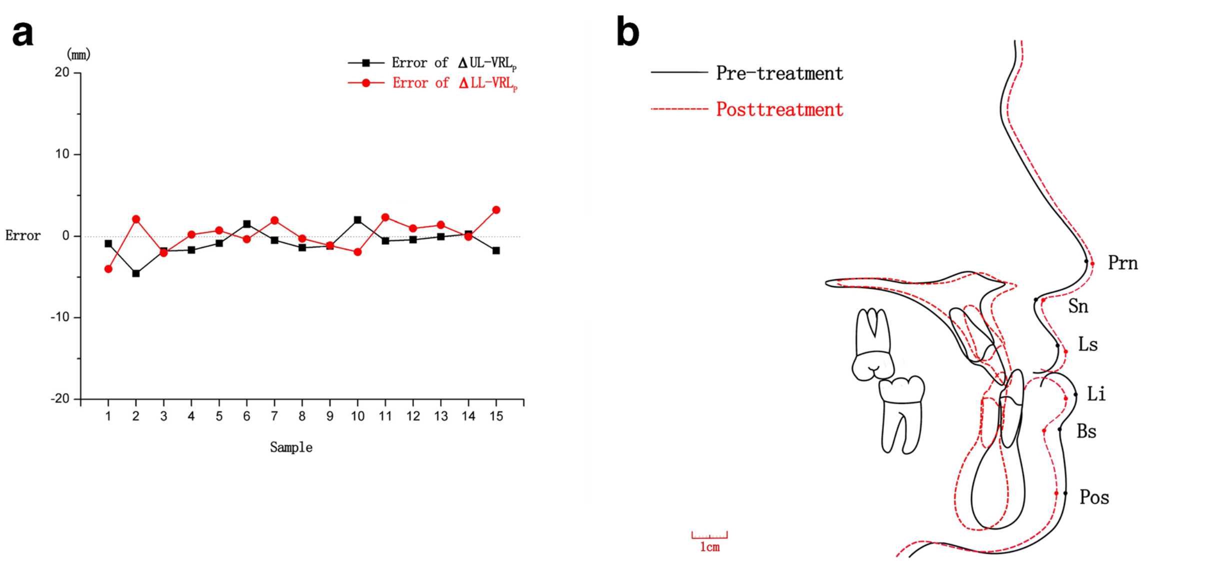

Fig. 5 **a** The prediction error curve for the upper and lower lips. **b** Schematic drawing of the changes in the nose, lips, and chin after bimaxillary surgery. We find anterior movements of the upper lip, the subnasale (Sn), and the nose tip (Pn). Black line, before surgery; red imaginary line, after surgery

Prediction of change in lip processes in the sagittal direction

Although considerable progress has been made in predicting skeletal changes in orthognathic surgery, it remains difficult to predict the behavior of soft tissue after treatment due to the inconsistency of soft and hard tissue changes [38]. The movement of landmarks observed in the present study is shown in Fig. 3. The maxillary landmarks generally moved forward and downward, whereas the mandibular landmarks generally moved backward and upward, except for point Li, which moved backward and downward. The schematic diagram of soft tissue changes before and after treatment is shown in Fig. 5B, and the average movement of each landmark is shown in Table S2. The concave shape before treatment had markedly improved after surgical-orthodontic treatment. Among the points, point Ls moved forward and point Li moved backward, consistent with previous findings [2, 13, 34].

With regard to the change in lip length, the upper lip length increase and the lower lip length decrease were concluded, consistent with other studies, in patients with skeletal class III malocclusion after surgical-orthodontic treatment [2, 41, 42]. Raschke et al. [43] believed that the upper lip length increased and the lower lip length remained unchanged, whereas Choi et al. concluded that the upper and lower lip lengths remained unchanged [44]. The reasons for the different conclusions may be the different measurement methods used or the large individual differences in soft tissue.

