Original Article

Lip Curve Changes in Females with Premolar Extraction or Nonextraction Treatment

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Abstract: Changes in lip curvature resulting from treatment have been largely ignored in orthodontic literature. The focus instead has been primarily directed at retraction of the vermilion border and changes in the nasolabial angle. This study, therefore, was designed to retrospectively analyze changes in the upper and lower lip curves associated with growth and treatment. The lateral cephalometric records of 137 female orthodontic patients were digitized. Sixty-two were treated with premolar extractions and 75 without extractions. The overall extraction group was further divided into subgroups on the basis of the chosen extraction sequence, which included extraction of 4/4, 4/5, or 5/5. Statistical analysis revealed no significant differences in changes in lip curve depth between the two overall samples, relative to either of the two reference lines. This would suggest that an appropriately selected plan, whether extraction or nonextraction, should allow treatment to be carried out without negative effects on the curvature of the lips. Calculation of correlation coefficients and regression analysis suggested that the inherent properties and morphology of the soft tissues themselves are probably the greatest determinants of lip curve behavior with treatment. The midface soft tissues appear to be less dependent on changes in the underlying hard tissues than do the lower face soft tissues. Pretreatment upper and lower incisor positions and angulations and the underlying vertical facial dimension appear to play more significant roles in the behavior of the lower lip than the upper lip. (*Angle Orthod* 2004;74:51–62.)

Key Words: Premolar extraction; Nonextraction; Soft tissue

INTRODUCTION

Most previous literature regarding soft tissue behavior during orthodontic treatment has focused on retraction of the vermilion border and changes in the nasolabial angle.[1–9] This is interesting because facial harmony is often described as determined by the morphologic relationships and proportions of the nose, lips, and chin.[8,10] Discussion is further complicated by the fact that the balance between these structures can be altered by both growth and orthodontic treatment. Little consideration has been given to the depth and regularity of the lip curves and their importance in the overall perception of the lateral facial profile. Holdaway[11,12] was one author who did emphasize the role of lip curvature in treatment planning and compensations that might be appropriate in patients with various underlying vertical facial patterns. Although the impact of the vertical dimension on the soft tissue profile has been discussed anecdotally,[13] scientific studies designed to identify potential relationships are rare.[14–16]

Incisal movements can vary greatly in cases treated either with or without extractions. Although incisor retraction is seen in the majority of patients treated with premolar extractions, it is certainly possible for minimal movement, or even incisal protrusion, to occur.[15,17–21] Similarly, nonextraction treatment may also result in either retrusion or protrusion of the incisors. This situation was highlighted by Shearn and Woods,[18] who noted that the primary determinant of the amount of incisor retraction occurring during treatment was the residual space present after initial alignment. This serves as a reminder that extractions are performed not only to allow incisor retraction but also to provide space for the relief of crowding and the correction of molar and canine relationships and midline discrepancies.[22,23] Each of these needs may have a significant impact on the total incisor retraction achieved with treatment.

The morphology of the soft tissues themselves is a major factor in determining the overall facial profile.[24–28] The soft

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TABLE 1. Age at Commencement and Completion of Treatment and Treatment Duration

Sample Group	Sample Number n = 137	Mean Pretreatment Age (y-mo)	Mean Posttreatment Age (y-mo)	Mean Treatment Duration (mo)
Exo 4/4[a]	12	13-6 ± 1-8	15-6 ± 1-7	25 ± 7
Exo 4/5[b]	24	12-11 ± 1-11	15-0 ± 1-11	25 ± 8
Exo 5/5[c]	26	13-10 ± 1-10	16-1 ± 1	26 ± 7
Premolar nonextraction	75	12-9 ± 1-10	15-1 ± 2-10	26 ± 10

[a] 4/4, upper and lower first premolars.
[b] 4/5, upper first and lower second premolars.
[c] 5/5, upper and lower second premolars.

tissue, for instance, has been termed ''the great compensator for skeletal discrepancies.''[13] The presence of varying inherent internal soft tissue architecture, however, has complicated attempts at predicting soft tissue responses to treatment.[1] Consequently, ratios of lip to incisor retraction have gained only limited acceptance because it has been recognized that the interactions that might determine soft tissue changes are complex.[2,4–8]

A predictable change in facial esthetics can be achieved only if the predetermined treatment objectives are adequately realized and the amount and direction of expected facial growth can be estimated.[29] It is therefore essential that clinicians be aware not only of the likely effects of treatment but also of the general amount and direction of growth expected in facial structures.[8,11,29–31] This is especially the case with the soft tissues of the lateral profile. The predictability of such changes appears limited, however, given the considerable variability in pretreatment soft tissue morphology.[29] With these things in mind, this study was designed to evaluate the effects of treatment, with and without premolar extractions, on the lateral facial profiles of growing females, with particular reference to the curvature of the upper and lower lips.

