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Original Article

Factors influencing craniofaciadental changes in skeletal Class III orthognathic surgery by using machine learning

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Abstract *Background/purpose:* In skeletal Class III patients, treatment options include camouflage and orthognathic surgery. This study used machine learning to investigate factors influencing dental, skeletal, and soft tissue morphological changes following skeletal Class III orthognathic surgery.
Materials and methods: A retrospective analysis was conducted at Taipei Medical University Hospital. The study analyzed the lateral cephalometric radiographs of 58 patients with skeletal Class III who underwent orthognathic surgery. Web-based cephalometric software was used to obtain cephalometric tracing measurements, including dental, skeletal, and soft tissue parameters at pretreatment (T0) and posttreatment (T1), and assess postsurgical changes (T1–T0). Conventional statistical models were used for data analysis, followed by the application of machine learning–based random forest regression to identify influencing factors, as characterized by the feature of importance (FI).
Results: All cephalometric variables except SNA, A to NP, overbite, and lower lip to E-plane differed significantly between T0 and T1. ANB was significantly influenced by surgery type ($P = 0.045$), whereas IMPA and lower lip to E-plane were significantly influenced by sex (IMPA $P = 0.029$; lower lip to E-plane $P = 0.033$). According to machine learning results on the influence of pretreatment conditions, overjet was a key factor influencing several dependent variables, namely, changes in ANB (FI = 0.226), B to N-Perp (FH) (FI = 0.259), and Pog to N-Perp (FH) (FI = 0.257).

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Conclusion: Machine learning revealed the overjet plays a dominant role in several dependent variables, including changes in ANB, B to N-Perp (FH), and Pog to N-Perp (FH). Future studies should use a larger dataset and three-dimensional data.

Introduction

Orthodontic treatment aims to achieve an attractive appearance by ensuring well-aligned dental arches, an ideal occlusal relationship, and a balanced facial profile.[1] In adult patients with nongrowing skeletal Class III malocclusion, treatment options include orthodontic camouflage or orthognathic surgery, which involves mandibular setback and maxillary advancement.[2–7] Accurate diagnosis and meticulous treatment planning are paramount for successful surgical outcomes in orthognathic cases.

Machine learning has revolutionized orthognathic surgery by streamlining diagnosis, treatment planning, and outcome prediction.[8] For example, deep learning systems using landmark-based geometric morphometric methods[9] or convolutional neural network-based segmentation have been used to evaluate postsurgical changes in pharyngeal anatomy and predict stability.[10] Additionally, a study employed six machine learning models, including classification and regression trees, conditional inference trees, and random forests, to predict postsurgery pogonion stability.[11]

Understanding the complex interplay between postsurgical changes in skeletal, dental, and soft tissues is crucial for optimal treatment planning. Therefore, this study used machine learning to investigate the factors influencing these morphological changes following orthognathic surgery in individuals with skeletal Class III malocclusion.

Material and methods

This retrospective study was conducted at the Department of Orthodontics at Taipei Medical University Hospital, Taipei, Taiwan. The study involved lateral cephalometric radiographs of 58 patients with skeletal Class III malocclusion who underwent orthognathic surgery. The inclusion criteria for the sample were as follows: 1) Diagnosis of skeletal Class III malocclusion (ANB $<2^\circ$, overjet <0 mm) and receipt of surgical orthodontic treatment and 2) clear pretreatment (T0) and posttreatment (T1) radiographs (The T1 measurement was taken after the post-surgery follow-up, which varied among patients, ranging from 3 to 6 months). Patients with short lips, congenital deformities, facial trauma, or prior facial surgeries; with incomplete or missing radiographic records; or who withheld consent for medical record use or study participation were excluded. A power analysis was used to determine the minimum required sample size. The equipment used for manual tracing in this study includes a cephalometric ruler, acetate paper (tracing paper), tape, pencil, eraser, and a paper scanner.

