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Soft Tissue Changes Measured With Three-Dimensional Software Provides New Insights for Surgical Predictions

Yu-Jen Chang, DDS, MS^{*}, Antônio C. O. Ruellas, DDS, PhD[†], Marilia S. Yatabe, DDS, PhD[‡], Philip M. Westgate, PhD[§], Lucia H. S. Cevdanes, DDS, PhD^{||}, and Sarandeep S. Huja, DDS, PhD[¶]

^{*}Faculty, Department of Orthodontics, Kaohsiung Chang Gung Memorial Hospital, Kaohsiung City, Taiwan, Republic of China

[†]Professor, Department of Orthodontics, Federal University of Rio de Janeiro, Rio de Janeiro, Brazil

[‡]Faculty, Department of Orthodontics, Bauru Dental School, University of São Paulo, Bauru, Brazil

[§]Associate Professor, Division of Biostatistics, University of Kentucky, Lexington, KY

^{||}Associate Professor, Department of Orthodontics, University of Michigan, Ann Arbor, MI

[¶]Professor, Division of Orthodontics, University of Kentucky, Lexington, KY

Abstract

Purpose—Although computer-aided craniofacial reconstructions allow for simulation of hard tissue changes, the prediction of the final soft tissue facial changes remains a challenge. The purpose of the present study was to evaluate the 3-dimensional (3D) soft tissue changes in patients undergoing 2-jaw orthognathic surgery.

Patients and Methods—For the present retrospective cohort study, 40 consecutive patients (11 men and 29 women; mean age 23.5 ± 4.9 years) who had undergone 2-jaw orthognathic surgery were selected. We obtained the medical and dental records from 3 weeks before surgery and 6 months after surgery. We used image processing software to segment, superimpose, and quantify the hard and soft tissue displacements in 3 dimensions before and after surgery at 15 paired locations. The soft tissue and hard tissue changes were determined through quantification of homologous landmark displacements between the preoperative and postoperative computed tomography data. We measured the 3D soft and hard tissue changes and the anteroposterior, inferosuperior, and transverse components of the changes. We quantified the ratios between the soft and hard tissue changes, tested Pearson's correlation between these changes, and developed a predictive regression equation for the observations at each location.

Results—We found that soft tissue movement followed the hard tissue movement, with a correlation nearly equal to 0.9 (range 0.85 to 0.98), suggesting that in general the soft tissues of

Address correspondence and reprint requests to Dr Huja: Division of Orthodontics, University of Kentucky, 800 Rose Street, Lexington, KY 40536; sarandeep.huja@uky.edu.

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the maxillary and mandibular landmarks are affected similarly by the skeletal movements. The anteroposterior component of the soft tissue 3D displacements followed the hard tissue movement with a ratio greater than 0.9 and with high correlation ($r > 0.9$) in the mandible.

Conclusion—The results of the present study provide surgeons with a ratio of hard to soft tissue change and the strength of the correlations, which will allow for more accurate 3D predictions for both midline and lateral structures in bimaxillary orthognathic surgical cases. In addition, predictive equations for various landmarks were developed and can be used in computer-based prediction programs to aid in treatment planning of soft tissue changes.

Craniofacial surgery allows for the correction of occlusion and jaw alignment using combined orthodontic and surgical approaches with the goal of improving dentoskeletal harmony and esthetics. The conventional approach for orthognathic surgery planning includes a comprehensive clinical examination, focusing on the face and its underlying skeletal and dental components. In this conventional approach, lateral and posteroanterior cephalometric analysis, supplemented with study model analysis, is routinely undertaken. For surgical planning, the conventional 2-dimensional (2D) approach will not necessarily reveal sufficient information about the causes of the asymmetry, which can compromise the final treatment plan and outcome.¹ The major limitation of 2D cephalometry is the application of 2D data sets to treat a 3-dimensional (3D) problem. Conventional radiographic images can be misleading when complex 3D structures are projected and mapped on 2D surfaces. Additionally, fabrication of the surgical splints introduces a degree of imprecision, because this approach relies on the experience and skill of the practitioner.

