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ORIGINAL ARTICLE

Evaluation of soft tissue prediction accuracy for orthognathic surgery with skeletal class III malocclusion using maxillofacial regional aesthetic units

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Abstract

Objectives This study aimed to evaluate the soft tissue prediction accuracy of patients undergoing orthognathic surgery to correct skeletal class III malocclusion using maxillofacial regional aesthetic units.

Materials and methods Pre- and postoperative cone-beam computed tomography (CBCT) and 3D facial scans were taken for 58 patients who had undergone orthognathic surgery. The preoperative 3D facial scan was integrated with the preoperative CBCT using ProPlan CMF software. The software simulated the surgery and generated postoperative soft tissue prediction. The simulated 3D facial scan was then compared with the actual 3D facial scan obtained at least 6 months after the surgery by the maxillofacial regional aesthetic units and the facial soft tissue landmark points.

Results The anatomical regions of the upper lip, lower lip, chin, right external buccal and left external buccal prediction were above 2.0 mm. As for the soft tissue landmarks, at chl, chr, ls, stm and li, the position of predicted scan was higher than that of the actual postoperative scan.

Conclusions The accuracy of 3D soft tissue predictions using ProPlan CMF software in Skeletal III patients was clinically satisfactory according to maxillofacial regional aesthetic units combined with facial soft tissue landmark points. However, the accuracy of prediction still needed improvement in some areas.

Clinical relevance The accuracy of soft tissue prediction can be analyzed more clearly through maxillofacial regional aesthetic units so that clinicians have a deeper understanding of the use of the software to predict soft tissue change after orthognathic surgery.

Keywords Facial aesthetic units · Orthognathic surgery · Skeletal class III malocclusion · Soft tissue prediction

Introduction

Orthognathic surgery is mainly a hard tissue surgery in which the maxillofacial bones and dentition are placed in a more suitable position. However, skeletal and dental structures act as a framework for supporting soft tissue, and their changes have a significant impact on the facial appearance and aesthetics of the patient [1]. People's requirements for appearance have gradually increased with the improvement in material living standards. An increasing number of patients pay more attention to the postoperative facial effect of orthognathic surgery than to postoperative occlusal function. The final surgical effect is still shown in the postoperative soft tissue morphology. Also, the doctors are paying increasing attention to the improvement in postoperative facial shape. Therefore, the main purpose of orthognathic surgery is to improve the appearance of the face and teeth, followed by the improvement in functions. The realization of postoperative soft tissue prediction is of great significance for doctor–patient communication, surgical design and so forth [2, 3].

Traditional soft tissue prediction mainly relies on the manual tracing of cephalometric radiographs and the use of

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well-established hard-to-soft tissue ratios [4, 5]. However, they do not take into account the third dimension and hence seem to be insufficient. In recent years, three-dimensional (3D) computer planning has gained popularity as an accurate surgical simulation in 3D. It is valuable for patient communication, surgical planning and assessment of surgical outcomes [6–8]. Additionally, 3D laser technology can scan the surface of the face, and the map underlines the effect of changes in facial appearance, thus helping surgeons to decide on the type of surgery as well as on the magnitude and direction of surgical movements to correct the facial deformity [9]. Based on this foundation, various commercial software programs for 3D planning and soft tissue prediction have been introduced. ProPlan is one such program based on a finite difference method. This is a relatively fast discretization technique that allows mathematical equations to be solved through numerical approximations and has no manual setting for specific material properties [10]. The accuracy of three-dimensional soft tissue prediction using Synthes ProPlan CMF for orthognathic surgery in Chinese patients' skeletal class III malocclusion has proven to be clinically satisfactory [1]. However, the available literature indicates that the use of specific anatomical regions is more clinically meaningful than the use of the full face.

Regarding the maxillofacial anatomical area, existing studies mainly evaluated the accuracy of soft tissue prediction according to the author's own definition of anatomical partition of the mid-face region involved in orthognathic surgery. However, these partitions did not consider the muscle attachment position and the direction and homogeneity of soft tissue. Gonzales-Ulloa [11] first described the regional aesthetic units of the face to emphasize the need for restoring facial skin units in complete regions as opposed to patchwork and divided them based on the thickness, tissue structure and muscle movement of soft tissue. The final results led to the development of 40 regions of the body and 14 regions of the face based on skin thickness and histology [12]. The application of this partition in soft tissue prediction may be conducive to the later algorithm and finite element partition assignment to improve the accuracy of soft tissue prediction.

This study aimed to evaluate the soft tissue prediction accuracy of ProPlan CMF for orthognathic surgery with skeletal class III malocclusion using maxillofacial regional aesthetic units.