Before sample collection, ethics approval for the study protocol was obtained from the Ethics Committee/Institutional Review Board of Taipei Medical University (N20240531). Pretreatment and posttreatment records, including lateral cephalograms, were retrieved from the hospital's patient database. The sample collection period was from May 2023 to January 2024, totaling 7 months. All cephalograms were individually traced and reviewed by two orthodontic specialists to ensure accuracy. Subsequently, radiograph landmark identification was performed using cephalometric landmarks, including hard tissue and soft tissue anatomical points (details provided separately).

The following cephalometric landmark were identified in this study: Sella (S), Nasion (N), A point (A), B point (B), Porion (Po), Orbita (O), Pogonion (Pog), Gonion (Go), Gnation (Gn), Upper Incisor (U1), Lower Incisor (L1), and Frankfurt Horizontal Plane (FH). The cephalometric measurements in this study include: SNA, SNB, ANB, Frankfurt Mandibular Plane Angle (FMA), A point to N-Perpendicular Line to FH (A to N-Perp (FH)), B point to N-Perpendicular Line to FH (B to N-Perp (FH)), Pogonion to N-Perpendicular Line to FH (Pog to N-Perp (FH)), U1 to FH, U1 to SN, Incisor Mandibular Plane Angle (IMPA), U1 to NA, L1 to NB, Upper lip to E-plane, Lower lip to E-plane, and Nasolabial angle. The T0 and T1 cephalograms were analyzed using WEBCEPH digital cephalometric analysis software (AssembleCircle Corp., Gyeonggi-do, Republic of Korea).

This analysis was based on measurements of radiograph landmarks, including dental, skeletal (both linear and angular measurement), and soft tissue landmarks. Measurement reliability was assessed in terms of the intraclass correlation coefficient. Data were processed and analyzed using standard statistical methods in SPSS Version 19.0 software (IBM Corp., Armonk, NY, USA) and machine learning in Python (Python Software Foundation, Wilmington, DE, USA). Statistical methods included linear regression models and paired or dependent t tests. The study aimed to identify factors influencing changes in each anatomical landmark, categorize their influence level, and identify the most significant factors by using a machine learning–based random forest regression model.

Results

Demographic data

The demographic characteristics of the study population, stratified by age and sex, are presented in Table 2.

Table 1 Intraclass coefficient correlation.

Samples	Intraclass coefficient correlation (average measurement)	
	T0	T1
1	0.992	0.995
2	0.993	0.990
3	0.995	0.990
4	0.992	0.992
5	0.994	1.000
6	0.982	0.993
7	0.992	0.997
8	0.988	0.994
9	0.986	0.995
10	0.996	0.997
11	0.994	0.998
12	0.990	0.990
13	0.990	0.996
14	0.993	0.995
15	0.998	0.993

Table 2 Demographic data.

Variable		n	%
Age (Mean = 21.96) (years)	16–30	55	94.8
	31–45	2	3.5
	>45	1	1.7
Sex	Male	28	48.3
	Female	30	51.7
Surgery type	1 jaw	45	77.6
	2 jaws	13	22.4
Procedure type	BSSO/SSRO	2	3.5
	IVRO	56	96.5

BSSO/SSRO: bilateral sagittal split osteotomy/sagittal split ramus osteotomy; IVRO: intraoral vertical ramus osteotomy.

Regarding age distribution, the majority of participants (90.2%) were within the 16–30 age range. Sex distribution revealed a nearly equal representation of male (45.9%) and female (49.2%) participants. Single-jaw surgery (73.8%) was the most common surgical procedure, followed by double-jaw surgery (21.3%). Regarding the specific surgical procedures performed, a vast majority (91.8%) underwent intraoral vertical ramus osteotomy, whereas a smaller fraction (3.3%) underwent either bilateral sagittal split osteotomy or sagittal split ramus osteotomy.

Cephalometric measurements

Table 3 presents a comprehensive overview of cephalometric measurements at pretreatment (T0) and posttreatment (T1) and the changes between them (T1–T0). All measurements except SNA, A to NP, overbite, and lower lip to E-plane exhibited statistically significant changes from T0 to T1. Notably, the mean change in SNB was −5.868 ($P < 0.05$). Overjet increased by a mean of 5.761 mm after treatment ($P < 0.05$).