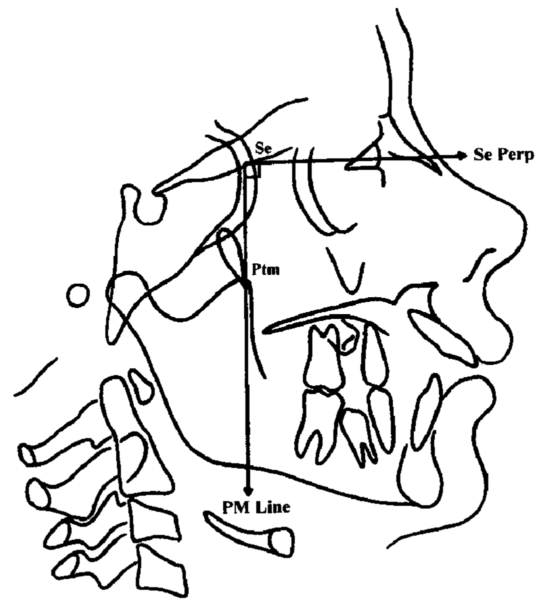

FIGURE 1. Pterygomaxillary line through Se and Ptm. Horizontal line constructed perpendicular to the PM line, through Se.

MATERIALS AND METHODS

The sample consisted of the records of 75 premolar nonextraction and 62 premolar extraction Angle Class I and II cases. All 137 patients were female and were treated by an experienced orthodontist. Premolar teeth were extracted for the relief of crowding, the correction of Class II buccal relationships, or the reduction of incisor protrusion. The extraction sample was further divided into three groups (Table 1)—four first premolars (4/4), upper first, lower second premolars (4/5), and four second premolars (5/5)—to facilitate examination of the tissue response for each subsample. High quality pre- and posttreatment lateral cephalograms, each exhibiting good soft tissue definition with lips relaxed, teeth in occlusion, and taken using the same cephalostat, were available for all subjects.

All patients had been treated with preadjusted 0.018-inch slot edgewise appliances using consistent contemporary biomechanical principles. None of the patients was treated with expansive devices; however, interarch elastics and headgears were used as required. Class III malocclusions were excluded.

Cephalometric analysis

All pre- and posttreatment cephalograms were traced by one examiner (Dr Moseling) and digitized with the aid of Westcef cephalometric software (Customized cephalometric analysis software written for the University of Melbourne by Mr Geoffrey West). Superimposition on the cranial base landmarks of the pretreatment radiograph, according to the method described by Bjork and Skieller,[32] and transfer of sphenoethmoidale (Se) and the inferior pterygomaxillary point (Ptm) from the first to the second tracing were undertaken to provide a consistent plane of reference for the subsequent evaluation of horizontal changes in landmarks.

Measurements to both hard and soft tissue landmarks were made with reference to the pterygomaxillary (PM) line[18,20,33–37] (Figures 1 and 2; Table 2). Landmarks chosen for the study were based on the definitions of Nanda et al.[29]

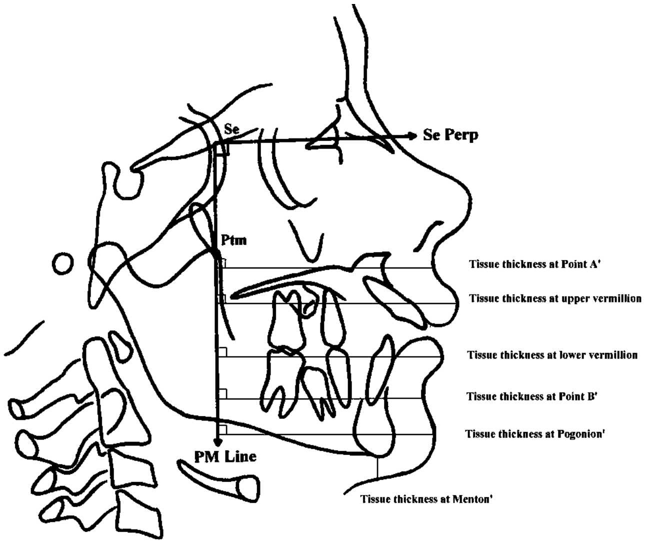

FIGURE 2. Lips and pogonion tissue thickness.

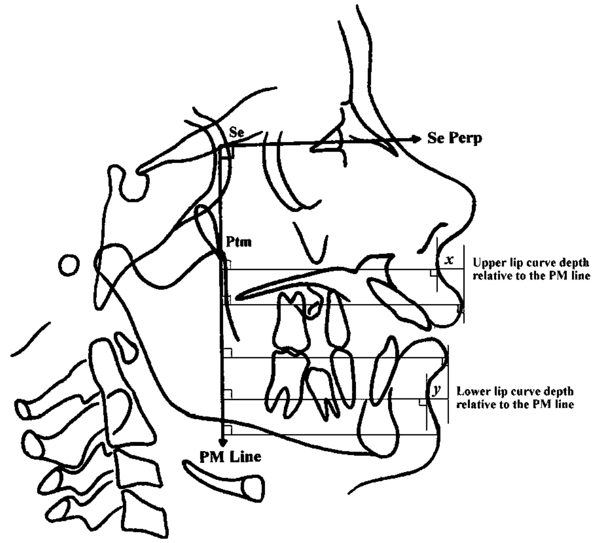

FIGURE 3. Location of upper and lower lip depths in relation to PM line. Upper and lower lip curve points A′ and B′ located as tangents to the deepest points of the respective curves, parallel to the PM line.