Advances in imaging and computer modeling have granted unprecedented clarity regarding the complex 3D anatomy of dentofacial structures and the corresponding soft tissues. This 3D assessment and corresponding surgical prediction provides the surgical team with unique insight to correct severe dentoskeletal issues.² The primary motivation of patients with severe deformities is the need to improve their appearance. Patients will be more concerned with improving their facial features than with the underlying skeletal bone changes.³ In contrast, the surgeon manipulates the skeletal bony segments with the intent of bringing the skeletal, dental, and soft tissue components into harmony.⁴ The diagnostic and treatment planning focus continues to be on the skeletal components, and the resulting soft tissue changes are assumed to follow the skeletal changes. However, our knowledge of the precise changes in the soft tissue in response to 2-jaw orthognathic surgeries is limited. However, with 3D imaging and planning, we are able to exploit data sets to precisely quantify the 3D soft tissue changes that occur in response to orthognathic surgery.⁵

The purpose of the present study was to analyze quantitatively the 3D soft tissue changes that occur after bimaxillary surgery. Specifically, we quantified and determined the relationship between the soft tissue responses to repositioning of the osseous structures in bimaxillary surgery in 3 dimensions. We hypothesized that 3D osseous repositioning would have no effect on the soft tissue response.

Patients and Methods

For the present retrospective cohort study, 40 consecutive adult patients (11 men and 29 women; mean age 23.5 ± 4.9 years) who had undergone 2-jaw orthognathic surgery (maxillary Le Fort I osteotomy and mandibular bilateral sagittal split osteotomy) from 2012 to 2014 were selected retrospectively after excluding those with craniofacial syndromes (Table 1). The entire data set was analyzed for changes associated with the hard tissue and the ensuing soft tissue response. The CT data at 3 weeks preoperatively and 6 months postoperatively were available for all 40 patients. The predictor variables were the 3D changes in the hard tissues, and the outcome variable was the ensuing 3D soft tissue changes.

SUBJECTS

All experimental procedures were performed in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) with the requisite institutional review board approval (approval no. 104-0373C). The study population included all consecutive patients who had undergone bimaxillary orthognathic surgery, with CT scans taken 3 weeks before surgery and 6 months after surgery at a single institution. To be included in the study sample, the patients were required to have undergone maxillary Le Fort I osteotomy and mandibular bilateral sagittal split osteotomy. Patients were excluded as study subjects if they had craniofacial syndromes.

In the present study, the traditional assessment tools, such as clinical examination, standardized photographs (intraoral and extraoral, including dental occlusion and oblique, frontal, and lateral views of the face), and 2D cephalograms (lateral and posteroanterior) were used for initial treatment planning. Once all the required orthodontic preoperative movements had been completed and 3 weeks before surgery (T_1), a medical CT scan (64:120 kVp, 350 mA, 0.5 second rotation time, $0.5 \text{ mm} \times 64$ slices; Aquilion, Toshiba Medical, Otawara, Japan) was obtained for surgical planning. This scan served as the preoperative (T_1) 3D image acquisition on which the simulated surgical procedures and repositioning of the osteotomized bony structures were performed using two 3D imaging programs (Rhinoceros; Robert McNeel & Assoc, Seattle, WA; and Geomagic; Geomagic Inc, Cary, NC). The maxillomandibular complex rotations in the yaw, roll, and pitch axes were used to plan the final skeletal and dental positions. Detailed manipulation in terms of intercuspal positioning and elimination of interference between the osteotomized bony structures and regions at the base of the skull were achieved using the computerized program (Fig 1A). The navigation process produces a stereolithographic model for miniplate and navigation splint fabrication. The navigation splint was fabricated according to the final simulation by generating drill guide splints, positioning splints, and occlusion splints for use during surgery (Fig 1B). The customized prebent miniplate was adjusted on the stereolithographic model, allowing the surgeon to place the preformed miniplate on to the bony segments accurately (Fig 1C) during the orthognathic surgery. A second CT scan was obtained at 6 months postoperatively (T_2). The T_2 scans were taken 6 months after surgery to assess the treatment outcome.