Correlation between demographic characteristics and cephalometric measurements

Linear regression analysis was conducted to assess the influence of sex and surgery type on postsurgical tissue changes (Table 4). The results revealed a significant association between surgery type and the change in ANB ($P = 0.045$). Conversely, sex was observed to significantly influence both IMPA ($P = 0.029$) and lower lip to E-plane ($P = 0.033$).

Correlation between pretreatment cephalometric measurement values and postsurgical changes

R-squared values obtained from a random forest regression model were employed to assess the predictive power of pretreatment (T0) cephalometric measurements on postsurgical changes (T1–T0), as shown in Table 5. The results revealed a strong correlation between pretreatment and postsurgical values for overjet (T0) and overbite (T0), with R-squared values of 0.955 and 0.872, respectively. This indicates that pretreatment overjet and overbite can significantly predict postsurgical changes.

Factors influencing postsurgical changes

Random forest regression with feature importance (FI) was used to gain insights into how various pretreatment cephalometric variables influence specific postsurgical changes (Table 6). Each dependent variable was examined to identify the features contributing most significantly to its variance, reflecting the complex interplay of craniofacial characteristics. Notably, overjet was demonstrated to be a dominant factor for several dependent variables, including changes in ANB (FI = 0.226), B to N-Perp (FH) (FI = 0.259), and Pog to N-Perp (FH) (FI = 0.257). Overjet (FI = 0.908), overbite (FI = 0.852), and L1 to NB (°) (FI = 0.388) are self-referential.

Discussion

This retrospective study investigated factors influencing dental, skeletal, and soft tissue morphological changes following orthognathic surgery among individuals with skeletal Class III malocclusion. Machine learning (random forest) was used to analyze and interpret the data. One of the most valuable aspects of random forest regression is its ability to rank the importance of each feature (factor) in predicting the outcome. This helps researchers identify which factors have the most significant impact on the dependent variable. Women were slightly overrepresented in the sample. High intraclass correlation coefficient values confirmed the reliability and consistency of cephalometric measurements (see Table 1).

Dental measurements revealed notable posttreatment adjustments. Overjet considerably increased posttreatment, indicating changes in the horizontal relationship between the upper and lower incisors. This finding aligns with those of previous studies investigating surgical orthodontics for Class III malocclusion,[12–15] including the

Table 3 Pretreatment (T0) and posttreatment (T1) cephalometric measurements of patients and the changes between the two time points (T1−T0).

Variable	Measurement						P value
	T0		T1		T1−T0		
	Mean	SD	Mean	SD	Mean	SD	
Skeletal							
SNA (°)	82.586	3.753	82.961	3.812	0.375	2.287	0.216
SNB (°)	86.267	4.786	80.399	3.926	−5.868	2.739	0.000*
ANB (°)	−3.681	3.018	2.563	2.232	6.245	2.446	0.000*
FMA (°)	26.257	6.144	33.015	6.813	6.757	0.476	0.000*
A to N-Perp (FH) (mm)	−0.4	3.687	0.102	4.448	0.502	2.756	0.170
B to N-Perp (FH) (mm)	6.427	7.58	−4.916	7.38	−11.343	5.898	0.000*
Pog to N-Perp (FH) (mm)	8.006	8.775	−4.562	8.691	−12.568	6.798	0.000*
Dental							
Overjet (mm)	−2.924	3.957	2.837	1.006	5.761	3.866	0.000*
Overbite (mm)	1.041	2.954	1.364	0.879	0.323	3.122	0.434
U1 to FH (°)	121.678	7.68	114.24	8.343	−7.438	8.738	0.000*
U1 to SN (°)	114.587	8.656	107.071	8.594	−7.516	8.782	0.000*
IMPA (°)	83.114	7.811	85.288	7.278	2.173	6.625	0.015*
U1 to NA (mm)	8.375	3.05	5.644	3.017	−2.731	2.979	0.000*
U1 to NA (°)	31.994	6.965	24.109	7.774	−7.885	8.54	0.000*
L1 to NB (mm)	5.721	2.717	7.1429	2.433	1.421	1.978	0.000*
L1 to NB (°)	22.73	7.019	25.871	5.035	3.14	6.759	0.001*
Soft tissue							
Upper lip to E-plane (mm)	−4.057	2.751	−0.68	2.411	3.377	2.078	0.000*
Lower lip to E-plane (mm)	1.708	3.178	1.943	3.198	0.234	2.282	0.438
Nasolabial angle (°)	75.695	15.482	84.409	14.448	8.713	1.376	0.000*