To quantify the soft tissue effects of growth and treatment, the depths of the upper and lower lip curves were calculated in two ways as illustrated in Figures 3 and 4 and described in Table 2. All linear cephalometric measurements were multiplied by a factor of 0.92 to take into account the 9% cephalometric enlargement factor. Pretreatment differences among the sample groups are presented in Table 3. It can be seen that the 4/4 group generally displayed a reduced pretreatment lower lip curve depth relative to the other subgroups. The 4/5 group exhibited the greatest mean incisal overjet and upper incisor proclination. The premolar nonex-

TABLE 2. Definitions of Cephalometric Landmarks and Measurements of Soft Tissue Thickness

Landmarks and Measurement	Definition
Upper vermilion point	Most anterior point of the upper lip
Lower vermilion point	Most anterior point of the lower lip
Soft tissue point A′	Deepest point on the outline of the upper lip, established by a tangent parallel to the PM line.
Soft tissue point B′	Deepest point on the outline of the lower lip, established by a tangent parallel to the PM line.
Upper lip thickness	
Soft tissue point A′	Distance between hard tissue point A and point of intersection with the outline of the upper lip drawn perpendicular to PM line.
Vermilion	Distance between vermilion point of the upper lip and inner aspect of the lip, drawn perpendicular to PM line.
Lower lip thickness	
Vermilion	Distance between vermilion point of the lower lip and inner aspect of the lip, drawn perpendicular to PM line.
Soft tissue point B′	Distance between hard tissue point B and point of intersection with the outline of the lower lip drawn perpendicular to PM line.
Pogonion thickness	Distance between hard tissue pogonion and point of intersection with the outline of the chin drawn perpendicular to PM line.
Depth of upper lip curve	
Relative to PM line	X axis coordinate distance PM to soft tissue point A′ subtracted from PM to upper vermilion point.
Relative to anterior soft tissue reference line	Distance to soft tissue point A′ measured perpendicular to a line joining the nasal tip and the upper vermilion point.
Depth of lower lip curve	
Relative to PM line	X axis coordinate distance PM to soft tissue point B′ subtracted from PM to lower vermilion point.
Relative to anterior soft tissue reference line	Distance to soft tissue point B′ measured perpendicular to a line joining the lower vermilion point and soft tissue pogonion.

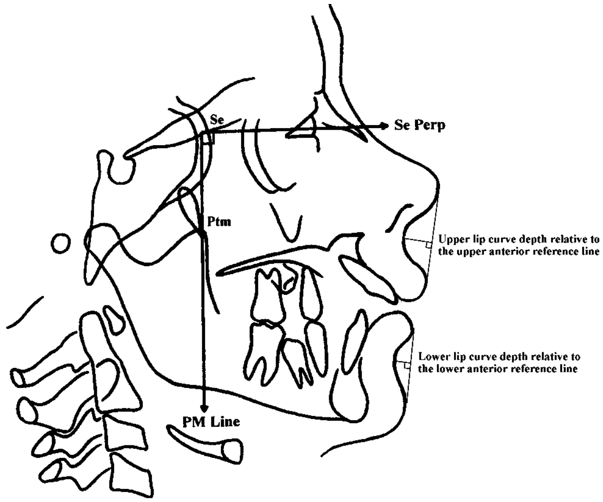

FIGURE 4. Location of upper and lower lip depths in relation to anterior soft tissue lines. The upper and lower anterior soft tissue lines were constructed through the nasal tip and upper vermilion point, and lower vermilion point and soft tissue pogonion, respectively. Curve depth was established as the perpendicular distance from soft tissue Point A′ or B′ to the respective anterior line.

traction group typically presented with a brachyfacial or short face underlying pattern.

Statistical analysis

The cephalometric measurements were imported into a Microsoft Excel spreadsheet (Microsoft Excel Office 2000). Changes occurring during treatment were calculated and the data statistically analyzed using the Minitab statistical software package (Minitab Statistical Software Release 13). Analysis of variance was used to search for statistically significant differences among the changes in depths of lip curves for the three extraction groups and also between the extraction and nonextraction samples (Tables 5 and 6). Pearson correlation coefficients (r) and associated levels of significance (P values) were then calculated to determine the levels of correlation between pretreatment curve depths, changes in the curve depths with treatment, and various other skeletal, dental, or soft tissue factors (Tables 7 through 11). Stepwise regression equations were formulated at 5% level of significance[38] to enhance the prediction of responses of the upper and lower lips with growth and treatment (Table 12).

Error measurement

To evaluate the tracing and measurement error associated with the method, 20 radiographs from 10 patients were selected at random and traced and measured twice, four weeks apart. Results of the paired Student's t-test demonstrated no clinically significant differences between the two sets of measurements at the 95% confidence level (Table 4).

RESULTS

Changes in depth of upper lip curvature

Changes relative to posterior PM reference line. The changes in depth of the upper lip curve at soft tissue point A′ are summarized in Table 5. The mean depth of the lip curve was reduced with treatment in all extraction groups as well as in the nonextraction sample. At a 5% level of significance, analysis of variance demonstrated that the differences between the mean changes of −0.28 mm in the 4/4 group, −0.63 mm in the 4/5 group, −0.20 mm in the 5/5 group, and −0.18 mm in the nonextraction group were not statistically significant. Within all nonextraction and extraction groups, there was a wide range of individual variation such that both increasing and decreasing upper lip curve depths were noted.

