Tufts UNIVERSITY | School of Dental Medicine

The Role of Lip Thickness in Upper Lip Response to Orthodontic Movement of Incisors

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ABSTRACT

<u>Aim</u>: The aim of this retrospective study was to investigate the association between upper lip thickness and the amount of upper lip repositioning upon retraction of maxillary incisors. We also intended to explore the possible creation of a method for prediction of profile changes in orthodontic patients treated with premolar extractions based on their initial upper lip thickness. **<u>Hypothesis</u>:** Subjects with thick upper lips will experience less changes in upper lip position subsequent to retraction of maxillary incisors. **<u>Materials & Methods</u>:** Pre- and post-treatment lateral cephalograms of 101 patients (34 males and 67 females; mean age 14.8 years at pretreatment and 17.5 years at posttreatment) were evaluated. All patients were treated with fixed orthodontic appliances and extraction of two maxillary premolars or four premolars. Only subjects where lip thickness did not change more than 1 mm between pre- and post-treatment cephalograms were included. Hard and soft tissue landmarks were identified and digitized by one investigator (R.A.) using "View Box" software (Version 4.0.1.7., dHal software). Two constructed lines were established as reference lines: a vertical line that is perpendicular to sella-nasion line minus 7 degrees (SN-7º perpendicular), and another vertical line passing through subnasale (VL). Three linear measurements were identified in reference to those vertical lines: upper lip thickness, upper lip protrusion and maxillary incisor position. **<u>Results:</u>** The Pearson correlation coefficient revealed that there was a significant correlation between change in maxillary incisor position following premolars extraction and change in upper lip position (r = 0.95, $p < 0.001$) and (r = 0.88, $p < 0.001$) in reference to SN-7º perpendicular and VL, respectively. The average ratio between maxillary incisor retraction and upper lip repositioning was 1.4:1. However, the upper lip thickness was not significantly associated with this ratio (r = 0.003, $p > 0.05$) and (r = -0.155, $p > 0.05$) in reference to SN-7º perpendicular and VL, respectively. **Conclusion:** This study concluded that although there is a highly significant correlation between maxillary incisor retraction and upper lip repositioning, lip thickness does not have a significant association with the amount of upper lip repositioning. It appears that the amount of pretreatment compression of the upper lip due to maxillary incisor protrusion plays a primary role in profile change in patients where maxillary incisors are retracted.

DEDICATION

I dedicate this thesis work to my beloved husband, Fahad, who has been a great source of support and inspiration. I am truly thankful for having you in my life.

To my parents, Mohammed and Huda, who have always stressed the importance of education. A special feeling of gratitude for their unconditional love and support throughout my life.

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LIST OF ABBREVIATIONS

CFH: Constructed Frankfort Horizontal

CBCT: Cone beam computed tomography

EM: Error of measurement

LS: Labrale superius

NHP: Natural head position

NHO: Natural head orientation

S: Sella

SD: Standard deviation

Sn: Subnasale

SN: Sella-Nasion line

SN-7 º: Horizontal line drawn 7 degree below Sella-Nasion line

TUSDM: Tufts University School of Dental Medicine

U1: Maxillary incisor prominence

VL: Vertical line passing through subnasale

The Role of Lip Thickness in Upper Lip Response to Orthodontic Movement of Incisors

Introduction

Soft tissue and profile changes associated with orthodontic treatment have been an area of controversy in orthodontics for decades. It is generally accepted today that orthodontic treatment can influence the soft tissue profile, especially when four premolars are extracted and incisors are retracted. However, there is still lack of agreement on the amount of response of soft tissues to the changes in position of teeth and alveolar process. These soft tissue changes could either result in substantial improvements in the profile or lead to a flatter and “dished-in" profile.

An essential part of facial profile are the lips, which have been commonly perceived as an important feature contributing to beauty and facial attractiveness. Public believe that fullness is a component of attractive lips. A trend has been increasing toward fuller and more protruded lips among fashion magazine’s models over the past century.[1] Despite ethnic differences, loss of fullness and decreased lip projection have overall been identified as signs of ageing and unattractiveness.[2,3] When evaluating lips, the profile view is of specific importance; it displays the critical influence of the dentition and alveolar ridges on the lips appearance.[3] Due to the profound effect that orthodontic treatment can have on incisor position, the role of the orthodontist in influencing the soft tissue profile becomes critical.

