Three-dimensional soft-tissue and hard-tissue changes in the treatment of bimaxillary protrusion

R. Christian Solem,a Richard Marasco,b Luis Guiterrez-Pulido,b Ib Nielsen,c Seong-Hun Kim,d and Gerald Nelsone
San Francisco, Calif, and Seoul, Korea

Introduction: Facial convexity related to bimaxillary protrusion is prevalent in many populations. Underlying skeletal protrusion combined with increased dentoalveolar protrusion contributes to facial muscle imbalance and lip incompetence, which is undesirable for many patients. In this study, we evaluated the relationship between soft-tissue and hard-tissue changes in an orthodontically treated Asian population.

Methods: Twenty-four consecutive adult Asian patients (mean age, 24 years), diagnosed with severe bimaxillary dentoalveolar protrusion, were evaluated using pretreatment and posttreatment cone-beam computed tomography. The patients were treated with 4 first premolar extractions followed by anterior retraction with either skeletal or intraoral anchorage. Serial cone-beam computed tomography radiographs were registered on the entire cranial base and fossa. Soft-tissue and hard-tissue changes were determined through landmark displacement and color mapping.

Results: Upper lip retraction was concentrated between the nasolabial folds and commissures. Lower lip retraction was accompanied by significant redistribution of soft tissues at pogonion. Soft-tissue changes correlated well with regional facial muscle activity. Significant retractions (2-4 mm) of the soft tissues occurred beyond the midsagittal region. Use of skeletal anchorage resulted in 1.5 mm greater lower lip retraction than intraoral anchorage, with greater retraction of the maxillary and mandibular incisor root apices. Conclusions: Profound soft-tissue changes accompanied retraction of the anterior dentition with both treatment modalities. (Am J Orthod Dentofacial Orthop 2013;144:218-28)

Bimaxillary protrusion is a common dentofacial trait particularly prevalent in Asian and African populations and present in almost every ethnic group. Underlying skeletal prognathism and dentoalveolar protrusion produce a convex lower facial profile, procumbent lips, and a protrusive anterior dentition, often resulting in lip incompetence, mentalis strain, and excessive gingival display. This situation is esthetically unacceptable to some patients, and they seek treatment by an orthodontist or oral surgeon. Both orthodontic and surgical treatments can improve facial balance. Orthodontic treatment can correct dentoalveolar protrusion by uprighting and retracting the anterior teeth, typically after the extraction of 4 premolars. Surgical treatment reduces protrusion by repositioning segments of the jaws. Both treatment approaches can reduce facial convexity and improve lip posture significantly.

Improvement of the soft-tissue profile depends on many variables related to the anatomy of the face, including lip thickness, facial muscle activity, and ethnicity. The relationship between dentoalveolar movement and soft-tissue change is complex and contingent on soft-tissue relationships in all 3 planes of space. Previous studies have focused on lip changes only in the midsagittal plane, using superimposed lateral cephalograms and facial photos. However, the 2-dimensional approach fails to consider the complex 3-dimensional (3D) geometry of the human face. In particular, soft–tissue changes in the frontal view are judged more severely by patients but are often

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overlooked in clinical studies. Computer simulations that predict soft-tissue changes from orthodontic and surgical movement rely on relationships derived from the midsagittal plane. Accurate treatment predictions require data on the 3D relationships between hard-tissue and soft-tissue changes. Advances in 3D imaging with cone-beam computed tomography (CBCT) and 3D photography can be used for global evaluation of these changes.

This study was designed to evaluate the 3D changes in soft tissues resulting from hard-tissue changes produced by orthodontic treatment of bimaxillary protrusion. The goals were to (1) characterize the 3D changes to the face and skeleton resulting from retraction of the anterior teeth, (2) identify and quantify relationships between incisor and lip movement outside the midsagittal plane, and (3) test differences in results using skeletal and nonskeletal anchorage mechanics in the treatment of bimaxillary protrusion.

MATERIAL AND METHODS

The study population consisted of 24 consecutive nongrowing Asian patients with bimaxillary dentoalveolar protrusion treated in the orthodontic clinic at the University of California, San Francisco. All were treated with extraction of 4 first premolars and retraction of the anterior dentition using controlled maxillary anchorage. Institutional review board approval for the study was obtained from the University of California before treatment.