Prediction accuracy

Some researchers have provided prediction equations for the soft tissue profile after surgical-orthodontic treatment in patients with skeletal class III malocclusion. Jeon [10] reported an upper lip prediction equation, whereas Rupperti [11] mentioned a lower lip prediction equation. In the present study, the predicted regression equations for the horizontal change in the lips, and the goodness of fit of the model for the equations are 0.69 in the upper lip and 0.84 in the lower lip. To verify the accuracy of the equation, 15 new patients' cephalometry data were used for analysis. The mean errors of the upper and lower lips were 1.29 mm and 1.51 mm respectively.

This present study improved accuracy by including an appropriate number of cases, thereby equalized single aberrations and decreased the limitation of relevant differences concerning the lips. Although two-dimensional data cannot provide more referential evidence for asymmetric occlusion, facial asymmetry, and facial features, the results showed that the prediction effect of sagittal changes in the lips was reliable on the basis of simple application.

In the age of computer analysis, several computer-assisted software methods are available for predicting postoperative soft tissue changes. Various studies have found that cephalograms are useful for computer prediction, wherein the upper lip error ranges from 0.12 to 1.8 mm, and lower lip error ranges from 0.06 to 2 mm [23–25, 45, 46]. However, due to the complexity of the calculations and the large number of variables, most computer-predicted studies do not provide specific calculation equations, as these are most suitable for prediction using a computer. In contrast, the equations provided in the present study contain 2–3 variables, which are easy to use, can help in accurately predicting the changes in lip protrusion, and can offer a reference in orthodontic treatment plans.

Conclusion

This study showed that the factors influencing the treatment outcome included ΔUIE-V, ΔA-V, ΔU1A-V, and ΔL1A-V in the upper lip; and ΔLIE-V, ΔL1A-V, ΔB-V, ΔPog-V, and Δfacial angle in the lower lip. It explored the soft tissue changes in patients with skeletal class III malocclusion after the surgical-orthodontic treatment, and obtained multiple regression equations predicting the changes in lip protrusion after treatment. The equation for the horizontal change in the upper lip was represented as follows: ΔUL-vertical reference line (VRL) = 9.430 + 0.779 (ΔUIE-VRL) − 0.542 (VULT) ($P < 0.05$) with a mean error of 1.04 mm; the corresponding equation for the lower lip was ΔLL-VRL = −1.670 + 0.530 (ΔB-VRL) + 0.360 (Ls-E) + 0.393 (ΔLIE-VRL) ($P < 0.05$), with a mean error of 1.51 mm. The clinical signification of this study was providing a fast, simple, and relatively accurate method for orthodontist and orthognathic surgeons to predict the lip changes after surgical-orthodontic treatment in patients with skeletal class III malocclusion. These findings may help dentists to make appropriate treatment plans and offer a reference for dentists and patients of the treatment outcome before the start of orthognathic treatment.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00784-021-03830-x.

Funding This work was supported by grants from the National Natural Science Foundation of China (51672009), Beijing Municipal Natural Science Foundation (7172241), National Natural Science Founds for Outstanding Young Scholars of China (81922019), and National Youth Top-notch Talent Support Program (QNBJ2019-3).

Declarations

Ethics approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent For this type of study, formal consent is not required.

Conflict of interest The authors declare no competing interests.

Abbreviations CBCT, cone beam computed tomography; HRL, the horizontal reference line; ICC, intra-group correlation coefficient; Li, labrale inferius; LIA, the root apex of the lower central incisor; LIE, the incisal edge of the lower central incisor; LL, lower lip; Prn, pronasale; SPSS, Statistical Product and Service Solutions; UIA, the root apex of the upper central incisor; UIE, the incisal edge of the upper central incisor; UL, upper lip; VRL, the vertical reference line