Changes relative to the upper anterior soft tissue reference line. Changes in the depth of the upper lip curve at

TABLE 3. Statistically Significant Pretreatment Group Differences (Mean ± SD)

Variable	4/4[a] (n = 12)	4/5[b] (n = 24)	5/5[c] (n = 26)	Nonexo[d] (n = 67)
Lower lip depth curvature—lower anterior reference line (mm)	3.82 ± 1.85**	4.96 ± 1.24**	4.86 ± 1.35**	4.96 ± 1.28**
Thickness upper vermilion (mm)	10.90 ± 2.27	11.90 ± 1.86	12.40 ± 1.61	12.60 ± 1.94
Thickness soft tissue point B′ (mm)	11.70 ± 1.44	11.90 ± 2.15**	10.80 ± 1.52**	11.00 ± 1.48**
Nasal tip projection—PM line (mm)	71.86 ± 2.34**	71.79 ± 2.98**	74.71 ± 3.52**	72.44 ± 3.66**
MLA (°)	141.89 ± 10.57**	128.93 ± 13.39**	131.27 ± 12.37**	129.50 ± 11.10**
UiAPo (mm)	6.77 ± 3.20	6.56 ± 2.08**	5.34 ± 2.21*	5.51 ± 1.65**
Overjet (mm)	4.67 ± 2.07*	5.95 ± 1.94***	4.25 ± 1.50***	5.00 ± 2.12**
Facial gnomon (°)	61.03 ± 6.10**	58.15 ± 6.15	59.53 ± 4.70**	56.59 ± 5.13**
Oral gnomon (°)	46.97 ± 3.88***	44.62 ± 4.05**	44.25 ± 3.42**	42.53 ± 3.64**
MPA—Ricketts (°)	30.28 ± 7.04**	26.78 ± 4.96	27.71 ± 4.13**	25.69 ± 4.36**

[a] 4/4, upper and lower first premolars.
[b] 4/5, upper first and lower second premolars.
[c] 5/5, upper and lower second premolars.
[d] Nonexo, premolar nonextraction.
* $P \leq .1$, ** $P \leq .05$, *** $P \leq .005$.

TABLE 4. Cephalometric Measurements and Error Study

Variable	Mean	SD	SE Mean	*P* Value
Lower lip to E plane	0.18	0.45	0.10	0.088
Upper lip to E plane	−0.03	0.47	0.11	0.797
Upper lip curve depth relative to PM line	0.04	0.47	0.11	0.737
Upper lip curve depth relative to upper anterior reference line	0.09	0.37	0.08	0.311
Lower lip curve depth relative to PM line	−0.10	1.18	0.26	0.707
Lower lip curve depth relative to lower anterior reference line	−0.03	0.67	0.15	0.856
Thickness at soft tissue point A′	0.25	0.77	0.18	0.275
Upper lip thickness at vermilion	0.04	0.73	0.17	0.829
Lower lip thickness at vermilion	−0.29	0.57	0.13	0.047
Thickness at soft tissue point B′	0.02	0.65	0.15	0.892
Thickness at soft tissue pogonion′	−0.12	0.47	0.11	0.292
Thickness at soft tissue menton′	−0.31	0.60	0.14	0.046
Nasal tip projection relative to PM line	0.26	1.23	0.28	0.350
Upper lip length	−0.30	2.28	0.51	0.565
Lower lip length	0.02	0.88	0.20	0.924
Nasolabial angle	0.19	3.48	0.78	0.808
Mentolabial angle	0.43	5.09	1.14	0.709
Lower incisor to mandibular plane angle	0.13	1.77	0.40	0.741
Upper incisor to palatal plane	0.07	1.55	0.35	0.842
Interincisal angle	−0.27	2.18	0.49	0.593
Upper incisor to APo (°)	0.30	1.72	0.39	0.446
Upper incisor to APo (mm)	0.13	1.13	0.63	0.623
Lower incisor to APo (°)	−0.04	1.58	0.35	0.922
Lower incisor to APo (mm)	−0.16	1.01	0.24	0.508
SNA	0.06	0.65	0.15	0.670
SNB	0.08	0.60	0.14	0.565
ANB	−0.02	0.40	0.09	0.861
Facial gnomon	0.08	0.95	0.22	0.742
Oral gnomon	0.01	0.84	0.20	0.635
Mandibular plane angle	0.001	0.65	0.15	0.997

TABLE 5. Change in the Upper Lip Curvature[a]

Group	Mean	SD	Maximum	Minimum
In relation to PM line				
Exo 4/4[b]	−0.28	0.79	1.43	−1.64
Exo 4/5[c]	−0.63	1.02	0.76	−2.37
Exo 5/5[d]	−0.20	1.45	4.93	−2.24
Premolar nonextraction	−0.18	0.95	3.04	−1.91
In relation to upper anterior reference line				
Exo 4/4	−0.23	1.13	1.25	−2.80
Exo 4/5	−0.16	1.40	2.48	−2.66
Exo 5/5	−0.23	0.98	1.61	−2.28
Premolar nonextraction	0.08	1.14	2.41	−3.03

[a] No significant difference between the groups was identified using ANOVA.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.