Many studies investigating the effect of orthodontic treatment on the facial profile have focused on predicting lip response relative to incisor movement. This relationship has been expressed as the ratio of maxillary incisor retraction to upper lip retraction.[4-17] Previously reported ratios range between 1.4:1 and 3.6:1.[7,11-20] However, these vary considerably between different studies and according to age, sex, ,ethnicity and treatment modality.[4,7,8,21] Baum[22] reported that dental changes and related facial profile changes subsequent to orthodontic treatment could be predicted, to some extent, from the age, sex, and developmental level of the patient. Kocadereli[23] agreed that the patient's sex should be considered when planning treatment for an adolescent patient, especially when reduction of lips protrusion is a primary objective of the treatment. Considering that lip position is evaluated in relation to the nose and chin, the fact that the lips will drop back while the nose and the chin will continue to grow needs to be taken into account. Residual growth of the nose and chin is more evident in males compared to females.

Ethnicity could also affect upper lip response to retraction of incisors; ethnic differences exist in morphology and composition of the soft tissues of the lips. Brock et al[24] reported ethnic differences in upper lip response to incisors retraction between black and white females. However, these differences were thought to be more related to ethnic differences in initial lip thickness and incisor inclination rather than ethnicity itself. Blacks tend to have a greater incisor proclination and a more protrusive soft tissue profile.[25]

Several studies have suggested that soft tissue profile changes after orthodontic retraction of incisors may be related to multiple variables such as pretreatment lip strain, variations in lip structure and thickness, and amount of incisor retraction.[5,8,10,26-28] Oliver[6] reported more lip retraction following incisors retraction in patients with thin lips or high lip strains. Wisth[21] suggested that lips have some inherent support; he observed that the lip response to incisor movement decreased as the amount of incisor retraction increased.

Growth changes in soft tissue of the lips:

Many studies in the past have described the effect of growth in soft tissue changes and made attempts to separate it from the effect of orthodontic treatment.[4,15,17,29,30] Growth can either enhance or mask the profile changes produced by orthodontic treatment, thus, growth effects must be eliminated for a more accurate evaluation of orthodontic treatment effects on profile. Hershey,[4] Rains et al[7] and others[17,24,29] have limited their samples to adult females to reduce variables caused by growth and sex differences.

Adolescent changes:

Soft tissue profile changes due to growth have been well documented in the literature. Subtelny[31] published a longitudinal study evaluating the growth of untreated patients. He analyzed thirty subjects from the Bolton Growth Study with cephalograms taken periodically from 3 months to 18 years of age. Based on the results, the upper lip continued to increase in length until the age of 15 years, when growth slowed down noticeably. Upper lip thickness increased in both, males and females, until the age of 14 years. Thereafter, the upper lip continued to grow in thickness in males but not in females. It was concluded that the lip posture closely follows the growth of underlying dentoalveolar structures.

Nanda and Ghosh[32] studied growth of the soft tissues of the face and long term profile changes in untreated subjects between the ages of 7 and 18 years who were considered to have a balanced facial appearance. They found that upper and lower lips increased in both length and thickness. Males experienced a greater lip elongation than females. This significant increase in lip length in males accommodates more protrusion of incisors compared to the lips of females. The study reported the presence of a sexual dimorphism in the soft tissue growth of the nose, lips, and chin; males showed a greater growth over a longer time compared to females.

Hoffelder et al[33] investigated growth changes in the soft tissue of the nose, chin, and lips from age 6 to 16 years. The Cephalomgrams of 36 subjects with skeletal Class II malocclusions obtained from the Burlington Growth Study were analyzed. They found that in both sexes, all structures showed growth changes with the nose presenting the greatest amount of growth. Sexual dimorphism was present with greater changes in boys. Based on their results, they recommended completing orthodontic treatment for adolescent patients, especially boys, with a more prominent lip due to the anticipated growth of the nose and chin. They also suggested that orthodontic treatment involving teeth extractions has a greater effect on the facial profile of girls than boys, because of the differences between sexes in the growth effect on lip thickness.

Adult changes:

Nanda and Ghosh[32] evaluated the growth of soft tissues in 47 adults between the age of 18 and 42, and reported that in males the profile tends to become straighter with age, due to a decrease in lip thickness, lip retrusion and changes in nose and chin prominence. In female subjects, the profile appeared to be more convex with age due to a greater growth of the nose than the chin and mandible. The upper lip increased in length in both sexes which resulted in a reduction in incisor exposure by 1 mm. They observed a sexual difference in the age around which the majority of the adult soft tissue changes have occurred. In males, the age range was between 18 and 24 years, whereas in females between the ages of 20 and 30 years. They explained these findings by the fact that male growth can continue until early adulthood. However, female changes that occurred at a more advanced adult age were difficult to explain. It was suggested that these changes may be related to childbearing and hormonal changes around this age.