Materials and methods

Patients

A retrospective search of clinical notes for patients treated at the Department of Oral Maxillofacial Surgery, Peking University School and Hospital of Stomatology, Beijing, China, between 2016 and 2019, with available pre- and post-operative cone-beam CT (CBCT) scans and time-matching 3D facial stereophotogrammetric scans (within 24 h) was conducted. All patients enrolled in the study met the following additional inclusion criteria:

(1). The patient was diagnosed with skeletal class III malocclusion.
(2). The patient's age was 18–35 years.
(3). Postoperative 3D photogrammetric scans and CBCT were taken at least 6 months after the surgery.
(4). The patient had no congenital craniofacial deformity and no previous history of facial surgery or trauma.
(5). No other plastic surgery was performed during the follow-up period.

The Biomedical Ethics Committee of Peking University School and Hospital of Stomatology approved this study (Number: PKUSSIRB-202059180).

CBCT scan acquisition

A NewTom Scanner (NewTom AG, Marburg, Germany) was used to take CBCT images for the participants. All images were taken with 0.3-mm axial slice thickness, 15 × 15 cm field of view, 8.9 s scan time, 110-kV tube voltage and 5-mA tube current. CBCT was exported in digital imaging and communications in medicine format. All CBCTs were performed with the head in the natural position, lips at rest, neutral facial expression, open eyes and intercuspidation without visible activation of the muscles of mastication.

3D facial surface image acquisition

Three-dimensional facial stereophotogrammetric scans were taken using a 3dMDTrio System multicamera (3dMD, Atlanta, GA, USA) with a capture speed of 1.5 ms and 200° full-face capture. The system was equipped with three modular units, each consisting of two machine vision stereo cameras for geometry, one machine vision colour camera for texture and one speckle projector. All 3D photographs were taken with the head in the natural position, lips at rest, neutral facial expression, open eyes and intercuspidation without visible activation of the muscles of mastication.

Virtual surgery and computer image analysis

Fusion of preoperative CBCT and 3D facial scan

Both the preoperative CBCTs and 3D facial scans were imported into ProPlan CMF software. The preoperative 3D facial scan was fused with the untextured CBCT skin surface via a built-in fusion tool of the software. This resulted in a 3D textured photograph with underlying hard tissue.

Registration of pre- and postoperative CBCT

The pre- and postoperative CBCT images were reconstructed in three dimensions using ProPlan CMF software. Volumetric registration of the two 3D models was performed using the superior half of the skull that was unchanged by orthognathic surgery (Fig. 1a–b).

Virtual osteotomies and soft tissue prediction

Virtual osteotomies were performed on the preoperative 3D models to reproduce the postoperative position of the maxilla and mandible using the postoperative 3D models as a guide (Fig. 1c–d). The amount of LeFort I advancement and bilateral sagittal split osteotomy setback in the anteroposterior plane were derived for these 58 cases. Software-generated textured facial soft tissue prediction was performed for all cases (Fig. 2).