The inclusion criteria for the patients were Class I molar and canine relationships, mild or no crowding, severe dentoalveolar protrusion, and complete pretreatment and posttreatment CBCT radiographs and photos. Only Asian adults were included. The group was mostly female (n = 20), with ages ranging from 20 to 29 years. Initial protrusion was quantified by measuring the distance between the most anterior point on the maxillary and mandibular incisors to the A-point pogonion line. Lip thickness was measured from the most anterior points on the upper and lower lips to the cervical aspects of the maxillary and mandibular incisors, respectively.

Fig 1. A, Initial cephalometric measurements were made using a section centered at the midsagittal plane and aligned to the Frankfort horizontal plane. Dentoalveolar protrusion was quantified by measuring the horizontal distance from the most anterior point on the maxillary and mandibular incisors to the hard tissue A-point–pogonion line. Lip thickness was measured from the most anterior points on the upper and lower lips to the cervical aspects of the maxillary and mandibular incisors, respectively. B, Changes to the lips between pretreatment and posttreatment were measured by dividing the intercommissure distance into 5 sagittal planes and placing landmarks at the most anterior point on the upper and lower lips in each plane.

Patients meeting the inclusion criteria were divided into 2 treatment groups based on the type of anchorage used. Both groups were treated with extraction of 4 first premolars and full fixed appliances with an 0.018-in slot and twin brackets (3M Unitek, Monrovia, Calif; or Ensignia; Ormco, Orange, Calif). After the resolution of anterior crowding, the mandibular anterior teeth were retracted en masse in both groups as shown (Fig 2). In the skeletal anchorage group (n = 11), bilateral C-tube temporary skeletal anchor miniplates were placed mesially to the maxillary first molar (Fig 2). The maxillary anterior teeth were then retracted en masse on a 0.016 × 0.022-in stainless steel archwire using elastomeric chain ligated from the C-tube to a canine retraction arm placed close to the height of the center of resistance. In the nonskeletal anchorage group (n = 13), the maxillary canines were first retracted segmentally on a 0.016 × 0.022-in stainless steel archwire using a soldered 0.032-in stainless steel transpalatal archbar or arch between the maxillary first molars for anchorage (Fig 2). After retraction of the canines, the maxillary incisors were retracted en masse using intrusion-retraction loops placed distally to the lateral...
incisors. Finishing was performed on a 0.0175-in square stainless steel archwire.

CBCT scans were taken at pretreatment and posttreatment using a CB MercuRay machine (Hitachi, Tokyo, Japan). Both scans were taken with the patient in maximum intercuspal position with the lips and face in repose, as instructed by the technician. A scan captured 512 images with a 12-in diameter spherical volume encompassing the face, jaws, and entire cranial base. The voxel dimension was 0.376 mm³. DICOM data sets were converted into Amira mesh files (Visage Imaging, San Diego, Calif) and manipulated with the Amira software (version 5.4.2, Visage Imaging).

The pretreatment and posttreatment scans were registered on stable structures in the cranial base. Regions of the scan volumes were individually defined as a reference, masking structures outside the volume. This region included the entire cranial base, zygomatic arches, maxillary sinuses, frontal bone, and posterior cranial fossa (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3). These structures are stable in nongrowing regions included the entire cranial base, zygomatic arches, and maxillary sinuses. The masked posttreatment volume was plotted on the cranial base (Fig 3).

To quantify absolute changes to the dentition and soft tissues, landmark points were defined on the teeth and lips with InVivo software (InVivoDental5.0; Anatomage, San Jose, Calif). A coordinate system was constructed using an adjusted Frankfort horizontal plane passing through sella prime, right porion, and right orbitale. Orthogonal vertical planes passing through nasion were defined relative to the horizontal. Twelve hard-tissue landmarks were selected on the segmented surfaces of the skull and teeth. These landmarks included the right and left maxillary and mandibular central incisor edges and root apices, and the maxillary and mandibular first molar crowns and mesiobuccal root apices. Ten soft-tissue landmarks were defined by dividing the lips into 5 equally spaced slices spanning the intercommissure length (Fig 1, B). The most anterior points on the upper and lower lips were landmarked in each sagittal section (Fig 1, B). Vectors were then determined at each landmark between the pretreatment and posttreatment surfaces, representing movement at each location between time points. A separate mandibular superimposition using established stable structures was performed to measure the movement of the mandibular incisors.