In another adult longitudinal study, Formby[34] studied profile changes in Caucasians between the age of 18 and 42 years. He found that in males, there was a decrease in thickness of both lips and an increase in the soft tissue thickness at pogonion. These changes resulted in a straighter profile and a more retrusive lips with age. This was in contrast to females: their profiles did not become straighter with age, nor did the lips become more retrusive and there was a decrease in soft tissue thickness at pogonion. In both sexes, the size of the nose increased in all dimensions, suggesting soft tissue growth continues into adulthood. In agreement with the findings of Nanda and Ghosh[32], Formby[34] reported that adult growth changes occurred in males mostly before the age of 25, however, in females more changes occurred after that age.

Behrents[35] conducted a longitudinal study to evaluate aging of the craniofacial complex. He evaluated 113 untreated patients from the Bolton Growth study. Aging resulted in a greater soft tissue than hard tissue changes. The nose grew in a downward and forward direction in both sexes, but more in males, while the upper lip elongated and flattened in both sexes. The overall profile became straighter with age.

Cephalometric Reference Planes:

Several reference planes are prescribed in the literature and have been used in previous studies for evaluating lip posture and soft tissue profile. These include Rickett's "E" line,[36] Stiener "S" line,[37] Holdaway's "H" line,[38,39] Merrifield's "Z" line[40] and Burstone's "B" line.[41] All of these lines are affected by facial growth; therefore, they could not be reliably used as reference planes to measure facial profile changes with orthodontic treatment on a longitudinal basis. Other studies used reference planes that are affected to a lesser degree by facial growth such as Frankfort plane,[42] palatal plane[6,43] and pterygomaxillary line.[27,44,45]

In most previous studies, the horizontal reference line was assigned to be the Constructed Frankfort horizontal (CFH) drawn 7 degrees below the SN line (SN-7°). The vertical reference line was assigned to be a constructed line perpendicular to SN-7° passing through Sella or Nasion.[7,8,12,15,17,18,24,46-48] These lines have been claimed by the authors to be an approximation of the true horizontal and true vertical planes, respectively.[5,24] Other authors mentioned that this method was used to facilitate comparisons with other studies.[5,15]

Literature review:

In the literature, there appear to be opposing views about the soft tissue response to orthodontic treatment. [6] Some investigators have reported a high correlation between maxillary incisor retraction and upper lip retraction; indicating a close relationship between hard tissue and soft-tissue changes.[11-13,16,43,49] Others, however, did not find a definite relationship between dentoalveolar changes and soft tissue profile changes; position of maxillary incisors does not necessarily relate to upper lip position. [4,7,8,21,41,43,50]

Bloom[43] reported a high degree of correlation between teeth movement and changes in perioral soft tissue in sixty orthodontically treated white patients. Change in maxillary incisors was associated with changes in the superior sulcus, upper lip, and lower lip. Furthermore, change in mandibular incisors resulted in changes in the inferior sulcus and lower lip. He concluded that it was possible to predict the soft tissue profile changes from the anticipated amount of incisors movement. Jamilian et al[17] found the same significant correlation between incisor movement and soft tissue profile changes in adult Caucasian females. Similar findings were also reported in adult Japanese and Indonesian individuals with bimaxillary protrusion.[18,15]

Rudee [11] assessed proportional profile changes concurrent with orthodontic treatment in 85 patients from his practice. He found a high degree of correlation between maxillary incisors and upper lip movements. He suggested that although orthodontic treatment can influence the soft tissue profile by changing tooth and lip positions, equal concern should be given to the growth of nose and chin that results in flattening of the profile. Rudee's findings agree with Anderson et al[51] who evaluated profile changes 10 years out of retention in seventy patients. They found that orthodontic treatment resulted in reduction of dentofacial protrusion with both lips becoming less prominent during treatment with the retraction of maxillary and mandibular incisors. Long-term results showed that lips becoming progressively more retrusive as the nose and chin continue to grow during maturation.

Hershey[4] found a moderately strong correlation between movement of upper incisors and upper lip changes in 34 post-adolescent females; as the amount of incisor retraction increased there was a decrease in the lip prominence. However, lip will follow incisor movement to a certain extent; gross retraction of incisors may not result in gross lip repositioning. A similar significant correlation was reported by Waldman[45] in class II division 1 patients.

Another study by Rains[7] evaluated cephalometric films of 30 early-adult female patients for changes in profile subsequent to maxillary and mandibular incisor movement. The results exhibited a high variability in upper lip response after retraction of upper incisors, and thus it was concluded that upper lip response is also affected by other factors, such as mandibular rotation and lower lip repositioning.

Garner[13] studied a group of African-Americans and reported ratios of incisor change to lip posture change similar to those reported by Rudee[11] and Hershy[4] in Caucasian samples. He concluded that the degree of the lip repositioning is not always predictable, and that equal incisor retraction in different patients can produce different lip responses. Caplan and Shivapuja[12] found no significant correlation between upper lip and maxillary incisor retraction in black females. The upper lip was correlated more strongly with lower lip retraction. They observed that there was more variability in the response of upper lip than lower lip relative to the variation in incisor retraction.