3D ANALYSIS OF SURGICAL OUTCOMES

We used 2 open-source software programs, ITK-SNAP (available at: <http://www.itksnap.org/pmwiki/pmwiki.php>) and 3D-Slicer (available at: <http://www.slicer.org>) to precisely segment, superimpose, and quantify the hard and soft tissue changes after surgery.⁶⁻⁸ Open source software tools have been applied to quantify dental and skeletal changes and have been validated for intra- and inter-rater reliability. Previous assessments of the soft tissue changes for mandibular advancement have been limited by assessments using only closest point color-coded maps that cannot be used to measure homologous or corresponding distances. The present study used a recently validated method to quantify the 3D changes and their anteroposterior, vertical, and transverse components. We applied these tools to quantify the soft tissue changes after bimaxillary orthognathic surgery in our patient population.⁹ We identified and labeled 15 hard tissue and their corresponding soft tissue landmarks using ITK-Snap, including 7 midsagittal structures (ANS/tip of nose, A/subnasale, upper-central-incisor/upper lip, lower-central-incisor/lower lip, B/Si, Pog/Pog', Me/Me') and 8 corresponding lateral landmarks (tip of right/left maxillary/mandibular canine root to corresponding soft tissue landmarks, tip of right/left maxillary/mandibular first molar mesial root to corresponding soft tissue landmarks). Landmark identification was conducted by one trained and calibrated operator. These landmarks are depicted in Figure 2 and were identified on both the T₁ (3 weeks before surgery) and the T₂ (6 months after surgery) scans. All T₁ and T₂ scans were registered using voxel-based registration relative to the cranial base. The method also included the head orientation relative to the FH plane, which was critical.⁹ The corresponding 3D points (Fig 3) were visualized using 3D Slicer's quantitative 3D cephalometrics (quantification of 3D components [Q3DC]) tool.⁸ By placement of fiducial markers, this tool allows users to compute the 3D distance between the T₁ and registered T₂ hard and soft tissue points and the distances along each of the axes in the 3D space: right-left, anteroposterior (AP), and superoinferior components of the 3D distances. The data collected 3 weeks before surgery and 6 months after surgery were used to determine the soft tissue changes in response to the bimaxillary surgery.

ANALYSIS OF HARD AND CORRESPONDING SOFT TISSUE CHANGES

First, the correlations between the T₁ and T₂ hard tissue displacements and the T₁ and T₂ soft tissue corresponding landmarks were determined. For the purposes of the present study, the correlations were defined as follows: 0.90 to 1.00, very high correlation; 0.70 to 0.89, high correlation; 0.50 to 0.69, moderate correlation; 0.30 to 0.49, low correlation; and 0.00 to 0.29, very low correlation.¹

Second, the ratio of the soft to hard tissue changes was determined. The ratio was defined as the displacement of the landmarks between T₁ and T₂ for both the 3D soft tissue and the 3D bone. The displacement of landmarks was calculated using the Q3DC tool in the 3D Slicer software.

Finally, multiple regression analysis was used to provide additional information about the relationship between several independent or predictor variables and a dependent or criterion variable. We developed a predictive regression equation (3D Soft Tissue= $a_0+a_1\times\text{BONEAP}+a_2\times\text{BONEVer}+a_3\times\text{BONELa-t}$) for each landmark in all 3 dimensions, where BONEAP is

coefficient bone anteroposterior, BONEVer is coefficient bone vertical, and BONELat is coefficient bone lateral (a_1 , a_2 , a_3 are coefficient constants).

