Original Article

Prediction of Lip Response to Four First Premolar Extractions in White Female Adolescents and Adults

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ABSTRACT

Objective: To develop models for predicting changes in lip position of Class I extraction patients.

Materials and Methods: Pretreatment and posttreatment lateral cephalograms of 46 white female adults and 109 white female adolescents were examined. Mean pretreatment ages for the adolescent and adult groups were 12.2 ± 1.2 years and 23.0 ± 8.5 years, respectively. Subjects were treated with conventional edgewise mechanics. Multivariate prediction models were derived from a randomly selected sample of 119 subjects and validated on the remaining 36 subjects.

Results: Adolescents demonstrated significant vertical and horizontal skeletal growth and treatment changes, while adults showed only small increases in anterior face height. While significant retraction of the upper and lower incisors occurred in both groups, the amounts were greater in adults than in adolescents. Ratios for horizontal hard tissue to soft tissue movements ranged from 1.4:1 to 1.1:1 and 1.3:1 to 1:1 for the upper (Ls) and lower (Li) lips, respectively. There were moderate relationships between horizontal lip and underlying hard tissue movements (correlations ranged from .57 to .78 for Ls and from .58 to .86 for Li). Multiple regressions to predict lip movements showed moderately strong relationships for the upper lip (R = .79 to .81) and strong relationships for the lower lip (R = .89 to .90). Two to three variables were necessary to predict vertical lip movements (R = .82 to .87). The validation sample showed no systematic biases and similar levels of accuracy.

Conclusions: Upper and lower lip retraction in four first premolar extraction cases can be predicted with moderately high levels of accuracy in white female adolescents and adults. (*Angle Orthod.* 2009;79:413–421.)

KEY WORDS: Soft tissues; Prediction; Cephalometrics; Treatment changes; Adolescents; Adults

INTRODUCTION

Determining changes in lip position is a priority during diagnosis and treatment planning of cases requiring premolar extractions. It is important because the public tends to focus more on lip changes than on changes of the nose or chin.[1] Unlike other facial soft tissue features, orthodontic treatment has the potential to alter dramatically the position and contour of the lips.

Most studies have used ratios to quantify lip response to incisor retraction in premolar extraction cases. Ratios of maxillary incisor retraction to posterior movements of labrale superioris have been reported to vary from 1.2:1 to 3.2:1.[2–9] Ratios for the horizontal response of the lower lip, ranging from 0.4:1 to 1.8:1, are only slightly more consistent across studies.[3–7]

While ratios are simple and readily applicable, they are limited in their ability to predict soft tissue response. Despite the fact that lip response has been shown to depend on multiple measures, ratios tacitly assume that the lip movements can be predicted by a single hard tissue measure.[4,5,8–14] Ratios also imply that the relationship between hard and soft tissue changes is linear, even though studies have shown

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that this is not necessarily the case.[15,16] Ratios also provide no information about their predictive accuracy.

While multiple regressions provide more precise estimates of soft tissue changes than ratios or bivariate regression[3] and are less biased than ratios,[17] it remains controversial whether they produce clinically meaningful predictions for upper lip movements. Talass et al,[12] for example, showed that multiple regressions explained 75% of the variability in the change of upper lip length during treatment, but only 49% of the variability in upper lip retraction. Caplan and Shivapuja[4] produced regressions that explained 70.1% and 42% of the variation in lower and upper lip response to premolar extraction therapy. Brock et al[9] only explained 52% to 61% of the variation in upper lip response to maxillary premolar extractions.

To maximize the esthetic positions of the lips, the influence of soft tissue growth occurring independent of treatment must be considered. Adolescents' lips become relatively more retrusive over time, substantially longer, and somewhat thicker.[18–21] Adults show more limited growth changes.[22] It has been suggested that latent soft tissue growth in men explains why upper lip position does not correlate with incisor retraction.[3,23] In addition to age effects, sex differences in growth need to be controlled because women have less growth potential and reach maturity years before men.[18–20,24]

The purpose of this retrospective study was to develop more precise and reliable models for predicting final lip position in white female adolescents and adults following orthodontic treatment involving four first premolar extractions. Studies specifically designed to control for sex differences and to compare the soft tissue response in growing and nongrowing premolar extraction patients do not exist presently.