Oliver[6] was the first to conduct a study to investigate the influence of upper lip thickness and lip strain on the relationship between dental and soft tissue changes in orthodontically treated patients. Although, previous studies suggested an influence of lip thickness on lip response to tooth movement, Oliver[6] made the first attempt to statistically quantify this relationship. His sample consisted of 40 Caucasian patients with Class II Division 1 malocclusion. Percentile groups were created within this sample based on magnitude of upper lip thickness and lip strain. He found strong correlations between hard-tissue changes and soft-tissue changes in subjects with thin lips or high lip strain whereas no significant correlations were found in subjects with thick lips or low lip strain.

Wholley and Woods [27] studied the effects of different premolar extraction patterns on the curvature of upper and lower lips and found similar changes in different groups of premolar extractions. They concluded that the pretreatment characteristic with the greatest potential to affect changes in lip curvature was the pretreatment lip thickness. They suggested that when the pretreatment vermilion lip thickness increased, it provides protection against a significant change in the depth of lip curvature.

A recent study by Kuhn et al[28] evaluated the soft tissue profile changes in non-growing patients following a wide range of incisor movements in labial and lingual directions. Forty-seven pairs of lateral cephalograms (pre- and post-treatment) were superimposed in reference to a palatal implant. The results showed a significant correlation between horizontal changes of maxillary incisor and horizontal changes of the upper and lower lips. They observed that patients with initially thicker lips had less pronounced lip retraction than patients with thinner lips. The study concluded that the factors that contributed mostly to the prediction of profile changes with orthodontic treatment are: the horizontal movement of maxillary incisor, the amount of bite opening, and the pretreatment lip thickness.

Based on the above review of the literature, there is insufficient information for orthodontists to help predict soft-tissue changes at the time of treatment planning. Reporting ratios of hard-tissue to soft-tissue changes as previous studies have done are unlikely to be generalized due to great variation among individuals. Multiple factors related to initial incisors position, lip thickness, lip length and strain play a significant role in predicting the soft tissue response to orthodontic tooth movement.[10,47] In our study, we aim to investigate the relationship between upper lip thickness and upper lip changes subsequent to maxillary incisor movement.

Aim and Hypothesis

Aims:

1- To investigate the association between upper lip thickness and the amount of upper lip repositioning upon retraction of maxillary incisors.

2. To explore the possible creation of a method for prediction of profile changes in orthodontic patients treated with premolar extractions based on their initial upper lip thickness.

Hypothesis:

Subjects with thick upper lips will experience less changes in upper lip position subsequent to retraction of maxillary incisors.

Clinical Significance of the study

We hope that the results of this study will aid orthodontists in formulating the treatment plan for individual patients, especially deciding between extraction and non-extraction treatment. This study aimed to create a method that will enable orthodontists to predict the profile changes in patients treated with premolar extractions based on the pretreatment lip thickness.

Research Design

The study design was a retrospective cohort study. Records of all patients treated at the Department of Orthodontics, Tufts University School of Dental Medicine (TUSDM) between January 2008 and January 2017 were reviewed.

The inclusion criteria were as follow:

1. Patient had extraction of two upper premolars or four (two upper and two lower) premolars (either first or second premolars).
2. Availability of pre- and post-treatment lateral cephalograms of diagnostic quality, including a millimeter ruler for calibration.
3. No change more than 1 mm in lip thickness between pre- and post-treatment, as measured on a cephalometric radiograph.
4. No syndromes, cleft lip and palate or craniofacial anomalies.
5. No congenitally missing permanent teeth (except third molars).
6. No history of orthognathic surgery.

A power calculation was conducted using nQuery Advisor (Version 7.0). Assuming a correlation of 0.40 between lip thickness and the ratio between change in incisor position and change in upper lip protrusion[6], a sample size of n = 101 was adequate to provide a Type I error rate of 5% and a power of 98% *(Table 1)*.

Materials and Methods

The protocol of this study was reviewed and approved by the Tufts Health Sciences Institutional Review Board (IRB #: 12112). In order to obtain the necessary study sample, all electronic records of extraction cases treated in the Tufts orthodontic clinic between 2008 and 2017 were identified and reviewed. One hundred and one subjects met the inclusion criteria of this study (*n* = 101) and comprised the final study sample. The following data were collected for each subject: demographic information (gender, date of birth), extraction pattern, date of pre- and post-treatment lateral cephalometric radiographs. Patients were randomly assigned with identification numbers and those numbers were used to label patients throughout the study. Data were saved in a password protected Excel (Microsoft Excel, Microsoft©, Richmond WA, USA) spreadsheet on Tufts Box.