References

1. Ngan P, Moon W (2015) Evolution of Class III treatment in orthodontics. Am J Orthod Dentofac Orthop 148(1):22–36. https://doi.org/10.1016/j.ajodo.2015.04.012
2. Chew MT (2005) Soft and hard tissue changes after bimaxillary surgery in Chinese Class III patients. Angle Orthod 75(6):959–963. https://doi.org/10.1043/0003-3219(2005)75[959:SAHTCA]2.0.CO;2
3. Kiyak HA, Zeitler DL (1988) Self-assessment of profile and body image among orthognathic surgery patients before and two years after surgery. J Oral Maxillofac Surg 46(5):365–371
4. Proffit WR, Jackson TH, Turvey TA (2013) Changes in the pattern of patients receiving surgical-orthodontic treatment. Am J Orthod Dentofac Orthop 143(6):793–798. https://doi.org/10.1016/j.ajodo.2013.01.014
5. Verdenik M, Ihan HN (2014) Differences in three-dimensional soft tissue changes after upper, lower, or both jaw orthognathic surgery in skeletal class III patients. Int J Oral Maxillofac Surg 43(11):1345–1351. https://doi.org/10.1016/j.ijom.2014.06.017
6. Koh CH, Chew MT (2004) Predictability of soft tissue profile changes following bimaxillary surgery in skeletal class III Chinese patients. J Oral Maxillofac Surg 62(12):1505–1509
7. Jones RM, Khambay BS, McHugh S, Ayoub AF (2007) The validity of a computer-assisted simulation system for orthognathic surgery (CASSOS) for planning the surgical correction of class III skeletal deformities: single-jaw versus bimaxillary surgery. Int J Oral Maxillofac Surg 36(10):900–908. https://doi.org/10.1016/j.ijom.2007.05.015
8. Park JY, Kim MJ, Hwang SJ (2013) Soft tissue profile changes after setback genioplasty in orthognathic surgery patients. J Craniomaxillofac Surg 41(7):657–664. https://doi.org/10.1016/j.jcms.2013.01.005
9. Marsan G, Oztas E, Kuvat SV, Cura N, Emekli U (2009) Changes in soft tissue profile after mandibular setback surgery in Class III subjects. Int J Oral Maxillofac Surg 38(3):236–240. https://doi.org/10.1016/j.ijom.2008.12.005
10. Jeon HM, Choi JY, Baek SH (2014) Soft tissue changes after posterior impaction and setback of the maxilla with Le Fort I osteotomy in skeletal class III patients. J Craniofac Surg 25(4):1495–1500. https://doi.org/10.1097/SCS.0000000000001005
11. Rupperti S, Winterhalder P, Rudzki I, Mast G, Holberg C (2018) Changes in the facial soft-tissue profile after mandibular orthognathic surgery. Clin Oral Investig 23:1771–1776. https://doi.org/10.1007/s00784-018-2609-5
12. Park SB, Yoon JK, Kim YI, Hwang DS, Cho BH, Son WS (2012) The evaluation of the nasal morphologic changes after bimaxillary surgery in skeletal class III maloccusion by using the superimposition of cone-beam computed tomography (CBCT) volumes. J Craniomaxillofac Surg 40(4):e87–e92. https://doi.org/10.1016/j.jcms.2011.05.008
13. Ghassemi M, Ghassemi A, Showkatbakhsh R, Ahmad SS, Shadab M, Modabber A, Jamilian A (2014) Evaluation of soft and hard tissue changes after bimaxillary surgery in class III orthognathic surgery and aesthetic consideration. Natl J Maxillofac Surg 5(2):157–160. https://doi.org/10.4103/0975-5950.154819
14. Fish LC, Epker BN (1987) Dentofacial deformities related to midface deficiencies. Integrated orthodontic-surgical correction. J Clin Orthod 21(9):654–664