FMA: Frankfort mandibular angle; N-Perp (FH): N-perpendicular line; Pog: pogonion; U1: upper incisor; FH: Frankfurt horizontal plane; SN: the line passing through S point and N point; NA: the line passing through N point and A point; L1: lower incisor; NB: the line passing through N point and B point; E-plane: the line passing through nose tip and soft tissue pogonion.
*$P < 0.05$ indicates significance.

observation of significant positive overjet changes reported by Florentine et al.[12] Furthermore, U1 to FH, U1 to SN, and U1 to NA (°) angles significantly decreased posttreatment (mean differences of −7.438°, −7.516°, and −7.885°, respectively), indicating changes in the upper incisor inclination. These results are consistent with those of Liu H et al.[15] However, Insawak R et al. and Troy et al. reported nonsignificant increases in these angles after surgery.[16,17] Additionally, IMPA, which represents the inclination of the lower incisors, significantly increased from T0 to T1 (mean difference = 2.173). Similarly, L1 to NB angle increased significantly (mean difference = 3.14). These findings are consistent with those of Liu et al., underscoring the treatment's effect on both the maxillary and mandibular dental arches.[15]

An analysis of skeletal measurements revealed significant posttreatment alterations. For instance, SNB decreased substantially from T0 to T1, suggesting notable changes in the mandibular position. Moreover, B to NP and Pog to NP decreased substantially posttreatment, whereas ANB and FMA increased significantly posttreatment. Studies have also reported negative SNB and positive ANB surgical changes.[13−15] Additionally, the increase in FMA (mean difference = 6.813°) suggests a change in the mandibular plane angle posttreatment. These results are in agreement with those reported in other studies.[18,19]

The upper lip to E-plane exhibited a substantial increase from T0 to T1 (mean difference = 3.377 mm), suggesting a notable change in the position of the upper lip relative to the E-plane following treatment. This finding aligns with the observations of Liu H et al., who reported a similar increase in upper lip to E-plane by 2.64 mm following surgery.[15] Furthermore, the nasolabial angle exhibited a significant increase from T0 to T1 (mean difference = 8.713 mm), indicating changes in the relationship between the nose and upper lip posttreatment. This is consistent with the findings of previous studies.[7−13]

Surgery type was demonstrated to significantly influence ANB, whereas sex significantly affected IMPA and lower lip to E-plane. Specifically, two-jaw surgery (maxillary advancement and mandibular setback) resulted in a smaller postsurgical ANB value compared with single-jaw surgery (mandibular setback only). Moreover, IMPA and lower lip to E-plane notably varied between male and female participants. These variables are interconnected because the inclination of the lower incisor can affect the position of the lower lip, which in turn influences the distance of the lower lip to the E-plane. The data suggest that sex influences IMPA and the position of the lower lip relative to E-plane. This difference may be attributed to the generally stronger and more active muscle activity in males compared to females. This factor may become more

Table 4 Correlation between sex, surgery type, and postsurgical tissue changes, as assessed using skeletal, dental, and soft tissue measurements.

Postsurgical changes (T1–T0)	Sex (*P* value)	Surgery type (*P* value)
Skeletal		
SNA (°)	0.052	0.260
SNB (°)	0.837	0.409
ANB (°)	0.409	0.045*
FMA (°)	0.372	0.307
A to N-Perp (FH) (mm)	0.736	0.732
B to N-Perp (FH) (mm)	0.211	0.184
Pog to N-Perp (FH) (mm)	0.146	0.236
Dental		
Overjet (mm)	0.074	0.176
Overbite (mm)	0.409	0.130
U1 to FH (°)	0.422	0.308
U1 to SN (°)	0.576	0.222
IMPA (°)	0.029*	0.124
U1 to NA (mm)	0.558	0.886
U1 to NA (°)	0.451	0.343
L1 to NB (mm)	0.124	0.696
L1 to NB (°)	0.059	0.103
Soft tissue		
Upper lip to E-plane (mm)	0.543	0.060
Lower lip to E-plane (mm)	0.033*	0.101
Nasolabial angle (°)	0.653	0.888