Lateral cephalometric radiographs of the 101 patients were exported and saved on Tufts Box prior to uploading them to the ViewBox software (dHAL Software, Kifissia, Athens-Greece). All cephalograms that were not taken initially in natural head position (NHP)[52] were adjusted to natural head orientation (NHO) by a single investigator (R.A.). NHO was described by Lundström[53] as the head position evaluated as "natural" by the clinician based on general experience. Jiang et al.[54] found a strong correlation between the estimated and the registered natural head position. The natural head position was used to establish a reliable and reproducible reference line from which the linear measurements could be calculated. After orienting all cephalograms into NHO, they were all adjusted to the same magnification.

Lip thickness was measured for each patient in pre- and post-treatment cephalograms as the horizontal distance between Labrale superius (Ls) and the most anterior point on the crown of maxillary incisor (U1) *(Figure 1)*. Only subjects where lip thickness did not change more than 1 mm between pre- and post-treatment cephalograms were included. This step was done to eliminate the effect of lip compression on our results.

For each patient, pretreatment and posttreatment cephalograms were digitally traced by one investigator (R.A.) using "View Box" software. Hard tissue, soft tissue, and constructed cephalometric landmarks were identified and digitized: three hard tissue and two soft tissue landmarks *(Table 2, Figure 2)*.

Cephalometric analysis involved the construction of three reference planes: a horizontal reference line was constructed at the level of nasion equal to the sella-nasion line minus 7 degrees and labeled SN-7°,[55] a vertical reference line was constructed perpendicular to SN-7° below Nasion,[4,5,12,14,40,47] and another constructed vertical line passing through subnasale (Sn) labeled VL[56,57] *(Figure 3)*. Three linear measurements were identified in reference to those two vertical lines: upper lip thickness, upper lip protrusion and maxillary incisor position *(Table 3)*. Measurements that were posterior to the reference line were recorded negative and those that were anterior to the reference line were recorded positive. Change for each measurement was calculated by subtracting the posttreatment value from the pretreatment value. Thus, upper incisor and upper lip that became more retruded with the treatment had more negative values.

Statistical Analysis

Descriptive statistics including means and standard deviations for each variable at pretreatment (T_1) and posttreatment (T_2) in addition to the changes between them (T_2 - T_1) were calculated. The association between change in maxillary incisor position and change in upper lip protrusion was assessed with Pearson correlation coefficient. Also, the Pearson correlation coefficient was used to assess the correlation between upper lip thickness and the ratio between change in maxillary incisor position and change in upper lip protrusion. Multivariate linear regression was conducted to assess the significance of the association between change in upper lip protrusion (the dependent variable) and change in maxillary incisor position (the independent variable) controlling for age, sex and lip thickness as confounding variables; the R^2 and *p*-values were obtained. The data were divided into four groups based on upper lip thickness using the quartiles as cutoff points; in the first group, subjects had the thinnest lips and in the fourth group, subjects had the thickest lips among the studied sample. The multivariate linear regression model that was used for the whole sample was run for each one of the four groups to investigate possible associations within different ranges of lip thickness. *P*-values less than 0.05 were considered statistically significant. The data were imported into Excel (version 15.30, Microsoft, Redmond, WA) for primary manipulation before final statistical assessment with SPSS (IBM, version 24).

Error of the method:

To determine the errors associated with radiographic measurements, 30 subjects were selected randomly. Randomization was conducted using the "sample" function of the statistical software package R (Version 3.1.2). A total of 60 pre- and post-treatment cephalograms of those 30 randomly selected patients were retraced by the same investigator (R.A.) three weeks after the initial tracing. Error of measurements (EM) was evaluated using two methods:

1-Dahlberg's error.

A formula was proposed by Dahlberg in 1940 as a method for quantifying measurement error. It has been used the most frequently in assessing random errors in cephalometric studies. It is a simple and efficient way to evaluate error of measurement. One shortcoming of the Dahlberg's error may be that it does not distinguish between systematic and random errors, by assuming only random errors.[58-61]

$$D = \sqrt{\sum_{i=1}^{N} \frac{d_i^2}{2N}}$$

d_i is the difference between the first and the second measure and N is the sample size which was re-measured (N=30).

There is almost no reference for the acceptable range of Dahlberg's error because it may depend on various clinical conditions. If therapeutic changes were small, the error of measurement can significantly influence the evaluated differences. Frequently, researchers have reported that “the amount of error was small enough” without any further explanation.[58,61]

2- Bland-Altman method.

The Bland-Altman method is a graphical approach based on visualization of the difference of measurements between two methods. A Bland-Altman plot enables visual judgment of how well two methods of measurement agree. For each pair of measurements, the Bland-Altman method plots the difference between the pair of measurements against the average of the pair. It also shows the mean difference between the two methods (across all pairs) as well as the mean difference ± 2 SD.[62]

Results

<u>Error of the method</u>:

1-Dahlberg's error.