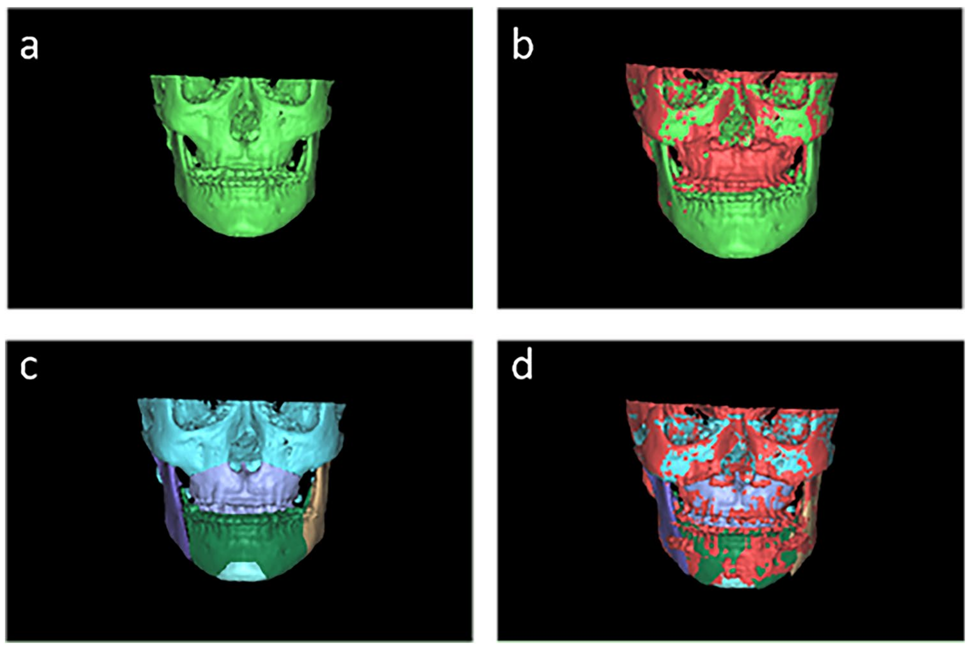

Fig. 1 Volumetric registration of pre- and postoperative 3D models and orthognathic surgery simulation. **a** CBCT reconstruction in the 3D model. **b** Volumetric registration of the pre- and postoperative 3D models. **c** Simulated osteotomy preoperative 3D model. **d** Bone blocks were registered to the postoperative 3D model to finish surgery simulation

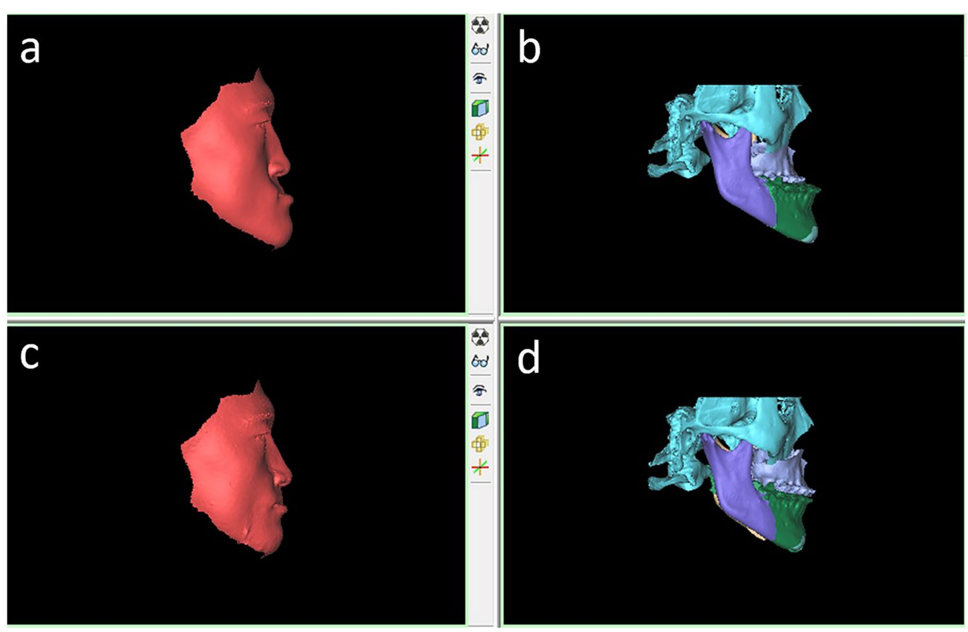

Fig. 2 Software-generated textured facial soft tissue prediction according to surgery simulation. **a** Preoperative 3D facial scan. **b** Preoperative 3D model. **c** Predicted postoperative 3D facial scan. **d** Postoperative bone blocks according to postoperative 3D model

Fusion of predicted and actual 3D facial images

The predicted and actual 3D facial scans were then imported into Geomagic Studio 2013 software (Raindrop Geomagic, Inc., NC, USA), where the registration of the two images was carried out using areas untouched by surgery. This included the forehead and nose bridge region. Following registration, the full-face images were cropped to remove the upper third of the face not affected by surgery (Fig. 3).

Prediction accuracy evaluation

Predicted and actual 3D facial images divided by maxillofacial regional aesthetic units

According to maxillofacial regional aesthetic units by Gonzales-Ulloa [12], the mid and lower thirds of the simulated and the actual faces were segmented to derive the following 10 anatomical regions: nose, upper lip, lower lip, chin, left internal buccal, left lateral buccal, left external buccal, right internal buccal, right lateral buccal and right external buccal (Fig. 4). After registration, the plane sweep was partitioned, and the root mean square (RMS) of each region was calculated. The prediction accuracy of RMS ≤ 2 mm was considered to be better [13].

Marking of soft tissue landmarks

To evaluate the 3D accuracy of soft tissue prediction, the commonly used facial soft tissue markers were marked on simulated and postoperative surface scans. The coordinates of the soft tissue points on the x, y and z planes were extracted and recorded. The three-dimensional accuracy of the soft tissue points was determined using preoperative and postoperative differences on the x, y and z planes. Based on previous findings, the soft tissue landmarks with good repeatability in the mid- and lower thirds of the face were selected as follows [14–17]: pronasale (prn), subnasale (sn), labrale superior (ls), stomion (stm), cheilion (ch) right and left, alare (al) right and left, subalare (sbal) right and left, labrale inferior (li), soft tissue B-point (B′), soft tissue pogonion (Pog′) and soft tissue menton (Me′) (Table 1 and Fig. 5).