MATERIALS AND METHODS

The sample includes 46 adults and 109 adolescents treated with extraction of four first premolars by three private practitioners. The inclusion criteria were:

—White, female;
—Angle Class I molar relationship;
—Radiographs showing good hard and soft tissue resolution with lips lightly touching;
—Pretreatment (T1) and posttreatment (T2) radiographs available;
—Adolescents between 10 and 14 years of age and adults 15 years of age or older at T1;
—Extraction of four first premolars;
—No syndromes, craniofacial anomalies, or congenitally missing teeth;
—No orthognathic or cosmetic facial surgery.

The mean pretreatment ages for the adolescent and adult groups were 12.2 ± 1.2 years and 23.0 ± 8.5 years, respectively. The average treatment durations were 2.8 ± 0.6 years for the adolescents and 2.5 ± 0.5 years for the adults.

Cephalometric Procedures and Measurements

All pretreatment (T1) and posttreatment (T2) cephalograms were digitized by the primary investigator using Viewbox (dHAL, Kifissia, Greece) imaging software. Magnification differences between cephalostats were corrected prior to data analysis. Eighteen hard and seven soft tissue landmarks were digitized on each cephalogram (Figure 1A). Nine linear and three angular measurements were computed (Table 1). In addition, the horizontal and vertical changes of the soft and hard tissue landmarks were evaluated relative to constructed horizontal and vertical reference planes (Figure 1B). The horizontal reference plane was registered on sella (S) and oriented 7° inferior to the sella-nasion (S-N) line.

Statistical Analyses

The SPSS (SPSS Inc, Chicago, Ill) was used for the statistical evaluations. Based on their skewness and kurtosis, the distributions were all normal. *T*-tests were used to evaluate the differences between the adolescent and adult groups. The primary outcome variables were superior labial sulcus (SLS), labrale superioris (Ls), labrale inferioris (Li), and inferior labial sulcus (ILS). Bivariate regressions were performed to determine the relationships between the four primary outcome variables and nine additional independent variables commonly used for predicting soft tissue changes. Stepwise multiple regression analyses were performed to identify the variables needed to predict the treatment changes. Predictions were derived from a randomly selected sample of 119 subjects (80% of the total sample). To test the accuracy of the prediction models (external validity), the actual soft tissue movements of the remaining 36 subjects (validation sample) were compared with the predicted movements.

RESULTS

The treatment changes of the adolescents and adults differed significantly (Tables 2 through 4; Figure 2). Adolescents showed significant increases in anterior and posterior face height, while adults demonstrated only a small increase in anterior face height. The incisors were retracted in both groups, but significantly more so in adults than adolescents. The upper incisors, which were significantly retroclined in adults, maintained their angulation in adolescents. The soft tissues most closely related to the underlying dental