INTRARATER RELIABILITY

Intrarater reliability was measured using intraclass correlations for 5 variables (3 midline and 2 lateral) for 5 subjects, with measurements taken on each subject 2 weeks apart.

Results

The entire data set was analyzed for changes associated with the hard and ensuing soft tissue responses. The 3-week preoperative and 6-month postoperative CT imaging data were available for all 40 patients. Intrarater reliability was conducted for measurement error in this 3D approach and ranged from 0.97 to 0.99 and was thus deemed excellent.

CORRELATION BETWEEN HARD AND SOFT TISSUE CHANGES

We analyzed the correlation between the 3D soft tissue and 3D bone movement and also subdivided the correlations into the AP, vertical, and lateral components of the 3D measurement (Table 2). The rationale for analyzing these correlations was to provide the surgeon with the predictive values to assess the strength of the correlation. From the 3D soft tissue/3D bone correlations, we found that the soft tissue movement followed the hard tissue movement, with a correlation nearly equal to 0.9 (range 0.85 to 0.98), suggesting that the soft tissues of the maxillary and mandibular landmarks are affected similarly by the skeletal bony movements (Table 2).

RATIOS BETWEEN AMOUNT AND DIRECTION OF CHANGES

The ratio of the 3D soft tissue to 3D bone is presented in Table 3. The 3D soft tissue movement followed the hard tissue movement with a ratio nearly equal to 0.9, suggesting that the soft tissues of the mandibular landmarks (B, Pog, Me) were affected in all 3 directions by the skeletal bony movements. All the landmarks, except for the ANS/tip of nose, A/subnasale, upper-central-incisor/upper lip, and lower-central-incisor/lower lip showed a relatively high ratio of 3D soft tissue to 3D bone.

REGRESSION ANALYSIS

When changes occur in multiple directions, such as described in the present study, multiple regression analysis can better describe the changes and replace the simple ratios described previously.^{10,11} We developed an equation to describe the changes in soft tissue based on the 3 components for each of the 15 landmarks: $3D \text{ soft tissue} = a_0 + a_1 \times BONEAP + a_2 \times BONEVer + a_3 \times BONELat$. The regression equations and their statistical significance for all the landmarks are listed in Table 4. Although the AP and vertical regression coefficients were significant, the lateral coefficients were not all statistically significant.

Discussion

The purpose of the present study was to analyze the soft tissue changes related to bimaxillary orthognathic surgery from 3D data sets. The specific aims of the present study

were to understand the relationships measured by the correlation, ratio, and regression between the alterations in the soft tissue in response to hard tissue changes obtained directly from the 3D measurements. In the midsagittal plane (ANS, A, upper [U] incisor, lower [L] incisor, B, Pog, and Me point), the most important variable that described the soft tissue change was the bone movement in the AP direction. This was likely because the muscles and overlying connective tissue were tightly bound to the bone structure in this area; thus, the bone movement in the AP direction results in a predictable and proportionate change in soft tissue movement. However, we found that additional factors, such as bone shape, tone, and soft tissue thickness, were likely associated with soft tissue movement in the other 2 directions (vertical and lateral), because the correlation and prediction required additional variables to fully describe the changes in soft tissue. Furthermore, for the lateral landmarks (canine and molar areas), the soft tissue changes reflected the bone changes in all 3 planes of space, because in this area, the soft tissue is affected by all possible 3D movements and one plane did not accurately represent or predict the soft tissue changes. Understanding the changes in the vertical and lateral direction for midline structures and in all planes of space for the lateral structures is the especially novel finding from the present 3D study, because they have not been reported previously.