The Dahlberg's method showed that the calculated error of measurement (EM) has a maximum value of 0.28 mm which was considered an insignificant error of the method *(Table 4)*.

2- Bland-Altman method.

The visual examination of the Bland-Altman plot allows to evaluate the agreement between the two measurements. An acceptable level of agreement between the two measurements was concluded *(Figure 5).*

<u>Descriptive statistics and correlations</u>:

The study sample was compromised of 101 patients, 34 males and 67 females, who met the inclusion criteria *(Figure 6)*. The mean age ± SD at pretreatment was 14.8 ± 4.5 and at posttreatment was 17.5 ± 4.5 *(Table 5)*. Means and standard deviations of pretreatment, posttreatment measurements and the changes between them are shown in *(Table 6)*.

The Pearson correlation test indicated significant positive correlation between change in maxillary incisor position and change in upper lip protrusion in reference to both vertical lines SN-7º perpendicular (r = 0. 949, $p < 0.001$) and VL (r = 0.884, $p < 0.001$) *(Table 7, Figure 7)*. An average ratio of 1.4:1 between the change in maxillary incisor position and the change in upper lip protrusion was found in reference to both vertical lines. On the other hand, the Pearson correlation coefficient showed no significant correlation between pretreatment lip thickness and the ratio between change in maxillary incisor position and change in upper lip position ($r = 0.003$, $p > 0.05$) and ($r = -0.155$, $p > 0.05$) in reference to SN-7º perpendicular and VL, respectively *(Table 8, Figure 8)*.

Multivariate linear regression analysis:

Multivariate linear regression *(Tables 9 and 10)* revealed that lip thickness, age and sex could not significantly predict the amount of upper lip repositioning following maxillary incisors retraction with premolar extractions. In this multivariate linear regression model, only maxillary incisor position had a statistically significant predictive role in upper lip repositioning *(Table 10)*.

Data were divided into four groups based on pretreatment lip thickness using quartiles as cutoff points *(Table 11)*. Multivariate linear regression did not show any significant role of lip thickness, sex or age in prediction of the change in upper lip protrusion within any of the four groups of lip thickness. Maxillary incisor position was the only independent variable that showed a significant association with upper lip repositioning within each of the four groups *(Tables 12 and 13)*.

Discussion

This retrospective study was conducted to evaluate the role of lip thickness on the amount of upper lip repositioning upon retraction of maxillary incisors after premolars extraction. Cases were studied without regard for the type of pretreatment malocclusion or treatment technique. Subjects were included only if their lip thickness did not change more than 1 mm between pretreatment and posttreatment in lateral cephalometric radiographs. Hence, the influence of growth and lip compression on the results was minimized.

The results showed a highly significant positive correlation between maxillary incisors retraction and upper lip retraction. This is in agreement with several previous studies.[11,4,15,17,18,43] However, Lai et al.[63] found no correlation of lip retraction to changes in incisor position with treatment. He attributed the difficulty in finding any relation to the great variability in soft tissue response among individuals. Caplan and Shivapuja[12] reported a weaker correlation between retraction of maxillary incisor and retraction of upper lip in adult African American females.

In this study, the average retraction of maxillary incisors was 1.8 mm that resulted in retraction of upper lip by an average of 1.5 mm in reference to both vertical lines. Nevertheless, measurements of mean treatment changes give a statistical evaluation of how the sample reacts as a whole, and they do not explain the variability in the amount of maxillary incisor retraction and the upper lip response. Kocaderili[23] found that the change in protuberance of the lips is highly individual, and while retraction of the incisors can cause a pronounced reduction in lip protrusion in some patients, in others, the same degree of retraction produces only a slight reduction. He attributed this to lip structure, which appears to influence its response to incisor retraction. Garner[13] reported similar findings in African Americans, and stated that a comparable incisor retraction does not result in equal lip retraction among different patients.

The average ratio for maxillary incisor retraction to upper lip retraction was 1.4:1 in this study. This is closest to the one reported by Hodges et al.[20] and Jamilian et al.[17] who reported a ratio of 1.4:1 and 1.58:1 respectively. However, both studies used the incisal edge as a landmark for incisor position, while in our study the most prominent point on the crown of the incisor was used. The difference between our ratio and the ratios reported in previous studies could be due to the variation in landmarks used to evaluate incisor position. The incisal edge has been used commonly in previous studies as a landmark for incisor position.[17,20] However, many studies revealed that it has a weak association to lip movement.[8,11,18,46] Ramos[46] reported that the correlation between upper lip retraction and maxillary incisor retraction was more significant with the incisor measured at cervical point than at the incisal edge . Yasutomi[18] reported similar findings. Other possible sources of variation in the reported ratios are ethnicity, growth and sample size.