FMA: Frankfort mandibular angle; N-Perp (FH): N-perpendicular line; Pog: pogonion; U1: upper incisor; FH: Frankfurt horizontal plane; SN: the line passing through S point and N point; NA: the line passing through N point and A point; L1: lower incisor; NB: the line passing through N point and B point; E-plane: the line passing through nose tip and soft tissue pogonion.
*$P < 0.05$ indicates significance.

pronounced during the post-surgery follow-up period, leading to less significant changes in IMPA and the lower lip position relative to the E-plane in males compared to females. Further research is warranted to elucidate the underlying mechanisms related to sex differences in lower incisor inclination and lower lip position.

R-squared values were employed to assess the predictive power of pretreatment (T0) cephalometric measurements on postsurgical changes (T1–T0), as shown in Table 5. The analysis revealed a strong correlation between pretreatment and postsurgical values for overjet (T0) and overbite (T0), with R-squared values of 95.5% and 87.2%, respectively, indicating that overjet and overbite can significantly predict their corresponding postsurgical changes. Furthermore, ANB (T0) explained 41.9% of the variance in postsurgical ANB changes. Additionally, SNB (T0) demonstrated moderate predictive power for both overjet (R-squared = 61.6%) and itself (R-squared = 18.0%). Lower lip to E-plane (T0) also exhibited a moderate association with changes in overjet (R-squared = 37.1%). Most other variables exhibited relatively low R-squared values, indicating limited predictive power for changes in cephalometric measurements.

Overjet was identified as a dominant factor for several postsurgical measurements, including ANB (FI = 0.226), B to N-Perp (FH; FI = 0.259), and Pog to N-Perp (FH; FI = 0.257). FI indicates a variable's contribution to the model's predictive accuracy. This indicates that the initial overjet influences the degree of changes in ANB (the relationship between the maxilla and mandible) as well as the horizontal position of the mandible, represented by B to N-Perp (FH) and Pog to N-Perp (FH). Skeletal Class III malocclusion is characterized by compensated upper and lower incisors, where the upper incisors are more proclined, whereas the lower incisors are more retroclined. This compensation helps balance the sagittal position of the mandible relative to the maxilla. We postulate that a larger pretreatment reverse overjet necessitates a greater degree of mandibular setback surgery to achieve ideal overjet postsurgery. This explains the observed association between pretreatment reverse overjet and the degree of surgical changes in ANB. Similarly, the backward mandibular movement during surgery results in negative changes in B to N-Perp (FH) and Pog to N-Perp (FH), further supporting the findings on the influence of pretreatment overjet on these parameters.

Furthermore, overjet and overbite exhibited high FI values of 0.908 and 0.852, respectively. These high values indicate a strong correlation between the pretreatment measurement (T0) and the magnitude of its postsurgical change (T1–T0). In simpler terms, the initial degree of overjet, overbite, and L1 to NB (°) can effectively predict the extent of their correction following surgery.

This study has some limitations. First, the relatively small sample size restricts the generalizability of the findings. Additionally, the dataset may not be amenable for analysis with complex machine learning techniques to identify underlying patterns and relationships. Consequently, the random forest regression analysis yielded a limited number of significant findings, which may not fully capture the complexity of the postsurgical changes. The random forest analysis employs bootstrap aggregation to construct decision trees, which are built from random bootstrap samples of the original data. This ensemble approach across all trees produces a robust and accurate classifier. This machine learning technique maximizes information by resampling the data (bootstrapping) with an acceptable sample size in our study. The accuracy of predictive variables can be assessed by the R-square score. Although the relationship between variables is not strong, the findings are still valuable for identifying correlated features. Another limitation is the restricted range of surgical techniques and patient ages. This homogenous nature of the surgical procedures and age groups hinders the exploration of the full spectrum of surgical outcomes and their variability across different patient demographics.