Digital 2-dimensional cephalometric tracings were generated and superimposed on the cranial base by the pretreatment and posttreatment surfaces, vectors were calculated from each vertex on the pretreatment surface to the nearest point on the posttreatment surface, with a length equal to the Euclidean distance between the points. To determine the degree of change relative to the surface, the component of the vector perpendicular to the pretreatment surface was calculated, representing either outward (positive) or inward (negative) displacement of the surface. Surface distances were converted into a color scale, with longer wavelength colors (red) representing inward displacement, and shorter wavelength colors (blue) representing outward displacement (Fig 3). Green indicated no displacement. The color maps are a global approximation of actual surface displacements.

The accuracy of the cranial base registration was verified by visualizing the surface displacement map of the interior surface of the cranial fossa. The only deviation occurred at the boundary of the scans, which are not identical because of differences in patient orientation. Based on the color scale, differences between the surfaces was less than 0.5 mm over the region of the cranial fossa. CBCT registrations were repeated by 2 independent observers (R.C.S. and R.M.) to verify consistency. Two-dimensional slices were taken through the maxillary and ethmoid sinuses to confirm the superimposition of the trabeculae and finer structures in the sinus.

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After the volumes were registered on the cranial base, the hard-tissue skeleton and exterior soft-tissue surface were isolated using voxel-value based segmentation. The segmentation values were selected for optimal rendering and kept constant for all time points and patients. Triangular mesh surfaces were then generated representing the skeleton, teeth, and exterior facial soft tissues. To quantify the relative changes between the pretreatment and posttreatment surfaces, vectors were calculated from each vertex on the pretreatment surface to the nearest point on the posttreatment surface, with a length equal to the Euclidean distance between the points. To determine the degree of change relative to the surface, the component of the vector perpendicular to the pretreatment surface was calculated, representing either outward (positive) or inward (negative) displacement of the surface. Surface distances were converted into a color scale, with longer wavelength colors (red) representing inward displacement, and shorter wavelength colors (blue) representing outward displacement (Fig 3). Green indicated no displacement. The color maps are a global approximation of actual surface displacements.

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Digital 2-dimensional cephalometric tracings were generated and superimposed on the cranial base by

<table>
<thead>
<tr>
<th>Table I. Population characteristics</th>
<th>Nonskeletal</th>
<th>Skeletal</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>anchorage</td>
<td>anchorage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mean (SD)</td>
<td>mean (SD)</td>
<td></td>
</tr>
<tr>
<td>U1i-A Pg (mm)</td>
<td>10.67 (2.38)</td>
<td>11.58 (2.57)</td>
<td>0.68</td>
</tr>
<tr>
<td>L1i-A Pg (mm)</td>
<td>6.43 (3.19)</td>
<td>6.81 (3.26)</td>
<td>0.91</td>
</tr>
<tr>
<td>SN/MP (°)</td>
<td>34.02 (5.84)</td>
<td>36.22 (5.64)</td>
<td>0.40</td>
</tr>
<tr>
<td>U1/PP (°)</td>
<td>122.10 (6.70)</td>
<td>119.58 (5.74)</td>
<td>0.45</td>
</tr>
<tr>
<td>L1/MP (°)</td>
<td>99.40 (5.35)</td>
<td>98.23 (4.98)</td>
<td>0.62</td>
</tr>
<tr>
<td>SNA (°)</td>
<td>83.79 (3.81)</td>
<td>83.29 (4.10)</td>
<td>0.45</td>
</tr>
<tr>
<td>SNB (°)</td>
<td>80.35 (4.42)</td>
<td>80.34 (3.45)</td>
<td>0.91</td>
</tr>
<tr>
<td>Maxillary crowding (mm)</td>
<td>-3.90 (2.02)</td>
<td>-3.85 (0.84)</td>
<td>0.94</td>
</tr>
<tr>
<td>Mandibular crowding (mm)</td>
<td>-2.60 (0.75)</td>
<td>-2.85 (0.57)</td>
<td>0.99</td>
</tr>
<tr>
<td>UL thickness (mm)</td>
<td>11.59 (1.45)</td>
<td>10.65 (2.59)</td>
<td>0.33</td>
</tr>
<tr>
<td>LL thickness (mm)</td>
<td>16.28 (1.64)</td>
<td>12.88 (2.08)</td>
<td>0.71</td>
</tr>
<tr>
<td>Age (y)</td>
<td>21.6 (7.1)</td>
<td>27.4 (7.9)</td>
<td>0.10</td>
</tr>
<tr>
<td>Sex (% female)</td>
<td>91</td>
<td>70</td>
<td>0.22</td>
</tr>
</tbody>
</table>