In the multivariate linear regression model that was used in this study, maxillary incisors movement was the only independent variable that play a significant role in predicting the dependent variable (upper lip repositioning). Other independent variables including sex, age and upper lip thickness had no significant role in predicting upper lip repositioning. Those results are in accordance with Mirabella et al.[64] results. They found significant variability among individuals and concluded that the prediction of upper lip behavior following maxillary incisors movement is barely possible.

Talass et al.[8] supported that changes in the lower lip in response to orthodontic tooth movement were more predictable than those of the upper lip. Similar findings were reported by Bloom[43] and Caplan and Shivapuja.[12] The poor predictability of upper lip response to incisor movement may be due to the complex anatomy of the upper lip, which is difficult to evaluate by the current cephalometric techniques.[8]

In an attempt to evaluate the upper lip response to maxillary incisors retraction among different lip thicknesses our sample was divided into four groups according to upper lip thickness; first group subjects fell within the lower 25 percent (<10.55 mm) and considered to have thin lips, while fourth group fell within the upper 25 percent (>13.4 mm) and considered to have thick lips. No statistically significant associations were found within any of the four groups, in regards to the relationship between lip thickness and upper lip repositioning.

Our findings did not agree with Oliver[6] who reported that a greater amount of upper lip retraction occurred in patients with thinner upper lips at pretreatment and that high variability in soft tissue tone, length and thickness can cause different lip responses during incisor retraction between persons with thick upper lips and those with thin upper lips.[6]

Hershey[4] tried to determine whether original lip morphology was a factor in the soft tissue response to treatment. He compared ten subjects exhibiting redundant lips with ten subjects exhibiting incompetent lips; no significant difference was found between the two groups. However, his findings should be interpreted with caution due to subjectivity in selecting subjects for the two groups and due to the small sample size.

Based on our results, we conclude that lip thickness does not play a significant role in upper lip response to maxillary incisors movement. Lip compression is probably a more important factor in clinically assessing lip response than lip thickness. If the upper lip was compressed due to proclination or protrusion of maxillary incisors before orthodontic treatment, then this compression will be relieved with incisors retraction; this will result in increase in lip thickness posttreatment. After upper lip compression is eliminated, the lip will start following the movement of the incisors. Assuming that thicker upper lips are more likely to be compressed with proclined maxillary incisors than thinner lips, they will not start following incisors retraction until their compression is relieved with the first few millimeters of incisors retraction. In other words, thicker lips do not reposition significantly unless considerable retraction of maxillary incisors takes place. On the other hand, thinner upper lips are unlikely to be compressed before treatment and will start following incisors movement with the first few millimeters of retraction. As a result, thinner upper lips will change to a greater degree than thicker lips due to the initial lip compression and not necessarily due to lip thickness itself. In our study, there was a minimal leeway of 1 mm where the upper lip could have decompressed before starts following maxillary incisors movement.

Several investigators have commented on the effect of incisor retraction on lip thickness. Rickettes[36] suggested that with every 3 mm of incisor retraction there is an increase in lip thickness by 1 mm. Anderson[51] reported an increase in upper lip thickness during treatment by an average of 1 mm for every 1.5 mm of maxillary incisor retraction. Although during retention, lip thickness decreased slightly, a significant increase was maintained 10 years postretention.[51] Erdinc et al[47] found no positive correlation between incisor retraction and changes in lip thickness. They observed increase in upper lip thickness with treatment even in non-extraction patients where the maxillary incisors were protruded. Therefore, they suggested that the increase in lip thickness could have been a result of growth during the study period.[65] Mirabella et al.[64] compared the behavior of upper lip following orthodontic movement of maxillary incisor between two groups of patients; incisor retraction group and incisor protraction group . They found that lip thickness was moderately increased in the retraction group. In the protraction group, a significant reduction in the lip thickness was observed. They explained that the difference between the two groups in lip thickness during treatment suggests that the incisor movement was absorbed by the lip thickness in the protraction group which masked the effect of incisor proclination on the profile. This supports our hypothesis of upper lip compression with proclined maxillary incisors.

Holdaway[38,39] described that retraction of the upper lip does not follow incisor retraction until the lip strain is eliminated. In the presence of lip strain, the upper lip must stretch over the protrusive incisors on closure and it becomes thinner. In our study, by limiting the sample to subjects with lip thickness difference of not more than 1 mm between pretreatment and post-treatment cephalometric images, we can assume that the lip strain factor was eliminated. Therefore it can be assumed that the upper lip followed the retraction of the maxillary incisors to a varying degree, without noticeable change in thickness.