CORRELATION BETWEEN HARD AND SOFT TISSUE CHANGES

The maxillary 3D bony changes had a high correlation with the soft tissue changes (ANS/tip of nose, 0.86; A/subnasale, 0.85; upper-central-incisor/upper lip, 0.86; UR/UL canine, 0.91 and 0.91; and UR/UL maxillary first molar, 0.92 and 0.9), specifically in symmetry groups. In general, our study showed slightly greater correlations than that reported in the 2D study (Table 5), suggesting a more realistic ratio of change in the present 3D study.

The changes in ANS/tip of nose and A/subnasale are highly affected by bony movement in the AP and vertical direction rather than in the lateral direction. The tip of the nose and subnasale points are firmly attached to the maxillary segment, and these surgical results were designed to bring the ANS and A points into a mid-sagittal position, with AP and vertical movement but little lateral movement.

The 3D maxillary correlation between the soft and hard tissues was weaker than the mandibular correlation. Although the reason was not entirely clear, certain factors might contribute to the relatively lower correlation and smaller ratios, including alterations in the maxillary bony landmarks during surgery, in particular, in the ANS after Le Fort I surgery.^{12,13} This likely reduced the soft-to-hard tissue ratio and influenced the horizontal and, perhaps even, the vertical change. The subnasale is located at the junction of the soft and hard tissue over the maxilla and the nasal base. The firm attachment at the base of the nose prevents it from moving horizontally and vertically proportional to the corresponding hard tissue movement.^{14–16}

The mandibular 3D bony changes (B/Si, 0.99; Pog/Pog', 0.99, Me/Me', 0.98) had a very high correlation with the soft tissue changes. Compared with a 2D study, the B/Si (0.99), Pog/Pog' (0.98), and Me/Me' (0.96) correlations obtained in the 2 dimensions and 3 dimensions were similar.¹ In addition to the high correlation, we also found a lower correlation in the vertical direction for the mandible mid-sagittal landmarks, such as the

lower-central-incisor/lower lip (-0.04), B/Si (0.08), Pog/Pog' (0.12), and Me/Me' (0.1). If significant mandibular soft tissue changes in the vertical direction are desired, it should be possible to produce the required vertical bony movement. Mandibular bony movement in the lateral direction correlated ($r > 0.7$) with the corresponding soft tissue changes in the asymmetry group, because a larger lateral movement was attempted. However, 9 landmarks (upper-central-incisor/upper Lip, UR/UL canine, UR/UL first molar, LR/LL canine, and LR/LL first molar) were affected by bony movement in all 3 directions and not in one preferential or predominate direction, because the canines and first molars are located outside the mid-sagittal plane.

Nine landmarks (ANS, A, upper central incisor, B, Pog, UR canine, UR first molar, UL canine, and UL first molar) of the lateral components of the regression were not significant, as shown by the P value of the equation of regression (Table 4). Most of the landmarks except B and Pog are located on maxilla structure, it is because the surrounding soft tissue are complex, especially because the muscles are aligned layer by layer on the maxilla lateral surface bone. Hence, the lateral components of the regression were not significant. An important finding of the present study was that lateral bony changes might not be followed by corresponding soft tissue changes. The surgeon should consider this in asymmetry cases, because the skeletal tissues might become aligned, but the soft tissues, with which our patients are mainly concerned because the soft tissues affect their appearance, might not have been adequately addressed.