Statistical analysis

All statistics were performed using SPSS software ver. 21.0 (IBM, NY, USA). Every measurement of the coordinate, as well as the superimposition and deviation analysis of 3D models, was performed three times, and the average was taken as the final value. The mean RMS, standard deviation and 95% confidence interval of the predicted and actual 3D facial scans and the preoperative and postoperative differences in soft tissue landmarks on the x, y and z planes were computed. One-sample Student *t* test was used to test the hypothesis that the mean absolute distance between the predicted and actual soft tissue surface mesh and soft tissue landmark coordinates was not greater than 2 mm. A *P* value of < 0.05 indicated that the results did not occur by chance.

Results

Fifty-eight patients were enrolled in this study: 37 female (63.8%) and 21 male (36.2%). The mean age at surgery was 26.7 (range 19–34) years.

Aesthetic unit analysis

The means of the RMS between the predicted and actual soft tissue postoperatively for the below two-thirds of the face image was 1.43 ± 0.40 mm. The means of the RMS of the selected anatomical area between the predicted and actual soft tissue postoperatively are shown

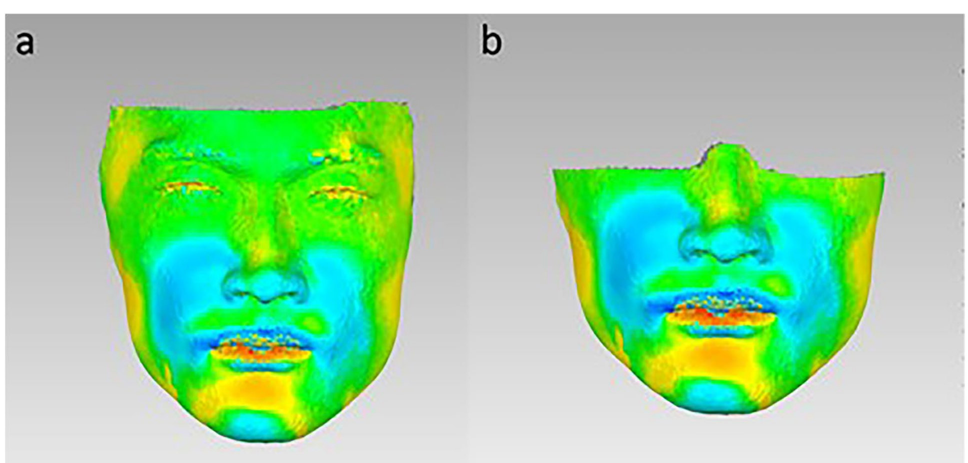

Fig. 3 Fusion of predicted and actual 3D facial images. **a** Registration of the two images according to the forehead and nose bridge region. **b** Full-face images were cropped to remove the upper third of the face not affected by surgery