TABLE 6. Change in the Lower Lip Curvature[a]

Group	Mean	SD	Maximum	Minimum
In relation to PM line				
Exo 4/4[b]	−0.28	1.99	2.14	−4.54
Exo 4/5[c]	−0.69	1.62	2.19	−3.25
Exo 5/5[d]	−0.27	1.62	3.85	−3.06
Premolar nonextraction	−0.55	1.72	2.48	−6.88
In relation to lower anterior reference line				
Exo 4/4	0.74	1.19	2.35	−1.73
Exo 4/5	0.11	1.33	2.28	−2.26
Exo 5/5	0.22	1.18	3.26	−2.26
Premolar nonextraction	0.06	1.04	2.53	−2.24

[a] No significant difference between the groups was identified using ANOVA.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.

soft tissue point A′ relative to the constructed upper anterior soft tissue line are summarized in Table 5. At a 5% level of significance, analysis of variance demonstrated that the differences between the mean changes of −0.23 mm in the 4/4 group, −0.16 mm in the 4/5 group, −0.23 mm in the 5/5 group, and +0.08 mm in the nonextraction group were not statistically significant. Again, within all nonextraction and extraction groups, there was a wide range of individual variation such that both increasing and decreasing upper lip curve depths were noted.

Changes in depth of the lower lip curvature

Changes relative to posterior PM reference line. The changes in depth of the lower lip curve at soft tissue point B′ are summarized in Table 6. The mean depth of the lip curve was reduced with treatment in all groups. At a 5%

TABLE 7. Significant Correlations Between Pretreatment Variables and Upper Lip Curvature

Lip Curvature	Correlation Variables	Sample Group	*r* Value
Upper lip curve depth	Soft tissue		
	Thickness at upper vermilion	Nonexo[a]	0.611****
		4/4[b]	0.0669**
		4/5[c]	0.622****
		5/5[d]	0.415**
	Thickness at lower vermilion	Nonexo	0.271**
		4/4	0.555*
		5/5	0.462**
	Lower lip curve depth	Nonexo	0.266**
		4/5	0.837****
		5/5	0.432**
	Nasolabial angle	Nonexo	−0.593****
		4/4	−0.759***
		4/5	−0.694****
		5/5	−0.775****
	Dental		
	Lower incisor to mandibular plane angle	4/4	−0.637**
		5/5	0.358*
	Upper incisor to palatal plane	5/5	0.414**
	Interincisal angle		−0.482**
	Lower incisor to APo angulation		0.573***
	Lower incisor to APo position		0.581***
	Upper incisor to APo position		0.462**
	Skeletal		
	ANB	4/4	−0.634**
	Facial gnomon	5/5	−0.409**

[a] Nonexo, premolar nonextraction.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.
* $P \leq .1$, ** $P \leq .05$, *** $P \leq .005$, **** $P \leq .001$.

level of significance, analysis of variance demonstrated that the differences between the mean changes of −0.28 mm in the 4/4 group, −0.69 mm in the 4/5 group, −0.27 mm in the 5/5 group, and −0.55 mm in the nonextraction group were not statistically significant. Within all nonextraction and extraction groups, there was a wide range of individual variation, and both increasing and decreasing lower lip curve depths were noted.

Changes relative to the lower anterior soft tissue reference line. The changes in depth of the lower lip curve at soft tissue point B′ relative to the lower anterior soft tissue line are summarized in Table 6. The mean depth of the lower lip curves increased with treatment in all groups. At a 5% level of significance, analysis of variance demonstrated that the differences between the mean changes of +0.74 mm in the 4/4 group, +0.11 mm in the 4/5 group, +0.22 mm in the 5/5 group, and +0.06 mm in the nonextraction group were not statistically significant. Again, within all nonextraction and extraction subgroups, there was a wide range of individual variation such that both increasing and decreasing lower lip curve depths were noted. The similarity of changes seen in the depths of both upper and lower lip curves obtained using the two different reference lines was further confirmed because significant coefficients of correlation were found for the changes in upper lip depth at point A′ and lower lip depth at point B′, relative to both reference lines. These significant correlations were found in both extraction and nonextraction samples.

Correlations and stepwise regression

Various pre- and posttreatment skeletal, dental, and soft tissue factors found to be statistically significant with regard to the depths of lip curvature are presented in Tables 7 through 11. Stepwise regression allowed prediction of the variability in response to treatment of both upper and lower lip curves, using only pretreatment measurement values. For example, the results for the 4/4 group are shown in Table 12.

DISCUSSION

Retrospective studies, by their nature, carry limitations in interpretation because the reasoning behind the diagnosis and treatment planning for each case can never be fully determined. This particularly applies to samples chosen from a pool treated by a number of different clinicians or

TABLE 8. Significant Correlations Between Pretreatment Variables and Lower Lip Curvature

Lip Curvature	Correlation Variable	Sample Group	*r* Value
Lower lip curve depth	Soft tissue		
	Upper lip curve depth	Nonexo[a]	0.377****
		4/4[b]	0.377****
		4/5[c]	0.404**
		5/5[d]	0.351*
	Thickness at lower vermilion	Nonexo	0.445****
		4/5	0.463**
		5/5	0.556***
	Mentolabial angle	Nonexo	−0.833****
		4/4	−0.88****
		4/5	−0.928****
		5/5	−0.934****
	Dental		
	Upper incisor to APo position	4/4	0.534*
		4/5	0.427**
		5/5	0.403**
	Skeletal		
	ANB	Nonexo	0.295**
		4/5	0.461**
		5/5	0.451**
	Facial gnomon	Nonexo	−0.418****
		4/5	−0.368*
		5/5	−0.359*

[a] Nonexo, premolar nonextraction.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.
* $P < .1$, ** $P < .05$, *** $P < .005$, **** $P < .001$.