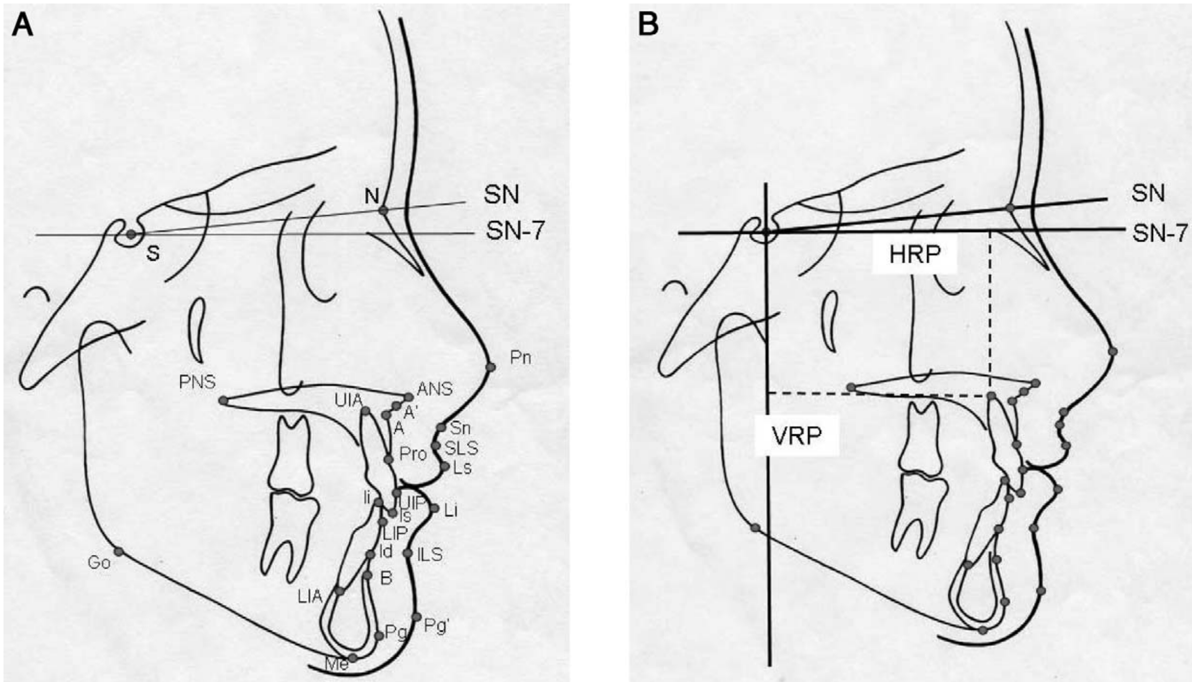

Figure 1. (A) Hard and soft tissue landmarks. (B) Horizontal (HRP) and vertical (VRP) reference planes used to measure movements of individual landmarks.

structures also showed statistically significant retraction in both groups. Adults demonstrated more lip retraction compared with adolescents, irrespective of upper lip taper decreasing significantly in both groups. Upper lip thickness increased slightly in adolescents and decreased slightly in the adults. Lower lip thickness decreased similarly in both groups. Treatment had no effect on lower lip taper or lower lip thickness.

Bivariate regressions evaluating the relationships between horizontal hard and soft tissue movements showed no significant group differences in slope (Table 5). The correlations between the horizontal lip

Table 1. Hard and Soft Tissue Variables

Abbreviation	Scale	Name	Definitions
Hard tissue			
PFH	mm	Posterior face height	Linear distance from the horizontal reference plane to constructed gonion
AFH	mm	Anterior face height	Linear distance from the horizontal reference plane to menton
MPA	deg	Mandibular plane angle	Angulation between sella-nasion plane and the mandibular plane
U1:PP	deg	Upper incisor angulation to palatal plane	Upper incisor angulation to the palatal plane
U1:SN	deg	Upper incisor angulation to sella-nasion plane	Upper incisor angulation to sella-nasion
IMPA	deg	Lower incisor to mandibular plane	Lower incisor angulation to mandibular plane
Soft tissue			
ULT	mm	Upper lip taper	BULT minus VULT
BULT	mm	Basic upper lip thickness	Linear distance from A′ to subnasale (Sn)
VULT	mm	Vermillion upper lip thickness	Linear distance from the most labial surface of the maxillary incisor (UIP) to the vermillion border of the upper lip (Ls)
LLT	mm	Lower lip taper	BLLT minus VLLT
BLLT	mm	Basic lower lip thickness	Linear distance between B point and inferior labial sulcus (ILS)
VLLT	mm	Vermillion lower lip thickness	Linear distance between the most labial surface of the lower incisor (LIP) and the vermillion border of the lower lip (Li)

Table 2. Treatment Changes of Adolescent and Adult Angle Class I Patients Treated With Four First Premolar Extractions

Variable		Adolescent		Adult		Group Comparisons	
Abbreviation	Landmark	Mean	SD	Mean	SD	Difference	*P* Value
Hard tissue							
PFH	Posterior face height	4.9*	0.4	0.5	0.4	4.4	<.001
AFH	Anterior face height	6.5*	0.3	0.9*	0.3	5.5	<.001
MPA	Mandibular plane angle	0.3	0.2	0.2	0.3	0.1	.90
U1-PP	U1 to palatal plane	−0.3	0.6	6.4*	1.0	−6.7	<.001
U1-SN	U1 to sella-nasion plane	0.7	0.6	6.9*	1.0	−6.2	<.001
IMPA	Incisor-mandibular plane angle	−2.5*	0.6	−6.7*	0.7	4.2	<.001
Soft tissue							
ULT	Upper lip taper	−1.2*	0.2	−1.9*	0.4	0.8	.05
BULT	Basic upper lip thickness	0.3	0.2	−0.6	0.3	0.8	<.001
VULT	Vermillion upper lip thickness	1.4	1.9	1.5	1.9	−0.1	.82
LLT	Lower lip taper	0.1	0.2	0.5	0.3	−0.3	.33
BLLT	Basic lower lip thickness	−0.5*	0.2	−0.8*	0.2	0.3	.25
VLLT	Vermillion lower lip thickness	−0.3	0.1	−0.4	0.3	0.1	.68

* Statistically significant ($P < .05$) treatment changes.