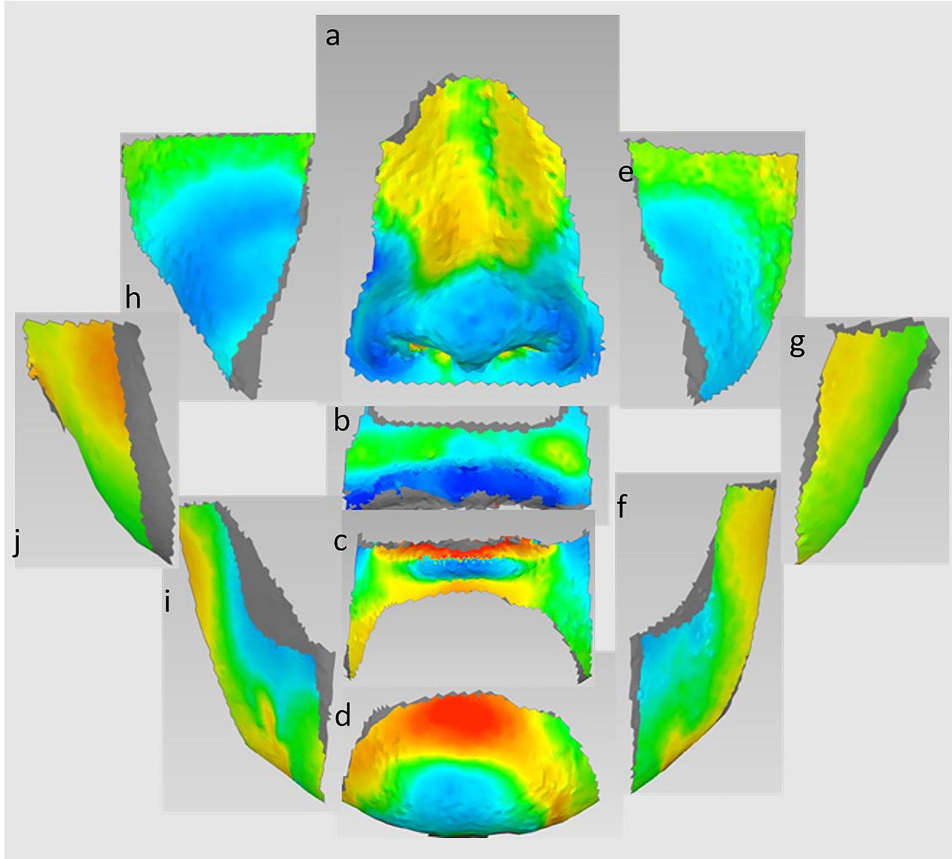

Fig. 4 Mid and lower thirds of the face were segmented to derive the following 10 anatomical regions. **a** nose, **b** upper lip, **c** lower lip, **d** chin, **e** left internal buccal, **f** left lateral buccal, **g** left external buccal, **h** right internal buccal, **i** right lateral buccal and **j** right external buccal

Table 1 Definitions of 14 soft tissue landmarks

Landmark	Abbreviation	Definition
Alare	al	The most lateral point on each alar contour
Subnasale	sn	The midpoint on the nasolabial soft tissue contour between the columella crest and the upper lip
Subalare	sbal	The point located at the facial insertion of the alar base
Pronasale	prn	The most anterior midpoint of the nasal tip
Cheilion	ch	The point located at each labial commissure
Stomion	stm	The midpoint of the horizontal labial fissure
Labrale superior	ls	The midpoint of the vermilion line of the upper lip
Labrale inferior	li	The midpoint of the vermilion line of the lower lip
Soft tissue B-point	B′	Deepest midpoint of the mentolabial sulcus
Soft tissue pogonion	Pog′	The most anterior midpoint of the chin
Soft tissue menton	Me′	Lowest median landmark on the lower border of the chin

in Table 2. The accuracy of the soft tissue simulation in the nose region was the highest (1.151 ± 0.593 mm), whereas the lower lip region was the least predictable (2.692 ± 1.251 mm). The anatomical regions of the right lateral buccal and left lateral buccal regions showed an accuracy of prediction that was significantly less than 2.0 mm ($P < 0.001$). The accuracy of the upper lip, lower lip, chin, right external buccal and left external buccal prediction was above 2.0 mm ($P < 0.001$).

Soft tissue landmark analysis

The means of the differences on the x, y and z planes of the soft tissue landmark points between the predicted and actual soft tissue postoperatively are shown in Table 3. We obtained the values of x, y and z by subtracting the simulated 3d coordinates from the postoperative 3D coordinates. The right (x-axis), front (y-axis) and below (z-axis) of the simulation and postoperative soft tissue landmark