Note: UL, upper lip; LL, lower lip.
using TIOPS software (Roskilde, Denmark; www.tiops.com). Lateral cephalograms were generated from the CBCT data with Dolphin software (version 11.7; Dolphin Imaging, Chatsworth, Calif).

**Statistical analysis**

Displacement vectors for landmarks on the central incisors and lips were determined between pretreatment and posttreatment on the CBCT radiographs. The inclination changes of the incisors were measured as the change in axial inclination between pretreatment and posttreatment. The vertical and anteroposterior components of each vector were averaged between the right and left incisors. The anteroposterior components of lip movement were averaged across 5 planes spanning the intercommissure length for the upper and lower lips to determine the average anteroposterior movement for each lip.

**Fig 2.** Clinical photos of the space-closing mechanics used in the 2 treatment groups. The mandibular arch was treated the same in both groups. After alignment and resolution of crowding, the mandibular anterior dentition from canine to canine was retracted en masse on 0.016 × 0.022-in stainless steel wire in 0.018-in slot brackets using elastomeric chains ligated from the first molar to the canine. In the skeletal anchorage group, the maxillary anterior dentition was retracted en masse with a 0.016 × 0.022-in stainless steel archwire passing through the labial c-tube temporary skeletal anchorage miniplates placed mesially to the maxillary first molar. Elastomeric chains were ligated from hooks on the archwire to the C-tube for retraction. In the nonskeletal anchorage group, the maxillary canines were retracted segmentally on a 0.016 × 0.022-in stainless steel archwire using a transpalatal archbar or arch between the maxillary first molars for anchorage.
The validity of superimposition and landmark placement was determined by having 2 independent observers (R.C.S. and R.M.) perform multiple observations on the records of 10 randomly selected patients from the combined groups. These calibrated observers repeated superimposition and landmark placement at 2-week intervals to determine interobserver and intraobserver errors. The variability in the anteroposterior and vertical components of the displacement vectors between observations was used to calculate intraclass correlation coefficients to test reliability. These values for intraobserver and interobserver correlations were all greater than 0.85. In addition, Bland-Altman plots were made to analyze the interobserver differences. Histograms were constructed for all variables to assess normality. Because of the small sample size and the lack of normality, nonparametric methods were used. Intergroup differences were compared using the Wilcoxon rank sum test. Interactions between variables were mostly linear, as determined from testing in linear and quadratic models. The nonparametric Spearman rank correlation coefficient was calculated for each comparison and adjusted for multiple comparisons using the Holm-Sidak correction. The Stata software package (StataCorp, College Station, Tex) was used for statistical calculations.

RESULTS

The profiles of our patients were characterized by convexity of the lower facial third. The typical lip profile was protrusive, demonstrating either mentalis strain or an interlabial gap at rest. The variability in lip thickness was relatively low in the population (mean SD of 1.94 mm). Crowding was mild (<4 mm) in each arch and not significantly different between groups (Table I). The skeletal sagittal jaw relationship was within normal limits in both groups. There were no statistically significant (P > 0.05) differences in the dental or skeletal parameters between the groups.