Table 3. Comparison of Horizontal Hard and Soft Tissue Landmark Movements (mm) of Adolescents and Adults Treated With Extraction of Four First Premolars

Variable		Adolescent		Adult		Group Comparisons	
Abbreviation	Landmark	Mean	SD	Mean	SD	Difference	*P* Value
Maxilla							
ANS-h	Anterior nasal spine	0.6*	0.2	0.4	0.3	0.2	.58
PNS-h	Posterior nasal spine	−0.7*	0.1	−0.0	0.3	−0.7	.03
A′-h	Holdaway point	0.2	0.2	0.3	0.3	−0.1	.76
A-h	A point	−0.5*	0.2	0.0	0.3	−0.5	.14
Pro-h	Prosthion	−2.3*	0.2	−3.3*	0.3	1.0	.01
U1A-h	U1 apex	−1.9*	0.2	−1.5*	0.3	0.4	.39
UIP-h	Upper incisor point	−2.7*	0.2	−4.3*	0.3	1.6	<.001
Is-h	Incision superioris	−2.6*	0.3	−4.7*	0.4	2.0	<.001
Pn-h	Pronasale	3.0*	0.3	0.4*	0.2	2.6	<.001
Sn-h	Subnasale	0.1	0.2	−0.9*	0.3	1.0	<.001
SLS-h	Superior labial sulcus	−0.8*	0.2	−1.8*	0.3	1.0	.01
Ls-h	Labrale superioris	−1.1*	0.3	−2.5*	0.4	1.5	<.001
Mandible							
Go-h	Gonion	−0.8	0.4	−0.2	0.6	−0.6	.4
Me-h	Menton	0.9*	0.3	−0.1	0.4	1.1	.04
Pg-h	Pogonion	1.3*	0.3	0.1	0.4	1.3	.01
B-h	B point	0.1	0.2	−0.3	0.4	0.4	.4
Id-h	Infradentale	−0.5*	0.2	−1.9*	0.4	1.5	<.001
L1A-h	L1 apex	0.0	0.3	−0.2	0.4	0.3	.6
LIP-h	Lower incisor point	−0.9*	0.2	−2.8*	0.4	1.8	<.001
Ii-h	Incision inferioris	−1.1*	0.2	−3.2*	0.4	2.1	<.001
Pg′-h	ST pogonion	1.0*	0.3	−0.4	0.4	1.4	<.001
ILS-h	Inferior labial sulcus	0.3	0.3	−1.2*	0.4	0.9	.1
Li-h	Labrale inferioris	−1.0*	0.3	−3.0*	0.4	1.9	<.001

* Statistically significant ($P < .05$) treatment changes.

movements and the underlying hard tissue movements were moderate to moderately high for both the upper ($r = .57$ to .78) and lower lip ($r = .58$ to .86) landmarks. The horizontal movements of labrale superioris and labrale inferioris showed the strongest correlation ($r = .91$). The ratios of hard to soft tissue movement ranged from 1:0.6 to 1:0.9 and 1:0.7 to 1:1 for the upper lip (Ls) and lower lip (Li), respectively.

Vertical movements of both lips showed significant group differences in slope, with adolescents showing greater soft tissue changes for every millimeter of hard tissue change than adults (Table 6). The correlations,

Table 4. Comparison of Vertical Hard and Soft Tissue Landmark Movement (mm) in Adolescents and Adults Treated With Extraction of Four First Premolars

Variable	Adolescent		Adult		Group Comparisons	
Abbreviation	Mean	SD	Mean	SD	Difference	*P* value
Maxilla						
ANS-v	2.3*	0.2	−0.0	0.2	2.4	<.001
PNS-v	1.4*	0.2	0.2	0.2	1.2	<.001
A′-v	2.4*	0.2	0.1	0.2	2.3	<.001
A-v	3.0*	0.2	0.6*	0.3	2.4	<.001
Pro-v	2.9*	0.2	0.6*	0.2	2.3	<.001
U1A-v	3.4*	0.2	1.5*	0.4	1.8	<.001
UIP-v	2.5*	0.2	0.2	0.3	2.4	<.001
Is-v	2.6*	0.2	0.5	0.3	2.1	<.001
Pn-v	2.7*	0.2	0.5*	0.2	2.2	<.001
Sn-v	3.5*	0.2	0.9*	0.2	2.6	<.001
SLS-v	3.8*	0.2	1.2*	0.2	2.6	<.001
Ls-v	2.6*	0.2	0.5*	0.3	2.1	<.001
Mandible						
Go-v	4.9*	0.4	0.5	0.4	4.4	<.001
Me-v	6.2*	0.3	0.9*	0.2	5.3	<.001
Pg-v	5.7*	0.3	0.7*	0.3	5.0	<.001
B-v	3.7*	0.3	1.8*	0.7	1.9	<.001
Id-v	4.0*	0.3	1.0*	0.3	3.0	<.001
L1A-v	4.1*	0.3	1.1*	0.3	3.0	<.001
LIP-v	4.1*	0.3	0.9*	0.3	3.2	<.001
Ii-v	4.2*	0.2	0.8*	0.3	3.4	<.001
Pg′-v	5.9*	0.3	1.4*	0.4	4.5	<.001
ILS-v	4.1*	0.3	0.3	0.4	3.9	<.001
Li-v	3.2*	0.2	0.4	0.3	2.8	<.001