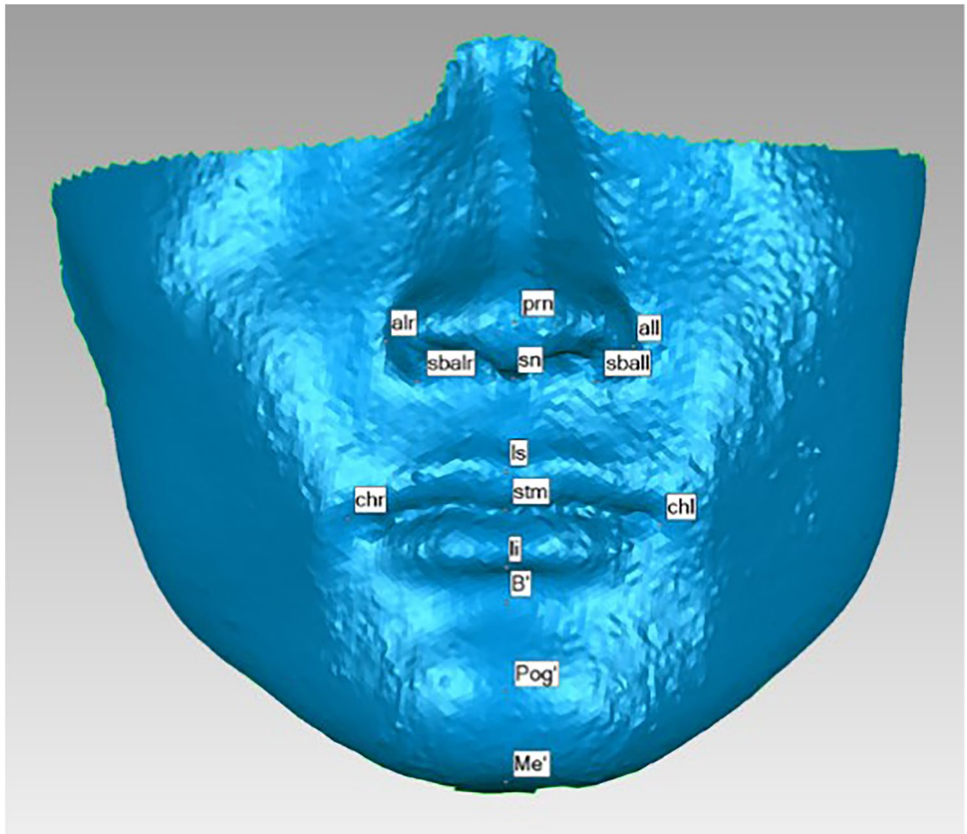

Fig. 5 Soft tissue landmarks used in this study

Table 2 Differences between the predicted soft tissue changes and the actual soft tissue changes in postoperative images

Anatomical region	*N*	Mean	SD	Min	MAX	95% CI		*T*	*P*
						Lower limit	Upper limit		
Nose	58	1.151	0.593	0.397	3.402	−0.080	0.153	0.625	0.534
Upper lip	58	2.034	0.732	0.689	3.914	0.549	0.742	13.381	<0.001
Lower lip	58	2.692	1.251	1.041	8.143	0.790	1.011	16.278	<0.001
Chin	58	2.416	1.578	0.671	7.874	0.545	0.858	8.998	<0.001
Right external buccal	58	2.206	1.210	0.526	5.552	0.500	0.792	8.867	<0.001
Right lateral buccal	58	1.738	0.813	0.651	3.892	0.320	0.569	7.141	<0.001
Right internal buccal	58	1.287	0.729	0.491	4.346	−0.010	0.254	1.851	0.069
Left internal buccal	58	1.234	0.580	0.529	3.178	0.019	0.229	2.369	0.021
Left lateral buccal	58	1.779	0.693	0.832	3.886	0.413	0.605	10.604	<0.001
Left external buccal	58	2.255	1.101	0.575	4.618	0.534	0.823	9.393	<0.001

The results of the one-sample t test are also shown together with the 95% confidence intervals. Abbreviations: *CI*, confidence interval; *Min*, the minimum value measured; *Max*, the maximum value measured; *SD*, standard deviation

point differences were defined as positive values. Most soft tissue landmarks differed by less than ± 2 mm on the x, y and z planes. The accuracies of chl, chr, ls, stm and li differed by more than − 2 mm on the z plane ($P < 0.001$). This meant that at these points, the predicted scan was higher than the actual postoperative scan.

Discussion

The mismatch in bone repositioning between preoperative planning and the final surgery is one of the important factors that affect the prediction effect of soft tissue. Previous

Table 3 Differences between soft tissue landmarks marked in the predicted soft tissue and the actual soft tissue in postoperative images