To address these limitations, future research should incorporate a larger and more diverse patient sample. Moreover, the current study only incorporated two-dimensional patient records in the sagittal and vertical directions, with no information on movement in the lateral dimension (side to side). Therefore, future research should incorporate three-dimensional imaging techniques, such as cone beam computed tomography and three-dimensional photogrammetry. These advanced imaging modalities would enable a more comprehensive and accurate assessment of postsurgical morphological changes, enabling

Table 5 R-squared values for the influence of pretreatment (T0) cephalometric measurements on postsurgical changes (T1−T0).

Pretreatment/Postsurgical changes	SNA (°)	SNB (°)	ANB (°)	FMA (°)	A to N-Perp (FH) (mm)	B to N-Perp (FH) (mm)	Pog to N-Perp (FH) (mm)	Overjet (mm)	Overbite (mm)	U1 to FH (°)
Skeletal										
SNA (°)	0.117	0.000	0.000	0.000	0.000	0.000	0.228	0.199	0.000	0.000
SNB (°)	0.178	0.180	0.126	0.109	0.006	0.143	0.325	0.616	0.000	0.000
ANB (°)	0.000	0.023	0.419	0.172	0.000	0.221	0.256	0.519	0.065	0.000
FMA (°)	0.000	0.000	0.000	0.098	0.000	0.000	0.000	0.000	0.000	0.000
A to N-Perp (FH) (mm)	0.000	0.000	0.286	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B to N-Perp (FH) (mm)	0.030	0.091	0.000	0.000	0.000	0.105	0.487	0.000	0.000	0.000
Pog to N-Perp (FH) (mm)	0.000	0.064	0.000	0.000	0.000	0.142	0.334	0.026	0.000	0.000
Dental										
Overjet (mm)	0.000	0.000	0.200	0.000	0.047	0.000	0.000	0.955*	0.000	0.000
Overbite (mm)	0.000	0.000	0.203	0.218	0.000	0.000	0.000	0.270	0.872*	0.000
U1 to FH (°)	0.000	0.014	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000
U1 to SN (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
IMPA (°)	0.000	0.000	0.000	0.000	0.000	0.238	0.000	0.000	0.000	0.000
U1 to NA (mm)	0.000	0.133	0.000	0.000	0.000	0.175	0.000	0.454	0.000	0.082
U1 to NA (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.046	0.000	0.029
L1 to NB (mm)	0.018	0.000	0.000	0.000	0.000	0.106	0.000	0.000	0.000	0.000
L1 to NB (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Soft tissue										
Upper lip to E-plane (mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.257	0.000	0.000
Lower lip to E-plane (mm)	0.000	0.000	0.000	0.000	0.000	0.371	0.000	0.000	0.000	0.132
Nasolabial angle (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Pretreatment/Postsurgical changes	U1 to SN (°)	IMPA (°)	U1 to NA (mm)	U1 to NA (°)	L1 to NB (mm)	L1 to NB (°)	Upper lip to E-plane (mm)	Lower lip to E-plane (mm)	Nasolabial angle (°)
Skeletal									
SNA (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
SNB (°)	0.125	0.286	0.000	0.015	0.000	0.000	0.000	0.000	0.000
ANB (°)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
FMA (°)	0.000	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000
A to N-Perp (FH) (mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
B to N-Perp (FH) (mm)	0.000	0.288	0.000	0.000	0.000	0.000	0.028	0.000	0.000
Pog to N-Perp (FH) (mm)	0.000	0.261	0.000	0.000	0.000	0.000	0.142	0.000	0.000
Dental									
Overjet (mm)	0.087	0.000	0.000	0.000	0.152	0.000	0.173	0.000	0.000
Overbite (mm)	0.000	0.000	0.000	0.291	0.000	0.000	0.000	0.000	0.000
U1 to FH (°)	0.041	0.060	0.000	0.000	0.102	0.000	0.204	0.000	0.000
U1 to SN (°)	0.199	0.105	0.000	0.000	0.154	0.000	0.089	0.000	0.000
IMPA (°)	0.000	0.169	0.000	0.000	0.000	0.179	0.198	0.246	0.000
U1 to NA (mm)	0.183	0.000	0.000	0.104	0.338	0.000	0.000	0.000	0.000
U1 to NA (°)	0.183	0.064	0.000	0.000	0.051	0.000	0.145	0.000	0.000
L1 to NB (mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.489	0.113	0.000
L1 to NB (°)	0.000	0.000	0.000	0.000	0.000	0.168	0.245	0.318	0.000
Soft tissue									
Upper lip to E-plane (mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lower lip to E-plane (mm)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nasolabial angle (°)	0.112	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.094