TABLE 9. Significant Correlations Between Pretreatment Variables and Changes in Upper Lip Curvature

Lip Curvature	Correlation Variable	Sample Group	*r* Value
Upper lip curve depth change	Soft tissue		
	Upper lip curve depth	Nonexo[a]	−0.366****
		4/4[b]	−0.661**
		4/5[c]	−0.555***
		5/5[d]	−0.1*
	Nasolabial angle	Nonexo	−0.199*
	Thickness at upper vermilion	Nonexo	0.201**
		5/5	−0.367*
	Thickness at soft tissue point B′	Nonexo	−0.289**
	Thickness at soft tissue pogonion′	Nonexo	−0.294**
	Upper lip length	Nonexo	−0.256**
		4/5	−0.382*
		5/5	0.379*
	Dental		
	Upper incisor to APo angulation	Nonexo	−0.371****
	Upper incisor to APo position		−0.312**

[a] Nonexo, premolar nonextraction.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.
* $P \leq .1$, ** $P \leq .05$, *** $P \leq .005$, **** $P \leq .001$.

TABLE 10. Significant Correlations Between Pretreatment Variables and Changes in Lower Lip Curvature

Lip Curvature	Correlation Variable	Sample Group	*r* Value
Lower lip curve depth change	Soft tissue		
	Lower lip curve depth	Nonexo[a]	−0.352***
		4/4[b]	−0.649**
		4/5[c]	−0.563***
		5/5[d]	−0.506**
	Upper lip to E plane	5/5	0.514**
	Lower lip to E plane	5/5	0.375*
	Dental		
	Upper incisor to palatal plane	4/4	−0.527*
	Interincisal angle	4/4	0.555*
		5/5	0.448**
	Lower incisor to APo angulation	4/4	−0.63**
	Lower incisor to APo position		−0.553*
	Upper incisor to APo angulation	5/5	−0.476**
	Upper incisor to APo position	Nonexo	−0.246**
		5/5	−0.396**
	Skeletal		
	SNA	4/5	−0.633****
	SNB		−0.527**
	Facial gnomon		0.429**
	Oral gnomon	4/5	0.373*
		5/5	−0.372*
	MPA	5/5	−0.397**

[a] Nonexo, premolar nonextraction.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.
* $P \leq .1$, ** $P \leq .05$, *** $P \leq .005$, **** $P \leq .001$.

from an era that no longer necessarily represents contemporary treatment practices. In an effort to overcome such issues, the sample for this study was chosen randomly from the practice of one experienced orthodontist who observes consistent and contemporary biomechanical principles. The choice of sample was limited only by the sex of the subject and by a history of either various extraction patterns or of premolar nonextraction treatment. It should be noted that cases defined as ‘‘nonextraction’’ had been treated without the extractions of any teeth up until the time of posttreatment records. The authors, however, do recognize that these cases may or may not have been treated with later extractions of other teeth, commonly the third molars.[39] The sample bias present because of pretreatment differences between the groups existed primarily between the 4/4 group and the other groups as shown in Table 3. The consequent reasoning behind the differential diagnosis and treatment planning for each group, therefore, is explained at least in part by these group differences.

The second limitation is that which accompanies any radiographic soft tissue study. It involves the influence of voluntary and involuntary muscle activity on soft tissue contours. As noted by Zierhut et al,[40] lip tensions will vary between individuals and even from time to time in one individual. An inability to quantify or control this variable remains a shortcoming of these studies. In response to this concern, every effort was made to eliminate those subjects displaying obvious soft tissue strain. No significant correlations existed between changes in depth of the lower lip curve and either the pre- and posttreatment values of the lower lip length or the thickness at soft tissue pogonion and menton. However, despite statistical analysis of the data indicating little or no evidence of lip strain in the overall sample, significant correlations were found between increased face height, larger overjet, and tissue thinning at soft tissue pogonion and menton in the 4/4 group. This would be consistent with the fact that reduction of lip strain may well be a significant treatment goal that influences the choice of extraction pattern in individual patients.

As with all radiographic studies, the fact that a two-dimensional assessment was made of three-dimensional structures causes problems of its own. When the various components are put together as a three-dimensional whole, there may or may not be a fine aesthetic balance—despite the successful provision of treatment to two-dimensional cephalometric norms. To address this concern, two frames of reference were used in this study to permit consideration of soft tissue changes relative to changes in both the underlying hard tissues and the nasal region. The skeletally defined PM line of Enlow et al[33] was used as the principal

TABLE 11. Significant Correlations Between Changes in Variables and Changes in Lip Curvature