* Statistically significant ($P < .05$) treatment changes.

ranging from low to moderate, tended to be higher for adolescents than adults. The ratios for hard to soft tissue vertical movements ranged from 0.4:1 to 0.8:1 for the upper lip (Ls) and from 0.3:1 to 0.9:1 for the lower lip.

Multiple regression equations explained 62% to 81% of the variation in horizontal lip movements (Table 7). Correlations were consistently higher for the lower than upper lip changes. Five variables combined to explain the horizontal changes of SLS and Li; three variables explained the changes of Ls and ILS. The horizontal changes of prosthion and infradentale were the most important determinants of horizontal upper and lower lip changes, respectively. Pretreatment lip thicknesses contributed negatively to the regressions, indicating that thicker lips produce greater lip retraction. Upper lip taper explained variation in the horizontal movements of SLS only. The regression models for vertical lip changes were simpler, incorporating 2–3 variables and explaining 67% to 76% of the variation. While the vertical change of pogonion was the most important determinant of vertical lip change, the vertical movements of prosthion, upper incisor point, and infradentale contributed significantly also. Pretreatment upper lip taper also explained variation in the vertical changes of SLS.

The validation sample showed no significant systematic differences between the actual and predicted lip changes (Table 8). The correlations and root mean square errors (RMSEs) derived for the validation sample compared closely to those of the larger sample.

DISCUSSION

Adolescents showed greater absolute and relative vertical changes than adults. Anterior and posterior facial heights showed the largest group differences, with the adolescents increasing 6–10 times more than adults. Differences were expected because adolescents have substantial vertical growth potential. Since treatment lasted approximately 2.5 years, small amounts of vertical growth were also expected among the adult group.[22] These growth differences must be factored into treatment plans because adults showed only half as much vertical lip change for every millimeter of vertical hard tissue change compared with adolescents.

Horizontally, the regions unaffected by treatment (eg, nose and chin) showed greater anterior growth changes in adolescents, while the dentition and lips demonstrated greater posterior movements in adults. In other words, growth dampened the treatment effect in adolescents as compared with adults.

The bivariate associations between upper lip and the underlying hard tissue retraction were moderate to moderately strong in both groups. The correlations for labrale superioris, were similar to those previously reported for four first premolar extraction treatments.[10,25,26] Weaker correlations have also been reported.[4–6] Our correlation for SLS ($r^2 = .56$) was almost identical to that published by Hershey.[10] Bivariate correlations appear to have only limited potential for predicting soft tissue changes, perhaps due to the complex anatomy of the upper lip at the attachment to the nose.[23] Different sample sizes, selection criteria, and measurement methods could explain the various associations reported.

The tip of the upper incisor showed weaker associations with upper lip retraction than prosthion. Higher associations for prosthion have been previously identified.[8,9] This is important because most studies only consider the facial surface or the tip of the upper incisor when predicting soft tissue changes.[2–6,8–12,26–29] The region above the crown may be expected to be more predictive than the crown because it incorporates information about both the crown and overlying bony support.

The soft-to-hard tissue relationships were consistently stronger for the lower than for the upper lip. Correlations for labrale inferioris were similar to those previously reported.[4–6] This finding reinforces the notion