FMA: Frankfort mandibular angle; N-Perp (FH): N-perpendicular line; Pog: pogonion; U1: upper incisor; FH: Frankfurt horizontal plane; SN: the line passing through S point and N point; NA: the line passing through N point and A point; L1: lower incisor; NB: the line passing through N point and B point; E-plane: the line passing through nose tip and soft tissue pogonion.
*$R^2 > 0.7$ indicates a strong correlation.

Table 6 Feature importance ranking for pretreatment cephalometric measurements (T0) in predicting postsurgical changes by using random forest regression.

Dependent variable		Feature	Importance
Skeletal	ANB	Overjet	0.226
		ANB	0.210
		SNB	0.097
		Upper lip to E-plane	0.079
		Nasolabial angle	0.068
	B to N-Perp (FH)	Overjet	0.259
		B to N-Perp (FH)	0.089
		Upper lip to E-plane	0.089
		SNB	0.07
		ANB	0.049
	Pog to N-Perp (FH)	Overjet	0.257
		Upper lip to E-plane	0.084
		Lower lip to E-plane	0.082
		B to N-Perp (FH)	0.077
		SNB	0.056
Dental	Overjet	Overjet	0.908
		L1 to NB	0.015
		Upper lip to E-plane	0.008
		B to N-Perp (FH)	0.007
		Overbite	0.007
	Overbite	Overbite	0.852
		Overjet	0.024
		A to N-Perp (FH)	0.014
		FMA	0.013
		Nasolabial angle	0.013
	L1 to NB (°)	L1 to NB	0.388
		L1 to NB	0.171
		IMPA	0.09
		ANB	0.057
		SNA	0.039
Soft tissue	Upper lip to E-plane	Upper lip to E-plane	0.225
		Overjet	0.134
		IMPA	0.122
		A to N-Perp (FH)	0.121
		SNA	0.055
	Lower lip to E-plane	Overjet	0.169
		Lower lip to E-plane	0.144
		SNB	0.086
		IMPA	0.071
		U1 to SN	0.060
	Nasolabial angle	Nasolabial angle	0.212
		Lower lip to E-plane	0.183
		SNA	0.080
		U1 to FH	0.061
		U1 to NA	0.060

E-plane: the line passing through nose tip and soft tissue pogonion; N-Perp (FH): N perpendicular line; FMA: Frankfort mandibular angle; L1: lower incisor; NB: the line passing through N point and B point; IMPA: incisor mandibular plane angle; SN: the line passing through S point and N point; FH: Frankfurt horizontal plane.

researchers to capture the full effect of surgery on the craniofacial structure.

This retrospective study investigated the effects of orthognathic surgery on craniofacial morphology in individuals with skeletal Class III malocclusion. The findings revealed significant postsurgical changes in most cephalometric measurements, with the exception of SNA, A to NP, overbite, and lower lip to E-plane. These findings suggest that orthognathic surgery effectively addresses various skeletal and dental discrepancies associated with Class III malocclusion. Furthermore, the analysis identified treatment type as a significant factor influencing the change in ANB, whereas sex was significantly associated with changes in IMPA and lower lip to E-plane. Overjet was identified as a dominant factor influencing postsurgical changes in ANB, B to N-Perp (FH), and Pog to N-Perp (FH). Future research incorporating a larger and more diverse patient population and three-dimensional imaging techniques is valuable in further elucidating the complex interplay between pretreatment characteristics, surgical approaches, and postsurgical outcomes in orthognathic surgery for skeletal Class III malocclusion.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

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