Lip Curvature	Correlation Variable	Sample Group	*r* Value
Upper lip curve depth change	Soft tissue changes		
	Nasolabial angle	Nonexo[a]	−0.505****
		4/4[b]	−0.648**
		4/5[c]	−0.524**
	Thickness at upper vermilion	Nonexo	0.349***
		4/5	0.393*
		5/5[d]	0.425**
	Dental changes		
	Upper incisor to palatal plane	Nonexo	0.348***
	Upper incisor to APo angulation		0.343***
	Upper incisor to APo position		0.328***
Lower lip curve depth change	Soft tissue changes		
	Thickness at lower vermilion	Nonexo	0.484****
		4/4	0.716**
		4/5	0.610***
		5/5	0.554***
	Mentolabial angle	Nonexo	0.893****
		4/4	−0.953****
		4/5	−0.898****
		5/5	−0.879****
	Dental changes		
	Lower incisor to mandibular plane angle	4/4	0.666**
		5/5	0.36*
	Upper incisor to palatal plane	4/4	0.544*
		5/5	0.372*
	Interincisal angle	4/4	−0.631**
		5/5	−0.483**
	Lower incisor to APo angulation	4/4	0.584**
	Lower incisor to APo position	4/4	0.729**
	Upper incisor to APo angulation	4/4	0.57*
		5/5	0.531***
	Upper incisor to APo position	4/4	0.641**

[a] Nonexo, premolar nonextraction.
[b] 4/4, upper and lower first premolars.
[c] 4/5, upper first and lower second premolars.
[d] 5/5, upper and lower second premolars.
* $P \leq .1$, ** $P \leq .05$, *** $P \leq .005$, **** $P \leq .001$.

hard tissue reference line. Anterior soft tissue reference lines were also constructed using the most protrusive points on the nose, upper lip, soft tissue pogonion, and lower lip. The use of these soft tissue reference lines was in accordance with the recommendations of Zierhut et al,[40] Foley and Duncan,[41] and Meng et al,[42] all of whom emphasized the need to consider the effects of nasal changes on the total facial profile, as well as changes in facial convexity.

Measurements in relation to the posterior hard tissue reference line and both the anterior soft tissue reference lines demonstrated that there were no significant differences in changes in the depth of the upper or lower lip curves associated with either premolar extraction or nonextraction treatment in these growing females. Two issues concerning this lack of difference between the groups must be recognized. First, within each group there was a wide range of individual variation in response, resulting in both increasing and decreasing depths of lip curvature. Second, the minimal difference between the groups is also a reflection of the retrospective nature of the study. This finding would be consistent with the conclusion of James,[22] who stated that an accurate diagnosis and well-considered treatment plan determines a course of treatment according to total arch length discrepancy, pretreatment profile, degree of skeletal disharmony, and facial type. The absence of a significant difference in lip curve changes between the groups might then suggest that pretreatment skeletal and dental factors are just as important as pretreatment lip curve depths in deciding the need or otherwise for extractions and, indeed, the choice of a particular extraction pattern.

In this study, variables associated with soft tissue morphology were the most frequent and strongly correlated factors associated with changes in lip curvature. Assessment of the pretreatment variables revealed that thicker upper and lower lips at the vermilion border, not surprisingly, were associated with greater depths of lip curve before treatment.

TABLE 12. Stepwise Regression Predictions for the 4/4 group (n = 12)[a]

Prediction	Predictive Pretreatment Variables	Percentage of Change Explained by Pretreatment Variable (R-Sq) and Residual SD	
Change in lower lip position to the E plane	Lower incisor position Upper and lower lip position to E plane	81.2%	±0.98 mm
Change in the lower lip curvature relative to PM line	Lower lip length Mentolabial angle Lower incisor position to APo	82.5%	±0.90 mm
Change in depth of upper lip curve relative to anterior reference line	Upper lip curvature relative to anterior reference line Upper lip length Lower lip curvature relative to anterior reference line Thickness of soft tissue Me′ ANB Thickness of soft tissue B′	99%	±0.12 mm
Upper lip thickness at vermilion	Facial gnomon Nasolabial angle Upper incisor position to APo	73.8%	±0.97 mm
Thickness of soft tissue B′	Facial gnomon Upper lip thickness at vermilion Upper incisor position to APo SNA Upper lip length Upper lip curvature relative to PM line Lower lip relative to E plane Lower lip thickness at vermilion Upper incisor angulation to APo	100%	±0.12 mm
Thickness of soft tissue Me′	Upper incisor position to APo Thickness of soft tissue Me′	60.4%	±1.24 mm
Nasolabial angle	Upper incisor to palatal plane Oral gnomon	67.4%	±2.59°
Upper lip length	Oral gnomon	56.6%	±1.21 mm
Lower lip length	Lower lip length Thickness at soft tissue Pg′ SNA Oral gnomon Upper lip length	98.1%	±0.30 mm

[a] 4/4, upper and lower first premolars.

Following on logically, larger pretreatment nasolabial or mentolabial angles were associated with reduced depths of upper or lower lip curves, respectively. In particular, the highly significant correlation between mentolabial angle and lower lip curve depth would not support Holdaway's[11,12] concern regarding the use of the mentolabial angle as an accurate indicator of lower lip curvature.