15. Marsan G, Hocaoglu E, Cura N, Emekli U (2015) Nasal profile changes with le fort I maxillary advancement surgery. Cleft Palate Craniofac J 52(2):152–156. https://doi.org/10.1597/13-150
16. Elnagar MH, Aronovich S, Kusnoto B (2020) Digital workflow for combined orthodontics and orthognathic surgery. Oral Maxillofac Surg Clin North Am 32(1):1–14. https://doi.org/10.1016/j.coms.2019.08.004
17. Farronato G, Galbiati G, Esposito L, Mortellaro C, Zanoni F, Maspero C (2018) Three-dimensional virtual treatment planning: presurgical evaluation. J Craniofac Surg 29(5):e433–e437. https://doi.org/10.1097/SCS.0000000000004455
18. Elshebiny T, Morcos S, Mohammad A, Quereshy F, Valiathan M (2019) Accuracy of three-dimensional soft tissue prediction in orthognathic cases using Dolphin three-dimensional software. J Craniofac Surg 30(2):525–528. https://doi.org/10.1097/SCS.0000000000005037
19. Bell RB (2018) A history of orthognathic surgery in North America. J Oral Maxillofac Surg 76(12):2466–2481. https://doi.org/10.1016/j.joms.2018.09.006
20. Xue C, Tian Y, Wang L, Yang X, Luo E, Bai D (2018) Surgical guide and CAD/CAM prebent titanium plate for sagittal split ramus osteotomy in the correction of mandibular prognathism. Br J Oral Maxillofac Surg 56(7):586–593. https://doi.org/10.1016/j.bjoms.2018.06.007
21. Politi M, Costa F, Cian R, Polini F, Robiony M (2004) Stability of skeletal class III malocclusion after combined maxillary and mandibular procedures: rigid internal fixation versus wire osteosynthesis of the mandible. J Oral Maxillofac Surg 62(2):169–181. https://doi.org/10.1016/j.joms.2003.04.010
22. Rocha VA, Neto AI, Rebello IM, de Souza GM, Esteves LS, dos Santos JN, Zanetta-Barbosa D, do Prado CJ (2015) Skeletal stability in orthognathic surgery: evaluation of methods of rigid internal fixation after counterclockwise rotation in patients with class II deformities. Br J Oral Maxillofac Surg 53(8):730–735. https://doi.org/10.1016/j.bjoms.2015.05.002
23. Pektas ZO, Kircelli BH, Cilasun U, Uckan S (2007) The accuracy of computer-assisted surgical planning in soft tissue prediction following orthognathic surgery. Int J Med Robot 3:64–71. https://doi.org/10.1002/rcs.127
24. Nadjmi N, Tehranchi A, Azami N, Saedi B, Mollemans W (2013) Comparison of soft-tissue profiles in Le Fort I osteotomy patients with Dolphin and Maxilim softwares. Am J Orthod Dentofac Orthop 144(5):654–662. https://doi.org/10.1016/j.ajodo.2013.06.019
25. Kaipatur NR, Flores-Mir C (2009) Accuracy of computer programs in predicting orthognathic surgery soft tissue response. J Oral Maxillofac Surg 67(4):751–759. https://doi.org/10.1016/j.joms.2008.11.006
26. Song GY, Li G, Lu WH, Han B, Xu TM (2019) Distortion and magnification of four digital cephalometric units. Niger J Clin Pract 22(12):1644–1653. https://doi.org/10.4103/njcp.njcp_184_19
27. Dibbets JM, Nolte K (2002) Effect of magnification on lateral cephalometric studies. Am J Orthod Dentofac Orthop 122(2):196–201
28. Cohen JM (2005) Comparing digital and conventional cephalometric radiographs. Am J Orthod Dentofac Orthop 128(2):157–160. https://doi.org/10.1016/j.ajodo.2005.03.017
29. Chadwick JW, Prentice RN, Major PW, Lam EW (2009) Image distortion and magnification of 3 digital CCD cephalometric systems. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 107(1):105–112. https://doi.org/10.1016/j.tripleo.2008.09.025