Landmark	Mean	SD	Min	Max	95% CI		*T*	*P*
					Lower limit	Upper limit		
all								
x	−0.519	1.087	−2.882	2.393	−0.805	−0.234	−3.640	0.001
y	0.015	3.201	−8.675	9.438	−0.827	0.856	0.035	0.972
z	−0.632	1.529	−6.807	3.203	−1.035	−0.230	−3.149	0.003
alr								
x	0.433	1.104	−3.217	4.281	0.142	0.723	2.985	0.004
y	−0.571	3.414	−9.882	7.997	−1.469	0.326	−1.274	0.208
z	−0.631	1.491	−4.895	2.663	−1.023	−0.239	−3.225	0.002
sball								
x	−0.462	1.560	−4.368	2.938	−0.872	−0.051	−2.254	0.028
y	0.129	1.357	−4.112	3.389	−0.227	0.486	0.727	0.47
z	−0.735	1.576	-5.852	3.323	−1.149	−0.321	−3.552	0.001
sbalr								
x	0.452	1.487	−2.512	5.309	0.061	0.843	2.317	0.024
y	0.095	1.203	−2.554	3.390	−0.221	0.411	0.601	0.55
z	−0.863	1.418	−4.968	1.702	−1.236	−0.490	−4.636	<0.001
chl								
x	1.041	2.908	−5.151	7.274	0.277	1.806	2.727	0.008
y	−0.929	2.753	−8.233	4.941	−1.653	−0.205	−2.568	0.013
z	−2.327	2.454	−7.919	2.368	−2.972	−1.682	−7.223	<0.001
chr								
x	−0.871	2.940	−7.402	6.052	−1.644	−0.098	−2.255	0.028
y	−1.046	2.688	−7.559	5.391	−1.752	−0.339	−2.963	0.004
z	−2.106	2.467	−12.262	2.911	−2.755	−1.458	−6.503	<0.001
prn								
x	0.074	0.979	−2.971	3.301	−0.183	0.332	0.577	0.566
y	0.694	1.327	−4.300	2.984	0.345	1.042	3.982	<0.001
z	−0.363	2.095	−7.341	4.431	−0.914	0.188	−1.319	0.192
sn								
x	0.082	0.983	−2.628	3.484	−0.177	0.340	0.632	0.53
y	0.825	1.462	−3.008	4.176	0.440	1.209	4.297	<0.001
z	−0.951	1.662	−6.256	4.646	−1.388	−0.514	−4.360	<0.001
ls								
x	−0.110	1.367	−4.564	2.380	−0.469	0.250	−0.611	0.543
y	−0.622	1.366	−3.955	2.108	−0.981	−0.263	−3.467	0.001
z	−2.169	2.378	−9.672	3.148	−2.794	−1.544	−6.948	<0.001
stm								
x	−0.090	1.317	−4.396	2.261	−0.436	0.256	−0.521	0.604
y	0.168	3.014	−8.934	5.681	−0.625	0.960	0.424	0.673
z	−2.374	2.694	−10.605	6.554	−3.082	−1.666	−6.712	<0.001
li								
x	−0.230	1.682	−6.967	3.305	-0.673	0.212	−1.043	0.302
y	1.102	2.405	−6.186	5.324	0.469	1.734	3.488	0.001
z	−3.339	3.361	−13.226	6.068	-4.223	-2.455	−7.566	<0.001
B′								
x	−0.014	1.555	−5.608	3.281	-0.422	0.395	−0.066	0.947
y	1.157	1.858	−3.832	6.578	0.668	1.646	4.742	<0.001
z	−1.738	2.865	−9.062	4.820	−2.492	−0.985	−4.621	<0.001

Table 3 (continued)

Landmark	Mean	SD	Min	Max	95% CI		*T*	*P*
					Lower limit	Upper limit		
Pog′								
x	−0.031	1.674	−3.712	3.826	−0.471	0.410	−0.139	0.89
y	0.064	1.407	−3.023	4.002	−0.306	0.433	0.345	0.732
z	−1.151	2.764	−7.678	7.876	−1.878	−0.424	−3.171	0.002
Me′								
x	−0.086	1.893	−5.961	3.612	−0.584	0.412	−0.345	0.731
y	−0.430	2.837	-9.647	5.106	−1.176	0.316	−1.154	0.253
z	−0.170	2.022	-5.031	5.367	−0.701	0.362	−0.639	0.525

The results of the one-sample *t* test are also shown together with the 95% confidence intervals

studies have shown that errors of 0.99 mm and 1.17 mm between the planned and actual result after Le Fort I osteotomies [18] and bimaxillary procedures [19], respectively. In order to accurately assess the prediction accuracy of the software, we performed osteotomy of the preoperative jaw according to the postoperative osteotomy line and directly registered the bone block to the postoperative position using surface based registration. Thus, the errors between the virtual planning and the final surgery were eliminated.

A difference of < 2 mm between the planned and actual outcomes in conventional lateral cephalometric analysis has been proposed to be clinically insignificant. This has been adopted by several authors as the success criterion for soft tissue prediction using 3D virtual planning [20–22]. Khambay et al. [20] compiled all the current methods of assessing the accuracy of three-dimensional soft tissue facial predictions and concluded that the use of specific anatomical regions was more clinically meaningful than the full face. Liebregts et al. [23, 24] divided the lower thirds of the face into the upper lip area, lower lip area and chin area based on specific anatomic landmarks and planes to calculate the differences between the simulation and the actual postoperative result using distance maps for these specific areas. Shafi et al. [25] divided the face into nose, right and left nares, right and left paranasal regions, upper and lower lips and chin according to the anthropometry of the head and face to validate Maxilim for predicting soft tissue changes following Le Fort I advancements. Ullah et al. [26] used the same anatomical regions to assess the accuracy of 3dMD Vultus in predicting the final 3D soft tissue facial morphology after Le Fort I advancement osteotomy.