The maxillary incisor edges were retracted 1.47 mm more posteriorly on average in the skeletal anchorage group than in the nonskeletal group (P = 0.13; Table II). The root apices of the maxillary incisors in the skeletal anchorage group were retracted approximately 0.9 mm on average, with little apical root retraction in the nonskeletal anchorage group (P = 0.053; Table II). This movement was accompanied by 3.36 degrees of greater reduction on average in maxillary
incisor proclination in the nonskeletal anchorage group. These differences, however, were not statistically significant with the available sample size. Movement of the maxillary incisor edge followed a consistent inferior and posterior vector, with a high degree of correlation between anteroposterior and vertical movement ($P = 0.0005$; Table III). The sagittal and vertical movements of the maxillary incisors were highly correlated with the degrees of retroclination ($P = 0.0002$; Table III), indicating primarily an apex-centered tipping movement, especially in the nonskeletal anchorage group.

The reduction in mandibular incisor proclination was not significantly different between treatment groups. Movement of the mandibular incisors was more variable in both groups. Coordination between vertical and horizontal movement was low ($\rho = -0.10$; Table III), indicating significant variability in the vector of movement. Retraction of the anterior teeth was accompanied by significant remodeling of the supporting alveolar bone. In both groups, remodeling of alveolar bone was measured around the roots of the maxillary and mandibular anterior teeth, and it was approximately 1 to 2 mm in magnitude (Figs 4, A2-C2, and 5, A2-C2).

The maxillary first molars moved significantly more mesially (2.40 mm) in the nonskeletal anchorage group ($P = 0.008$; Table II). No significant difference was detected in the vertical movement of the maxillary molars. However, there was considerable variability in vertical movements between subjects. This vertical movement produced measurable degrees of forward (Fig 4, A1) or backward (Fig 5, C1) rotation of the mandible.

Three-dimensional soft-tissue displacement varied considerably between patients and treatment groups (Figs 4, A3-C3, and 5, A3-C3). Significant redistributions of soft tissues were measured at the submental sulcus and soft-tissue pogonion. The lip change extended to the nasolabial folds laterally, the columella superiorly, and the mentolabial sulcus inferiorly. Patients beginning with a resting interlabial gap showed the greatest change in lower lip position in response to maxillary incisor retraction (Figs 4, A3 and C3, and 5, C2). Changes outside the lip region were seen in the lateral views in several patients, notably in the masseter region and cheeks, where inward soft-tissue movements were detected (Figs 4, C3, and 5, C3). Some patients experienced significant changes in weight during the treatment period, as noted in their facial photographs, consistent with generalized retraction of soft tissues in the cheeks. In patients in whom the mandibular plane angle decreased due to maxillary molar intrusion, the chin moved anteriorly, as shown in the skeletal and soft-tissue projections (Fig 4, A1 and A3).

Mean lower lip retraction was greater in the skeletal anchorage group by 1.49 mm, but this was not statistically significant ($P = 0.051$; Table II). Retraction of the lower lip was significantly correlated with the anteroposterior movements of the mandibular incisors ($\rho = 0.71$; Table III), with little correlation ($\rho = 0.52$; Table III) with upper incisor anteroposterior movement. Retraction of the upper lip was highly correlated with anteroposterior movement of the maxillary incisors ($\rho = 0.74$; Table III) and slightly correlated with anteroposterior movement of the mandibular incisors.