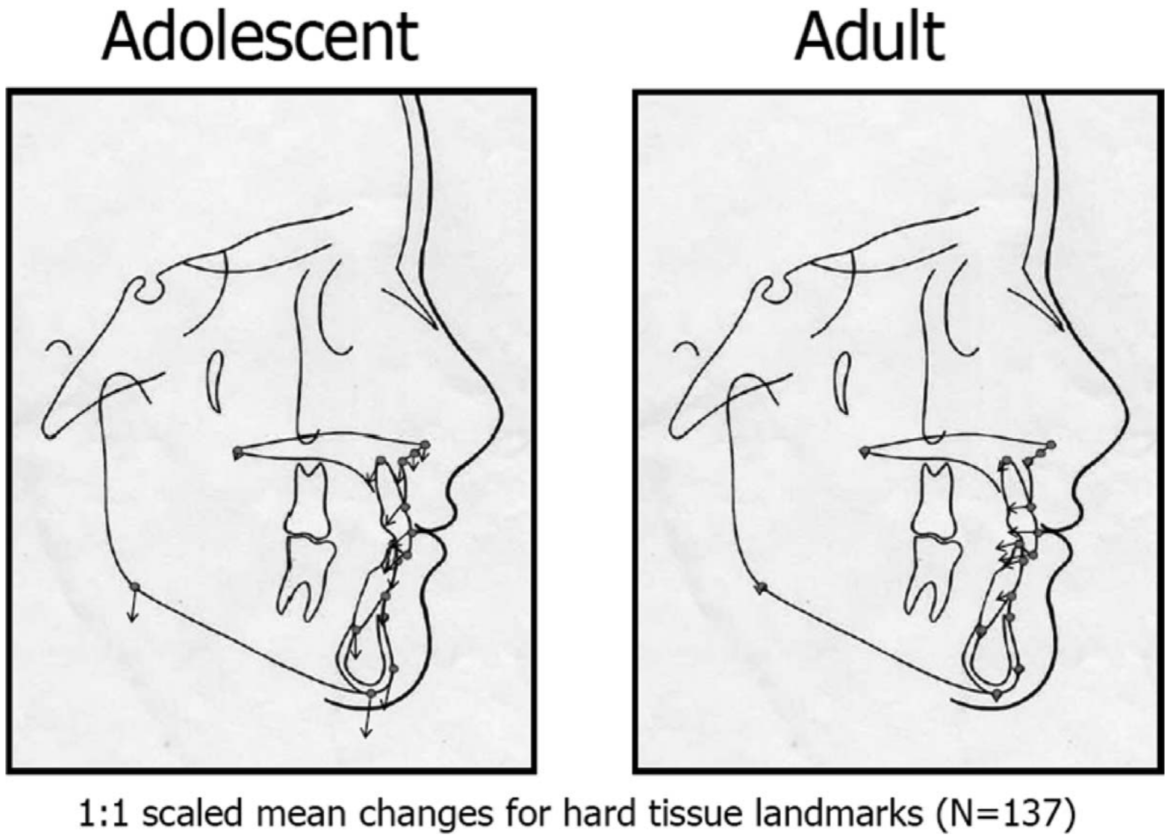

Figure 2. Hard and soft tissue response of (A) adolescent and (B) women to premolar extraction treatments.

Table 5. Bivariate Regression Analysis for Horizontal Movements of the Four Dependent Variables and Soft Tissue Landmarks

Variables[a]		Adolescents			Adults			Probabilities of Differences	
DV	IV	Constant	Slope	*R*	Constant	Slope	*R*	Constant	Slope
Ls-h	Pro-h	0.9	0.9	.69	0.8	1.0	.77	.87	.38
	UIP-h	0.9	0.7	.68	1.0	0.8	.73	.79	.44
	Is-h	0.5	0.6	.62	0.3	0.6	.62	.86	.78
	Li-h	−0.2	0.9	.91	0.1	0.9	.91	.26	.95
SLS-h	Pro-h	0.8	0.7	.75	1.2	0.9	.78	.35	.06
	UIP-h	0.7	0.5	.71	1.2	0.7	.69	.39	.17
	Is-h	0.4	0.4	.65	0.5	0.5	.57	.79	.51
	Li-h	−0.2	0.6	.85	0.4	0.8	.87	.02	.05
Li-h	Is-h	0.9	0.7	.75	0.5	0.7	.74	.53	.68
	Ls-h	−0.0	0.9	.91	−0.6	0.9	.91	.02	.86
	Id-h	−0.5	1.0	.83	−1.4	0.8	.77	.01	.19
	Ii-h	−0.1	0.9	.82	−0.5	0.8	.72	.31	.35
	Is-h	1.2	0.5	.58	2.1	0.7	.73	.20	.26
ILS-h	Ls-h	0.5	0.8	.76	0.7	0.8	.78	.63	.89
	Id-h	0.2	1.0	.85	0.5	0.9	.86	.29	.15
	Ii-h	0.6	0.8	.73	1.3	0.8	.75	.13	.76

[a] DV indicates dependent variable; IV, independent variable.

that the complex anatomy of the nose influences the upper lip and may contribute to its weaker relationships with the underlying hard tissues. As previously demonstrated for the upper lip, infradentale explained substantially more variation in lower lip change at ILS than the other hard tissue landmarks. Although not previously investigated, this further supports the notion that the region demarking the crown and root is the most important for predictive purposes.