The lack of general consistency in pretreatment correlations between dental variables and soft tissue form supports the hypothesis that soft tissues might have their own inherent architecture. However, in all extraction groups, greater depths of lower lip curve occurred in combination with more proclined upper incisors. Furthermore, the contradictory associations between lower incisor angulation and upper lip curve depth in the 4/4 and 5/5 groups suggest that it is the interplay of dental, skeletal, and soft tissue factors that ultimately determines the positions and curvature of the lips. In cases displaying excessive lip curvature, such as the lower lip trap typically associated with upper incisor protrusion, a reduction in the depth of lip curve is generally a treatment goal. Therefore, the results indicated that the greater the pretreatment depth of lip curve, the greater the likely reduction in lip curvature with treatment. All groups, except for the 4/5 sample, followed this expected pattern, displaying a consistent correlation between pretreatment dental variables and changes in lower lip curve depth. For example, the more protrusive and proclined the upper incisors were relative to A-Pog before treatment, the greater the likely reduction in lower lip curve depths during treatment. Interestingly, only the nonextraction sample displayed a consistent correlation between pretreatment dental variables and changes in upper lip curve depth. This may be due to some nonhomogeneity of the nonextraction sample, which included a wide range of Class I and II nonextraction cases.

After investigating the relationships between changes during treatment in lip curvature and in a wide range of dental, skeletal, and soft tissue variables, it was obvious that the soft tissue factors were still the most strongly and consistently represented. The highly significant correlation between changes in lower lip curve depth and changes in mentolabial angle would seem to further support the use of the mentolabial angle as a reasonable indicator of lower lip curvature. The association between the nasolabial angle and upper lip curvature, however, was not consistently strong in all the groups. Again, only in the nonextraction group did a change in upper lip curve depth correlate strongly with upper incisor changes. The lack of such a strong correlation between lip changes and upper incisor position in the extraction samples is consistent with the previous findings of Roos,[6] Hershey,[7] and Wisth,[5] all of whom concluded that individual variation makes a reliable prediction of upper lip retraction in individual cases almost impossible. In contrast, both the 4/4 and 5/5 groups exhibited significant and consistent correlations between changes in dental variables and changes in depth of the lower lip curve. It seems that the greater the posttreatment reduction in protrusion and proclination of the upper and lower incisors, the greater the likely decrease in lower lip curve depth. It, therefore, would appear that the positions and angulations of the incisors play far more influential roles in determining the position and curvature of the lower lip than of the upper lip. Again, this is consistent with the work of Subtelny,[25] who noted that the soft tissues of the lower face were more closely related with the underlying hard tissues than the soft tissues of the midfacial region. The lack of significant correlations between changes in dental variables and changes in lower lip curve depth in the 4/5 group might then be partly explained by the fact that limited changes occurred in lower incisor positions and angulation, in turn, maintaining the pretreatment lower incisor support for the lower lip.

When considering the role of the vertical dimension as an influence on soft tissue drape, correlations revealed significant pretreatment relationships between tissue thickness of the lower face at soft tissue point B′, pogonion′, and menton′, and the facial height measures—mandibular plane angle and facial gnomon. No such relation was noted with midface tissue thickness. Further correlations suggested that an increase in face height may be associated with an increase in tissue thickness at soft tissue point B′ and, contrary to the findings of Blanchette et al,[14] with a decrease in soft tissue thickness at pogonion and menton. As noted previously, this may be due to an increase in lip strain in longer-faced subjects when attempting to achieve lip closure. The correlations also indicated a consistency in the association of the lower lip curve depth and face height after treatment. There, however, was no apparent influence of face height on the upper lip curvature.

Stepwise regression was used to identify not only those pretreatment variables with the most likely influence on lip changes but also to attempt to describe the extent of variability in lip response that might be explained by those variables. This analysis was conducted with the aim of perhaps providing the clinician with a tool to estimate the type and direction of lip response using only pretreatment factors. Only regression equations providing 45% or greater explanation of the tissue response were reported. Lower percentage predictions were considered less clinically relevant, given the increasing deviation in the range of prediction. The predictions in the 4/4 group appeared to be the most promising, as seen in Table 12. They, however, should be interpreted with caution, given the small sample size. The predictive percentages of the total nonextraction or extraction samples were generally lower than those reported by Talass et al.[9] This is readily explained by those authors' inclusion of posttreatment variables in their predictive equation, which would be expected to immediately improve the likelihood of successful prediction. Ultimately, the stepwise regression simply confirmed, in a more statistically sophisticated way, the predominant role of the inherent soft tissue architecture in determining both the pretreatment forms and responses to treatment of the upper and lower lip curves.

CONCLUSIONS

Taking into account the limitations already outlined, the following conclusions can be drawn.

- The extraction of various premolars, or even treatment without premolar extractions, does not necessarily lead to changes in lip curve depth in particular directions. In fact, a wide range of individual variation appears to result from treatment with or without the extractions of premolars.
- It seems that the inherent properties and morphology of the soft tissues themselves are the greatest determinants of lip curve behavior with treatment. Furthermore, midfacial soft tissue form and position appear to be less dependent on underlying hard tissues than for the lower facial soft tissue variables.
- Upper and lower incisor positions and angulation and the underlying vertical dimension of the face appear to play more significant roles in the behavior of the lower lip curve than the upper lip curve. Changes in lower lip curve, therefore, are potentially more predictable. Overall, a greater proportion of changes in lower soft tissue variables might be somewhat predicted using stepwise regression.
- The response of the upper lip curvature to orthodontic treatment appears to be highly variable, even in cases treated with identical extraction patterns and consistent biomechanical principles.

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