### Table II. Intergroup differences

<table>
<thead>
<tr>
<th>Mean movement (pretreatment-posttreatment)</th>
<th>Nonskeletal anchorage</th>
<th>Skeletal anchorage</th>
<th>Difference</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1L retraction (mm)</td>
<td>2.26 (0.13)</td>
<td>2.67 (0.36)</td>
<td>−0.49</td>
<td>NS</td>
</tr>
<tr>
<td>L1L retraction (mm)</td>
<td>2.63 (0.40)</td>
<td>4.12 (0.73)</td>
<td>−1.49</td>
<td>0.051</td>
</tr>
<tr>
<td>U1i retraction (mm)</td>
<td>4.16 (0.74)</td>
<td>5.63 (0.66)</td>
<td>−1.47</td>
<td>0.13</td>
</tr>
<tr>
<td>U1i extrusion (mm)</td>
<td>1.79 (0.37)</td>
<td>1.84 (0.37)</td>
<td>−0.04</td>
<td>NS</td>
</tr>
<tr>
<td>U1 root retraction (mm)</td>
<td>−0.081 (0.33)</td>
<td>0.89 (0.47)</td>
<td>−0.97</td>
<td>0.053</td>
</tr>
<tr>
<td>L1i retraction (mm)</td>
<td>3.39 (0.74)</td>
<td>3.14 (0.71)</td>
<td>−0.25</td>
<td>NS</td>
</tr>
<tr>
<td>L1i intrusion (mm)</td>
<td>0.40 (0.23)</td>
<td>0.54 (0.37)</td>
<td>−0.13</td>
<td>NS</td>
</tr>
<tr>
<td>U1 retroclination (°)</td>
<td>13.18 (2.60)</td>
<td>9.82 (1.59)</td>
<td>−3.36</td>
<td>NS</td>
</tr>
<tr>
<td>L1 retroclination (°)</td>
<td>8.75 (1.45)</td>
<td>9.89 (1.72)</td>
<td>−1.14</td>
<td>NS</td>
</tr>
<tr>
<td>U6 crown A-P (mm)</td>
<td>1.95 (0.40)</td>
<td>−0.45 (0.55)</td>
<td>2.40</td>
<td>0.008*</td>
</tr>
<tr>
<td>U6 root A-P (mm)</td>
<td>1.81 (0.13)</td>
<td>−0.53 (0.32)</td>
<td>2.34</td>
<td>0.0004*</td>
</tr>
<tr>
<td>U6 crown extrusion (mm)</td>
<td>0.02 (0.23)</td>
<td>0.83 (0.46)</td>
<td>−0.81</td>
<td>0.17</td>
</tr>
</tbody>
</table>

Lip retraction was measured as the mean anteroposterior retraction at 5 landmarks spanning the intercommissure distance. U1L, Upper lip; LL, lower lip; U1i, maxillary incisal edge; L1i, mandibular incisal edge; L1, mandibular central incisor; U6, maxillary first molar; A-P, anteroposterior.

*P <0.05; NS indicates P >0.2.
Correlation with vertical movement of the maxillary incisors was observed, but it was not statistically significant ($p = -0.60$; Table III). Significant lip retraction occurred in vertical sections away from the midline, diminishing only slightly toward the nasolabial fold (Figs 4, A3-C3, and 5, A3-C3). The retraction vector progressed from an anteroposterior direction at the midsagittal plane to a more laterally oriented vector near the commissures. The lower lip retraction zone was narrower, bounded by the submental sulcus inferiorly and the commissures laterally (Figs 4, A3-C3, and 5, A3-C3).

**DISCUSSION**

Interpretation of the true soft-tissue displacement is complicated by confounders such as weight change, variations in head posture, and facial muscle activity.\(^{9,34}\) We observed significant retraction of the upper and lower lips during treatment; this corresponded with values from previous studies.\(^5\) Three-dimensional studies of soft-tissue changes after surgical advancement of the maxillary alveolar process were concentrated in a triangular area spanning the nasolabial folds, similar to our measurements.\(^{13}\)

The shape of the nasolabial fold is specifically influenced by muscle activity and age, and the nasolabial fold disappears in a paralyzed face.\(^{39}\) It is made up of dense fibrous tissue and striated muscle bundles, with insertions for the levator muscles of the upper lip. This connective tissue plane might function as a boundary to upper lip retraction, accompanied by changes in resting muscle activity in the lip levator and orbicularis oris musculature. Other studies have noted significant changes at the soft-tissue pogonion level from orthodontic retraction or anterior segmental osteotomy.\(^{40}\) These changes might be related to relaxation of the mentalis muscle and redistribution of the soft tissues in response to dental retraction.\(^{40}\) Three-dimensional evaluation of lower lip changes after surgical mandibular setback followed a similar pattern, with changes concentrated over the central portions of the lower lip and chin.\(^{22}\) Orthodontic retraction in this study produced lower lip changes that diminished toward the commissures in proportion to the degree of retraction. However, in patients with significant lower lip eversion, the extent and zone of retraction was significantly greater, extending beyond the commissures to the buccal regions.