RATIOS BETWEEN AMOUNT AND DIRECTION OF CHANGES

Traditionally, researchers used 2D cephalometric radiography to analyze and generate predictive ratios of the soft tissue to hard tissue changes. We found 2D data for the nasal, upper lip, lower lip, and chin areas but no reports on the canine and molar areas, because these are not captured on 2D analyses. The U incisor/U lip, L incisor/L lip, B/Si, Pog/Pog', and Me/Me' in the AP direction in our study were compared with those reported in previous 2D analyses (Table 5). Our study also showed that the A/subnasale ratio was 0.59 and different from the 0.33 reported in the 2D data.^{17,18} We also found that the AP component of the A/subnasale ratio was 0.59 and different from the 0.33 reported in the 2D data (range 0.06 to 0.51 ; mean $0.33:1$).^{19–24} The ratio of the subnasale to point A was smaller than that of the lower lip and chin, suggesting that more movement will be needed in this area to produce a harmonious change. The AP component of the upper incisor/upper lip ratio was 0.57 and almost the same as that reported in 2D studies (range $0.4:1$ and $0.80:1$; mean $0.57:1$).^{22,25–27} The lower lip in our study responded at a ratio of 0.73 to the corresponding hard tissues. This is similar to the ratio found in previous investigations, which ranged from 0.6 to 0.75 to 1.0 .^{13,25} The B, Pog, and Me in our study responded at a ratio of nearly 0.9 to the corresponding hard tissues. The historical reports of mandibular setback surgery showed a $1:1$ horizontal ratio at Pog and point B^{20,21,28}; however, the ratio for the same points reported in other studies was $0.9:1$.^{13,25}

REGRESSION BETWEEN HARD AND SOFT TISSUE CHANGES

The results from the regression equation suggested that the AP direction is the most important factor and presents with the strongest correlations of the 3 directions, especially

for B, Pog, and Me. The regression equation defines the contributions of different components and provides information for future computer programming and predicting surgical outcomes (eg, in commercial available programs used for surgical prediction). The limitation of regression equations and the other data reported is that we do not clearly understand the effect of ethnicity, race, and heterogeneity in general for different populations. The current 3D data generation described in the present study used nonautomated algorithms, which are extremely time consuming. With faster processors and data handling, it will be greatly advantageous to describe changes in an area of soft tissues (eg, the entire upper lip representing the larger number of points) of interest, instead of discrete points. With current technology, this is not possible. However, in the future, this will greatly aid an accurately predicting soft tissue changes in the craniofacial complex in response to repositioning of the underlying bony segments.

In conclusion, the present study determined the correlation and ratio between the soft tissue and hard tissue at specific anatomic locations from the 3D data set. We noted important differences in the maxillary and mandibular soft tissue responses in the 3 dimensions compared with traditional 2D measurements reported previously in published studies. The proposed system of direct 3D measurement is likely a more accurate depiction of the soft tissue changes after orthognathic surgery.

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FIGURE 1.

Surgical displacements were simulated and navigation used the CASNOS framework. *A*, We used maxillomandibular complex rotation (yaw, roll, and pitch rotations) to plan the final skeletal and dental positions expected after the simulation process. *B*, The navigation splint was fabricated according to the final simulation. The customized miniplate was adjusted on the stereolithographic model. *C*, The navigation splint and miniplate on the bony structure. The splint was used directly as a bone stabilization plate during surgery. The surgeon used the maxillary navigation splint to guide the Le Fort I osteotomy cutting line and drill a hole along the planned lines in the simulation.

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FIGURE 2.

Using the ITK-SNAP software, we identified and labeled the 15 landmarks as follows: 7 mid-sagittal landmarks (ANS/tip of nose, A/subnasale, upper-central-incisor/upper Lip, lower-central-incisor/lower Lip, B/Si, Pog/Pog', Me/Me') and 8 lateral landmarks (right/left maxillary/mandibular canine root to corresponding soft tissue landmarks, tip of right/left maxillary/mandibular first molar mesial root to the corresponding soft tissue landmarks). L, lower; LL, lower left; LR, lower right; U, upper; UL, upper left; UR, upper right.

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FIGURE 3.

Three-dimensional Slicer software was used to identify the 15 paired landmarks (see Fig 2) in 3 dimensions on the hard and soft tissues both.