The principle of facial aesthetic units stems directly from established reconstructive concepts. González-Ulloa [27] first described regional aesthetic units of the face and emphasized that facial units should be restored in facial reconstruction as a complete region as opposed to a patchwork fashion. Later, Thompson and Menick [28] incorporated principles of visual perception into their reconstructive surgical techniques. The same lines of aesthetic unit separation used to mask reconstructive facial surgery have become the targets of rejuvenation procedures. Orthognathic surgery, as plastic surgery, should focus more on the beauty of the facial area after surgery. The correlation of soft tissue changes is important for treating patients with malocclusion or dentofacial deformities because these changes are directly related to hard tissue changes and have significant effects on facial aesthetics [29]. ProPlan, due to its nature as commercial ad-hoc software, is designed to be user-friendly and intuitive for clinicians. Using Synthes ProPlan CMF, the accuracy of 3D soft tissue predictions for orthognathic surgery in Chinese skeletal III patients was clinically satisfactory. However, the use of specific anatomical regions is more clinically meaningful than the use of full face.

Therefore, in this study, soft tissue prediction was carried out using ProPlan software. The facial aesthetic unit was applied to evaluate soft tissue prediction after orthognathic surgery. We believed that the analysis of prediction results would be more clear, comprehensive and detailed using this method. Comparing coordinates retained more differences than comparing distances. Deviation analysis was suitable for quickly determining the differences between 3D models and where these differences were mainly concentrated due to the intuitiveness of the chromatogram. However, its accuracy was easily affected by the quality of the 3D model itself, such as metal artefacts, compression ratio in reconstruction and optimizing operation. In addition, the result of the deviation analysis was relatively simple, and the interpretation of local features was not as good as the 3D measurement. On the contrary, 3D measurement alone would not be completely accurate due to the subjectivity of manual location and the limitation of landmark coverage [30]. Therefore, this study combined deviation analysis with the analysis of soft tissue landmark points to evaluate the prediction accuracy of soft tissue.

The results showed that the prediction accuracy of the nose, right internal buccal, left internal buccal, right lateral buccal and left lateral buccal regions was significantly less than 2.0 mm. The prediction accuracy of the upper lip, lower lip, chin, right external buccal and left external buccal regions was above 2.0 mm, and the locations of chl, chr, ls, stm and li on the predicted surface scan were higher than those on the actual postoperative scan. Previous studies demonstrated inadequate accuracy in predicting postoperative three-dimensional soft tissue changes in the upper lip, lower lip and chin [31]. In these studies, bilateral external buccals were not included because of the focus on the change in the central area of the face. However, the prediction of this area involved the processing of bilateral mandibular angles and lower mandibular margins, which had a significant influence on the effect of the surgery. At the same time, the current commercial software did not modify mandibular angles and lower mandibular margins. Therefore, we included these regions in our study. The inaccurate interpretation of this area might be due to intraoperative trimming of the mandibular angle and lower mandibular margin. We found that the inaccurate soft tissue landmarks were all perioral points. The movement of the upper and lower lips was not a simple forward and backward movement but a sliding movement [32, 33]. ProPlan could not simulate this sliding movement. Previous studies found that most of the markings on the upper lip and corners of the mouth moved backward and downward after mandibular setback surgery in skeletal class III malocclusion [34]. Therefore, it was reasonable that the position of the perioral landmark point of the simulated surface scan was higher than that of the postoperative scan.

This study had some limitations. The cohort had orthodontic appliances in place during preoperative CBCT and not during postoperative CBCT, which might have introduced a small error. The selection of soft tissue marker points did not involve all aesthetic subareas. The reason for this analysis was that soft tissue marker points in other areas, such as the buccal and mandibular angles, were considered to have poor repeatability, thus increasing the error of the whole experiment. In future studies, we should select soft tissue marking points with high repeatability in each aesthetic unit to better combine the methods of maxillofacial regional aesthetic units and soft tissue landmark points.

Conclusions

The accuracy of 3D soft tissue predictions using ProPlan CMF software for bimaxillary orthognathic surgery in Skeletal III patients was clinically satisfactory according to maxillofacial regional aesthetic units combined with facial soft tissue landmark points. However, the prediction accuracy of the upper lip, lower lip, chin and bilateral external buccal regions was insufficient. Regarding the landmark points, chl, chr, ls, stm and li were higher than the actual postoperative positions. The application of this evaluation method may provide a strong foundation for the design of regional soft tissue prediction algorithms in the future.

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Author contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Lei Hou. The first draft of the manuscript was written by Lei Hou, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Declarations

Ethics approval All the procedure was approved by the Ethics Committee of Peking University School and Hospital of Stomatology (protocol no. PKUSSIRB-202059180) and was conducted in accordance with the relevant guidelines and regulations.

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

Conflict of interest The authors declare no competing interests.

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