30. Mankad B, Cisneros GJ, Freeman K, Eisig SB (1999) Prediction accuracy of soft tissue profile in orthognathic surgery. Int J Adult Orthodon Orthognath Surg 14(1):19–26
31. Enacar A, Taner T, Toroglu S (1999) Analysis of soft tissue profile changes associated with mandibular setback and double-jaw surgeries. Int J Adult Orthodon Orthognath Surg 14(1):27–35
32. Bengtsson M, Wall G, Greiff L, Rasmusson L (2017) Treatment outcome in orthognathic surgery-a prospective randomized blinded case-controlled comparison of planning accuracy in computer-assisted two- and three-dimensional planning techniques (part II). J Craniomaxillofac Surg 45(9):1419–1424. https://doi.org/10.1016/j.jcms.2017.07.001
33. Rustemeyer J, Martin A (2013) Soft tissue response in orthognathic surgery patients treated by bimaxillary osteotomy: cephalometry compared with 2-D photogrammetry. Oral Maxillofac Surg 17(1):33–41. https://doi.org/10.1007/s10006-012-0330-0
34. Georgalis K, Woods MG (2015) A study of Class III treatment: orthodontic camouflage vs orthognathic surgery. Aust Orthod J 31(2):138–148
35. Johnston C, Burden D, Kennedy D, Harradine N, Stevenson M (2006) Class III surgical-orthodontic treatment: a cephalometric study. Am J Orthod Dentofac Orthop 130(3):300–309. https://doi.org/10.1016/j.ajodo.2005.01.023
36. Troy BA, Shanker S, Fields HW, Vig K, Johnston W (2009) Comparison of incisor inclination in patients with Class III malocclusion treated with orthognathic surgery or orthodontic camouflage. Am J Orthod Dentofac Orthop 135(2):146 e141–146 e149; discussion 146-147. https://doi.org/10.1016/j.ajodo.2008.07.012
37. Mcneil C, Mcintyre GT, Laverick S (2014) How much incisor decompensation is achieved prior to orthognathic surgery? J Clin Exp Dent 6(3):e225
38. Becker OE, Avelar RL, Dolzan Ado N, Haas OL Jr, Scolari N, Oliveira RB (2014) Soft and hard tissue changes in skeletal Class III patients treated with double-jaw orthognathic surgery-maxillary advancement and mandibular setback. Int J Oral Maxillofac Surg 43(2):204–212. https://doi.org/10.1016/j.ijom.2013.06.006
39. Freihofer HP Jr (1976) The lip profile after correction of retromaxillism in cleft and non-cleft patients. J Maxillofac Surg 4(3):136–141
40. Jokic D, Jokic D, Uglesic V, Macan D, Knezevic P (2013) Soft tissue changes after mandibular setback and bimaxillary surgery in Class III patients. Angle Orthod 83(5):817–823. https://doi.org/10.2319/100112-775.1
41. Hemmatpour S, Kadkhodaei Oliadarani F, Hasani A, Rakhshan V (2016) Frontal-view nasolabial soft tissue alterations after bimaxillary orthognathic surgery in Class III patients. J Orofac Orthop 77(6):400–408. https://doi.org/10.1007/s00056-016-0047-z
42. Marsan G, Cura N, Emekli U (2009) Soft and hard tissue changes after bimaxillary surgery in Turkish female Class III patients. J Craniomaxillofac Surg 37(1):8–17. https://doi.org/10.1016/j.jcms.2008.07.004
43. Raschke GF, Rieger UM, Peisker A, Djedovic G, Gomez-Dammeier M, Guentsch A, Schaefer O, Schultze-Mosgau S (2015) Morphologic outcome of bimaxillary surgery–an anthropometric appraisal. Med Oral Patol Oral Cir Bucal 20(1):e103–e110
44. Choi JW, Lee JY, Oh TS, Kwon SM, Yang SJ, Koh KS (2014) Frontal soft tissue analysis using a 3 dimensional camera following two-jaw rotational orthognathic surgery in skeletal class III patients. J Craniomaxillofac Surg 42(3):220–226
45. Suh HY, Lee SJ, Lee YS, Donatelli RE, Wheeler TT, Kim SH, Eo SH, Seo BM (2012) A more accurate method of predicting soft tissue changes after mandibular setback surgery. J Oral Maxillofac Surg 70(10):e553–e562. https://doi.org/10.1016/j.joms.2012.06.187
46. Lee YS, Suh HY, Lee SJ, Donatelli RE (2014) A more accurate soft-tissue prediction model for Class III 2-jaw surgeries. Am J Orthod Dentofac Orthop 146(6):724–733. https://doi.org/10.1016/j.ajodo.2014.08.010