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Table 1**DEMOGRAPHIC PATIENT DATA AND MALOCCLUSION TYPES**

Variable	Value
Patients	40
Gender	
Male	11
Female	29
Skeletal pattern	
Skeletal Class I	5
Skeletal Class II	8
Skeletal Class III	27
Age (yr)	
Mean $\pm$ SD	23.5 $\pm$ 4.9
Range	18 yr, 1 mo to 40 yr, 2 mo

Patient selection criteria retrospectively selected in 40 consecutive adult patients (excluding those with craniofacial syndromes) who had undergone 2-jaw orthognathic surgery at Kaohsiung Chang Gung Memorial Hospital, Taiwan.

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Table 2

CORRELATION BETWEEN 3D SOFT TISSUE AND 3D BONE MOVEMENT AND COMPARISON OF 3D SOFT TISSUE WITH BONE CORRELATION IN 3 DIMENSIONS (AP, VERTICAL, AND LATERAL)

Paired Landmarks	3D Soft Tissue/3D Bone Correlation	3D Soft Tissue/AP Bone Correlation	3D Soft Tissue/Vertical Bone Correlation	3D Soft Tissue/Lateral Bone Correlation
ANS/tip of nose	0.86	0.74	0.59	0.3
A/subnasle	0.85	0.7	0.54	0.38
U central incisor/U lip	0.86	0.78	0.61	0.73
L central incisor/L lip	0.86	0.77	-0.04	0.49
B/Si	0.99	0.92	0.08	0.17
Pog	0.98	0.93	0.12	0.24
Me	0.98	0.94	0.1	0.26
UR canine	0.91	0.75	0.61	0.51
UR first molar	0.92	0.77	0.56	0.53
UL canine	0.91	0.77	0.59	0.5
UL first molar	0.9	0.76	0.52	0.55
LR canine	0.97	0.84	0.49	0.48
LR first molar	0.94	0.81	0.56	0.53
LL canine	0.98	0.85	0.46	0.45
LL first molar	0.93	0.8	0.45	0.56

Abbreviations: 3D, 3-dimensional; AP, anteroposterior; L, lower; LL, lower left; LR, lower right; U, upper; UL, upper left; UR, upper right.

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Table 3**RATIO OF 3D SOFT TISSUE TO BONE MOVEMENT**

Landmark	Soft Tissue/Bone Ratio
Tip of nose/ANS	0.54
Subnasale/A	0.58
U lip/U central incisor	0.67
L lip/L central incisor	0.76
Si/B	0.93
Pog	0.92
Me	0.92
UR canine	0.89
UR first molar	0.87
UL canine	0.87
UL first molar	0.88
LR canine	0.93
LR first molar	0.9
LL canine	0.91
LL first molar	0.88

For example, if A point was moved 1 mm, the subnasale would move 0.58 mm.

Abbreviations: 3D, 3-dimensional; L, lower; LL, lower left; LR, lower right; U, upper; UL, upper left; UR, upper right.

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Table 4**REGRESSION EQUATIONS**