The relationship between lip retraction and anterior incisor movement relies on complex multifactorial relationships that depend on lip strain and thickness,\(^{12}\) dentofacial morphology,\(^{21}\) and ethnicity and sex.\(^{5,6,16,41}\) Soft-tissue changes can be predicted using linear approximations of these relationships. Studies of lip movement after retraction of anterior teeth in Japanese populations showed that upper lip retraction correlated strongest with horizontal retraction of the maxillary incisor, followed by vertical movement of the mandibular incisor.\(^{5,35}\) Our measurements yielded similar results, indicating a strong correlation of upper lip retraction with maxillary incisor anteroposterior retraction. In addition, we observed that upper lip retraction slightly correlated with mandibular incisor anteroposterior retraction and maxillary incisor vertical movement, consistent with the results of previous studies.\(^5\) These studies also showed a strong correlation between lower lip retraction and both maxillary and mandibular incisor anteroposterior retraction.

### Table III. Soft-tissue and hard-tissue variable correlations both groups combined

<table>
<thead>
<tr>
<th></th>
<th>UL ret</th>
<th>LL ret</th>
<th>U1i y</th>
<th>U1i z</th>
<th>U1 retro</th>
<th>L1 retro</th>
<th>L1i y</th>
<th>L1i z</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL ret</td>
<td>0.69</td>
<td>0.74*</td>
<td>-0.60</td>
<td>0.53</td>
<td>0.26</td>
<td>0.63</td>
<td>-0.27</td>
<td></td>
</tr>
<tr>
<td>LL ret</td>
<td>0.08</td>
<td>-0.52</td>
<td>-0.24</td>
<td>0.26</td>
<td>0.30</td>
<td>0.71*</td>
<td>-0.14</td>
<td></td>
</tr>
<tr>
<td>U1i y</td>
<td>0.02*</td>
<td>0.50</td>
<td>-0.81*</td>
<td>0.83*</td>
<td>0.25</td>
<td>0.51</td>
<td>-0.36</td>
<td></td>
</tr>
<tr>
<td>U1i z</td>
<td>0.16</td>
<td>NS</td>
<td>0.0005*</td>
<td>-0.89*</td>
<td>-0.05</td>
<td>-0.30</td>
<td>0.44</td>
<td></td>
</tr>
<tr>
<td>U1 retro</td>
<td>NS</td>
<td>NS</td>
<td>0.0002*</td>
<td>&lt;0.0001*</td>
<td>0.13</td>
<td>0.25</td>
<td>-0.05</td>
<td></td>
</tr>
<tr>
<td>L1 retro</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-0.23</td>
<td>-0.14</td>
<td></td>
</tr>
<tr>
<td>L1i y</td>
<td>0.10</td>
<td>0.016*</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-0.26</td>
<td>-0.10</td>
<td></td>
</tr>
<tr>
<td>L1i z</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

Both groups combined ($n = 24$). Spearman rank correlation coefficients ($r$) are in the upper right half of the table; significance levels are in the lower left half.

* $P < 0.05$; NS indicates $P > 0.5$. 

($\rho = 0.63$; Table III).
In contrast, our subjects showed lower lip retraction strongly correlated only with anteroposterior retraction of the mandibular incisors. Brock et al.38 showed a strong correlation of upper lip movement with displacement of landmarks on the facial and cervical aspects of the maxillary incisor, consistent with our observations.