The hard-to-soft tissue retraction ratio for labrale su-

Table 6. Bivariate Regression Analysis for Vertical Movements of Soft Tissue Landmarks

Variable[a]			Adolescents			Adults			Probabilities of Differences	
DV	IV		Constant	Slope	*R*	Constant	Slope	*R*	Constant	Slope
Ls-v	Pro-v	Prosthion	0.6	0.8	.71	0.3	0.5	.51	.37	.17
	UIP-v	Upper incisor point	0.6	0.8	.77	0.5	0.6	.62	.72	.09
	Is-v	Incision superioris	0.9	0.7	.72	0.4	0.4	.48	.11	.03
	Li-v	Labrale inferioris	0.4	0.8	.86	0.4	0.8	.85	.99	.96
SLS-v	Pro-v	Prosthion	1.9	0.7	.64	0.9	0.5	.50	.02	.33
	UIP-v	Upper incisor point	1.9	0.7	.68	1.1	0.4	.38	.03	.02
	Is-v	Incision superioris	2.0	0.7	.68	1.0	0.3	.39	.01	.02
	Li-v	Labrale inferioris	1.8	0.6	.70	1.0	0.5	.55	.02	.34
Li-v	Is-v	Incision superioris	1.0	0.9	.75	0.1	0.5	.50	.01	.02
	Ls-v	Labrale superioris	0.5	1.0	.86	−0.2	1.0	.85	.01	.83
	Id-v	Infradentale	0.6	0.6	.70	−0.2	0.5	.52	.05	.52
	Ii-v	Incision inferioris	0.4	0.7	.70	0.1	0.3	.29	.46	.03
	Is-v	Incision superioris	1.7	1.0	.72	0.0	0.4	.34	<.001	.01
ILS-v	Ls-v	Labrale superioris	1.3	1.0	.78	−0.3	0.9	.64	<.001	.60
	Id-v	Infradentale	1.0	0.8	.74	−0.5	0.9	.63	<.001	.55
	Ii-v	Incision inferioris	0.6	0.8	.75	−0.3	0.6	.47	.08	.27

[a] DV indicates dependent variable; IV, independent variable.

perioris varied depending on the underlying hard tissue. The ratio between retraction of the upper incisal edge and labrale superioris was 1.4:1. Retraction ratios of the upper lip in four first premolar extraction cases have been reported to range from 3.2:1 to 1.5:1.[3,7] Comparisons across studies are difficult due to methodological differences. Interestingly, adolescents and adults showed similar ratios for the facial surface of the upper incisor and prosthion, 1.3:1 and 1.1:1, respectively. This supports the notion that growth has little influence on the horizontal treatment changes of the upper lip. The ratio between prosthion and the incision superioris was most valuable clinically, due to the relative strength of the correlation between the two variables.

For the lower lip, the hard-to-soft tissue ratios ranged from 1.2:1 to 1:1. These estimates fall between ratios previously reported with extractions, which range from 1.8:1 to 0.4:1.[3,4] This is the first study to identify the importance of infradentale for predicting lower lip retraction. Because, infradentale showed the strongest relationship to retraction of labrale inferioris and inferior labial sulcus, it may be clinically more useful for prediction than either the tip or the facial surface of the lower incisor. Infradentale can also be used to predict retraction of ILS; it again produced the strongest correlations, which were similar in both adolescents and adults.

The findings show that multiple regressions provide better predictions than bivariate regression and ratios. Our multiple regression equations explained 12% to 14% more variability in lip retraction than the corresponding ratios for labrale inferioris and labrale superioris. In addition, they explained 7% to 10% more of the variability of retraction at inferior labial sulcus and superior labial sulcus. This supports the notion that ra-

Table 7. Stepwise Multivariate Regression Models for Upper and Lower Lip (T1-T2) by Dental, Soft, and Hard Tissue Variables

Dependent Variable	*R*	RMSE[a]	Constant	Prediction Equation[b] 1st	2nd	3rd	4th	5th
Horizontal changes								
SLS	.81	1.22	5.44	0.61(Pro-x)	0.18(U1A-x)	−0.37(BULT)	0.15(ULT)	0.06(Pg-y)
Ls	.79	1.63	9.09	0.90(Pro-x)	−0.42(VULT)	−0.24(BULT)		
Li	.90	1.21	8.05	0.48(Id-x)	−0.63(VULT)	0.54(L1P-x)	0.26(Id-y)	−0.15(Pg-y)
ILS	.89	1.24	3.42	0.76(Id-x)	−0.25(BLLT1)	0.22(L1A-x)		
Vertical changes								
SLS	.82	1.38	1.35	0.28(Pg-y)	0.44(Pro-y)	−0.19(ULT)		
Ls	.83	1.28	0.15	0.46(UIP-y)	0.26(Pg-y)			
Li	.87	1.32	−0.14	0.38(Pg-y)	0.45(UIP-y)			
ILS	.86	1.73	−0.27	0.52(Pg-y)	0.33(Id-y)			

[a] RMSE indicates root mean square error.