Paired Landmark	Regression: 3D Soft Tissue = $a_0 + a_1 \times \text{BONEAP} + a_2 \times \text{BONEVer} + a_3 \times \text{BONELat}$
ANS/tip of nose	3D soft tissue = $0.176 + 0.45 \times \text{BONEAP}^* + 0.25 \times \text{BONEVer}^{\dagger} + 0.18 \times \text{BONELat}$
A/subnasale	3D soft tissue = $0.181 + 0.44 \times \text{BONEAP}^{\dagger} + 0.28 \times \text{BONEVer}^{\dagger} + 0.26 \times \text{BONELat}$
U central incisor/U lip	3D soft tissue = $0.318 + 0.43 \times \text{BONEAP}^{\dagger} + 0.26 \times \text{BONEVer}^{\dagger} + 0.34 \times \text{BONELat}$
L central incisor/L lip	3D soft tissue = $0.499 + 0.64 \times \text{BONEAP}^* + 0.02 \times \text{BONEVer} + 0.31 \times \text{BONELat}^{\dagger}$
B/Si	3D soft tissue = $-0.23 + 0.98 \times \text{BONEAP}^* + 0.38 \times \text{BONEVer}^* + 0.01 \times \text{BONELat}$
Pog	3D soft tissue = $-0.027 + 0.96 \times \text{BONEAP}^* + 0.38 \times \text{BONEVer}^* + 0.04 \times \text{BONELat}$
Me	3D soft tissue = $0.137 + 0.93 \times \text{BONEAP}^* + 0.36 \times \text{BONEVer}^* + 0.1 \times \text{BONELat}^{\ddagger}$
UR canine	3D soft tissue = $0.391 + 0.56 \times \text{BONEAP}^* + 0.47 \times \text{BONEVer}^* + 0.45 \times \text{BONELat}$
UR first molar	3D soft tissue = $0.433 + 0.66 \times \text{BONEAP}^* + 0.64 \times \text{BONEVer}^* + 0.1 \times \text{BONELat}$
UL canine	3D soft tissue = $1.271 + 0.5 \times \text{BONEAP}^* + 0.4 \times \text{BONEVer}^* + 0.17 \times \text{BONELat}$
UL first molar	3D soft tissue = $1.526 + 0.43 \times \text{BONEAP}^* + 0.42 \times \text{BONEVer}^* + 0.22 \times \text{BONELat}$
LR canine	3D soft tissue = $0.811 + 0.7 \times \text{BONEAP}^* + 0.32 \times \text{BONEVer}^{\dagger} + 0.55 \times \text{BONELat}^*$
LR first molar	3D soft tissue = $1.81 + 0.59 \times \text{BONEAP}^* + 0.19 \times \text{BONEVer}^{\dagger} + 0.37 \times \text{BONELat}^*$
LL canine	3D soft tissue = $0.581 + 0.7 \times \text{BONEAP}^* + 0.39 \times \text{BONEVer}^* + 0.46 \times \text{BONELat}^*$
LL first molar	3D soft tissue = $1.67 + 0.5 \times \text{BONEAP}^* + 0.31 \times \text{BONEVer}^{\dagger} + 0.38 \times \text{BONELat}^*$

3D soft tissue = $a_0 + a_1 \times \text{BONEAP} + a_2 \times \text{BONEVer} + a_3 \times \text{BONELat}$ ($X = Y + \text{coefficient bone AP} + \text{coefficient bone vertical} + \text{coefficient bone lateral}$; a_1, a_2, a_3 are coefficient constants).

An example: for case 10, the actual changes in 3D soft tissue, BONEAP, BONEVer, and BONELat was 10.217 mm, 8.168 mm, 5.213 mm, and 1.754 mm, respectively. The regression of Pog is 3D soft tissue = $-0.027 + 0.96 \times \text{BONEAP}^* + 0.38 \times \text{BONEVer}^* + 0.04 \times \text{BONELat}$. After calculating the equation of regression, the 3D soft tissue change was 9.865 mm. We can see that the calculated number is very close to the actual number. For this population, we believe these equations will be predictive of the changes that occur after orthognathic surgery.

Abbreviations: 3D, 3-dimensional; AP, anteroposterior; L, lower; Lat, lateral; LL, lower left; LR, lower right; U, upper; UL, upper left; UR, upper right; Ver, vertical.

* $P < .001$.

$^{\dagger} P < .01$.

$^{\ddagger} P < .05$.

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Table 5**COMPARISON OF 3D RATIOS IN AP DIRECTION AND FINDINGS FROM PREVIOUS 2D STUDIES**

Soft Tissue/Bone Ratio	Present Study, AP Direction Results	Results From Previous Studies
ANS/tip of nose	0.57	NR
A/subnasale	0.59	0.33
U lip/U central incisor	0.57	0.5
L lip/L central incisor	0.73	0.75
B/Si	0.89	1
Pog	0.91	1
Me	0.91	1

Abbreviations: 2D, 2-dimensional; 3D, 3-dimensional; AP, anteroposterior; L, lower; U, upper.

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