The ratio of maxillary incisor retraction to the mean upper lip retraction was 1.73:1 (Table IV); this is midway between reported ratios from 1.5:142 to 2.5:137 in bimaxillary dentoalveolar protrusive Asian populations.5,6,35,37,40-42 The ratio of mandibular incisor retraction to mean lower lip retraction in this study was

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**Fig 4.** Two-dimensional cephalometric tracings (A1-C1), 3D hard-tissue (A2-C2), and soft-tissue (A3-C3) superimpositions of 3 patients (A-C) representing variations in the skeletal anchorage group. Two-dimensional tracings are superimposed on the cranial base. **Black,** Pretreatment; **red,** posttreatment. Hard-tissue and soft-tissue colored displacement maps are projected onto the pretreatment CBCT scan. Color scale ranges from −2 mm (red, subtractive change) indicating inward displacement, to +2 mm (blue, additive change) indicating outward displacement; **green,** no change.
0.83:1 (Table IV), correspondingly lower than the ratios of 1.12 to 1.32:1 reported in previous studies. However, these correlation coefficients considered only the anteroposterior component of incisor movement, when both the maxillary and mandibular incisors are also moving vertically. Significant intrusion and reduction of overbite were measured in both groups in this study; these changes also contributed to anteroposterior lip retraction. Upper lip retraction was more sensitive to vertical incisor movement than was anteroposterior movement, with a ratio of −0.61 maxillary incisor vertical movement to upper lip anteroposterior retraction. Measurements of lip retraction

Fig 5. Two-dimensional cephalometric tracings (A1-C1), 3D hard-tissue (A2-C2), and soft-tissue (A3-C3) superimpositions of 3 patients representing variations in the nonskeletal anchorage group. Hard-tissue and soft-tissue colored displacement maps are projected onto the pretreatment CBCT scan. Color scale ranges from −2 mm (red, subtractive change) indicating inward displacement, to +2 mm (blue, additive change) indicating outward displacement; green, no change.
lateral to the midline were also greater in many subjects, contributing to a greater average lip retraction than seen with conventional 2-dimensional measurements. A similar effect was observed in 3D midfacial soft-tissue changes resulting from surgical mandibular setback, with greater retraction away from the midline.22

The difference could also be related to severe pre-treatment lip strain in this group. Many patients in this study exhibited a resting interlabial gap or an everted lower lip in repose, indicating high lip strain when the lips are closed. Previous studies demonstrated greater lip sensitivity in patients with either high lip strain or thin lips.9,12 Patients with a large resting interlabial gap showed the greatest lip retraction response per millimeter of incisor retraction. Retraction of the incisors in our study might have induced changes in lip posture and facial muscle balance that could have amplified lip changes, resulting in lower ratios of incisor to lip retraction. One could conclude that the lip response after treatment follows a nonlinear relationship with respect to initial lip protrusion.

The difference in lower lip retraction between anchorage types was consistent with results from previous studies showing significantly greater lower lip retraction in the skeletal anchorage group, with no detectable difference in upper lip retraction.36 However, this difference represents only 35% of the total anteroposterior lower lip retraction, which is not likely to be clinically significant. In contrast, studies in a dentally protrusive Chinese population showed the reverse, with greater upper lip retraction and no significant difference in the lower lip retraction.43

The intergroup difference in retraction of the maxillary incisor edges was measurable (1.47 mm) but not statistically significant with the available sample size. Similarly, Liu et al43 reported a 2.27-mm difference in maxillary incisor retraction in a similar study comparing anchorage types in a bimaxillary protrusive Asian population. The intergroup difference in maxillary molar anchorage loss in our study (2.4 mm) was less than the observed values in other studies (3.3-4.0 mm).36,43 This difference could be related to variations in the type of nonskeletal anchorage used in the treatments; previous studies used either transpalatal arches41 or transpalatal bars,36 occasionally including second molar ligation and headgear.

CONCLUSIONS

1. Three-dimensional soft-tissue changes resulting from retraction of the anterior teeth in patients with bimaxillary protrusion are variable but correlated with initial resting lip posture. Upper lip retraction is concentrated between the nasolabial folds and commissures laterally. Lower lip retraction is concentrated at the midline, diminishing toward the commissures. Significant redistribution of the soft tissues near pogonion can occur.

2. Anteroposterior and transverse lip retraction is correlated with both anteroposterior and vertical movement of the maxillary and mandibular incisors.

3. Clinical soft-tissue changes in bimaxillary protrusive patients treated with first premolar extractions are similar with either skeletal or nonskeletal forms of anchorage. Treatment with maxillary skeletal anchorage results in 2.4 mm less maxillary molar anchorage loss.

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REFERENCES