[b] Prediction equations: Y (dependent variable) = constant + (1st) + (2nd) + (3rd) + (4th) + (5th). For all values given, $P < .001$.

Table 8. Validation Results of the Horizontal and Vertical Prediction Equations on a Random Sample (20% of Study Sample)[a]

	Systematic Error			Random Error	
Variable	Mean	*T*	Sig	*R*	RMSE
Horizontal changes					
SLS-h	0.10	0.46	.65	.87	1.17
Ls-h	−0.29	0.93	.36	.77	1.83
Li-h	−0.12	−0.50	.62	.87	1.48
ILS-h	−0.05	−0.22	.83	.89	1.25
Vertical changes					
SLS-v	0.27	1.03	.31	.81	1.51
Ls-v	0.25	1.02	.31	.84	1.47
Li-v	0.33	1.74	.09	.93	1.14
ILS-v	0.24	0.89	.38	.89	1.59

[a] Sig indicates significance; RMSE, root mean square error.

tios are less precise than multiple regression for predicting soft tissue changes, including both surgical and orthodontic treatment changes.[9,13,17]

The multiple regression prediction equation for upper lip retraction at labrale superioris explained 62% of the variability. Previous multiple regression prediction equations have explained from 42% to 56% of the variability in the upper lip response to incisor retraction.[4,9] The stronger associations could have been due to the strict selection criteria used, which minimize confounding factors that could increase variability. In addition to changes at prosthion, information about basic upper lip thickness and vermillion upper lip thickness was necessary to explain retraction of labrale superioris. Both thicknesses contributed negatively, indicating that individuals presenting with less pretreatment lip strain (ie, thicker lips) displayed more lip retraction. Lip strain has been previously shown to be important in predicting the movement of labrale superioris.[9,12]

Our multivariate prediction equation for the retraction of superior labial sulcus was able to explain 66% of the variability. A combination of five variables including: prosthion, upper incisor apex, basic upper lip thickness, pretreatment upper lip taper, and pogonion, were important for predicting retraction of SLS. In 2005, Brock et al[9] found that 60% of the variability in upper lip retraction at SLS could be explained by basic pretreatment upper lip thickness, upper incisor angulation, and the horizontal treatment changes of prosthion and ANS. Talass et al[12] and Ramos et al[8] also found that the horizontal movements of prosthion and pretreatment upper lip thickness were important predictor variables.

The multivariate prediction equations for lower lip retraction at labrale inferioris and inferior labial sulcus were able to explain 81% and 79% of the variability, respectively. Therefore, in comparison to the upper lip, retraction of the lower lip was slightly more predictable, which agrees with others reporting that upper lip retraction is less predictable because of the complex anatomy of the upper lip.[12,30]

While the horizontal retraction of the lips has received the most attention, the vertical changes must also be considered for predictive purposes. The vertical change of pogonion was most important for predicting the vertical changes of both the upper and lower lips, probably because it represents a surrogate measure of mandibular displacement. Upper lip taper, prosthion, facial surface of the lower incisor and infradentale were also important for predicting vertical lip changes. Compared with the bivariate regressions, the multiple regressions explained 10% to 21% more variability in the vertical positions of the upper lip and 25% to 27% more variability in the lower lip. The results clearly show that when predicting lip position vertically and horizontally, multiple regression equations provide more precise estimates of soft tissue changes than do ratios.

CONCLUSIONS

- The hard and soft tissue changes in the adolescent group reflected significantly greater growth and treatment changes, both horizontally and vertically, compared with adults.
- Vertically and horizontally, the relationships between the lip changes and underlying hard tissue changes are strong in both white female adolescents and adults.
- Prosthion and infradentale showed the strongest relationship to upper and lower lip retraction, respectively, suggesting that the region immediately apical to the crown is singularly most important when evaluating lip retraction.
- Upper and lower lip retraction can be predicted with moderately high levels of accuracy using hard tissue treatment changes and pretreatment soft tissue characteristics.

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