Limitations of the study:

As in any retrospective lateral cephalometric study, any muscular activity whether a voluntary or involuntary that occurs during radiographs taking may affect the accuracy of measurements subsequently made from those radiographs.[27] Zierhut et al.[66] recommended that all studies evaluating the lip posture and soft tissue profile must always consider lip strain as a factor affecting the accuracy of measurements of the lip position and behavior. Inability to control or quantify this factor remains a shortcoming of all retrospective cephalometric studies evaluating soft tissues.[9,66,67]

Another limitation is the effect of growth on soft tissue and upper lip posture. The mean age at pretreatment of the studied sample was 14.8 ± 4.5; further growth changes in the soft tissues are expected at this age. Although this variable was controlled to some degree by limiting the sample to subjects who did not exhibit change in lip thickness more the 1 mm, it is still a confounding variable that could potentially have affected the results of this study. Also, the lack of control for ethnicity among the sample is a limitation of this study.

Conclusion

The following conclusions are drawn from this study:

1- There was a strong positive correlation between maxillary incisors retraction and upper lip retraction. The average ratio for maxillary incisor retraction to upper lip retraction was 1.4:1 in this study.

2- Upper lip thickness does not have a significant role in the amount of upper lip repositioning that occur with incisor retraction. Therefore, pretreatment lip thickness is not a good predictor of upper lip response to maxillary incisors movement specially when premolars extraction is planned.

3- It appears that the amount of pretreatment compression of the upper lip due to maxillary incisor protrusion is more important when assessing profile changes in patients where maxillary incisors are retracted. However, it may be difficult to identify and quantify this lip compression at diagnosis and treatment planning stage.

The variation in soft tissue response to orthodontic treatment and the impossibility of accurately predicting this response should be discussed with the patient before the initiation of orthodontic treatment especially when treatment plan includes extraction of teeth.

Recommendation

Future prospective studies are recommended to evaluate the role of lip thickness on a wider range of incisor movements, where incisors are moved towards both labial and palatal directions.

Furthermore, the advent of three-dimensional imaging and improvements in analysis software now permit a volumetric evaluation of soft tissues and facial structures. A study that compares three-dimensional radiographic imaging (CBCT) with three-dimensional analysis of soft tissue can provide orthodontist with more accurate information about the role of lip thickness on lip response to teeth movement.

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APPENDICES

- Appendix A: Tables 1-13
- Appendix B: Figures 1-7

Appendix A: Tables

Table 1: Power calculations for a significance level (α =0.05)

Power (%)	Sample size (*n*)
80	47
85	54
90	62
95	76
98	101
99	200

Table 2: Cephalometric landmarks

Landmark		Definition
Hard tissue landmarks		
N	Nasion	Most anterior point of frontonasal suture on midsagittal plane
S	Sella	Geometric enter of pituitary fossa of sphenoid bone
U1	Maxillary incisor prominence	The most anterior point on crown of most anterior maxillary incisor
Soft tissue landmarks		
Ls	Labrale superius	Most anterior point on convexity of upper lip
Sn	Subnasale	Point at junction of columella and upper lip
Constructed landmarks		
SN	Sella-nasion line	Line extending between sella and nasion
SN-7º	Horizontal line	Horizontal line 7 degrees inferior to SN plane
SN-7º perpendicular	Vertical line 7º below N	Vertical line perpendicular to horizontal line 7 degrees inferior to SN line and below nasion
VL	Vertical line through Sn	Vertical line passing through subnasale

Table 3: Linear cephalometric measurements (mm)

Linear measurement (mm)		Definition
U1 to Ls	Upper lip thickness	Horizontal distance from the most anterior point on maxillary incisor crown to the most anterior point of the upper lip
Ls to SN-7º perpendicular	Upper lip protrusion to SN-7º perpendicular	Distance from the most anterior point of the upper lip to SN-7ºperpendicular, measured on a horizontal line perpendicular to this vertical line
U1 to SN-7º perpendicular	Maxillary incisor position to SN-7º perpendicular	Distance from the most anterior point at maxillary incisor crown to SN-7º perpendicular, measured on a horizontal line perpendicular to this vertical line
Ls to VL	Upper lip protrusion to VL	Distance from the most anterior point of the upper lip to the vertical line VL, measured on a horizontal line perpendicular to this vertical line
U1 to VL	Maxillary incisor position to VL	Distance from the most anterior point at maxillary incisor crown to the vertical line VL, measured on a horizontal line perpendicular to this vertical line

Table 4: The results of Dahlberg's formula (*n* =30)

Paired variables	Dahlberg's Error (mm)	
	Pre-treatment	Post-treatment
U1 to SN-7°perpendicular	0.26	0.18
Ls to SN-7° perpendicular	0.28	0.16
U1 to VL	0.12	0.13
Ls to VL	0.13	0.12
Lip thickness	0.05	0.03

Table 5: Age at pre-treatment and post-treatment

Age (years)	N	Minimum	Maximum	Mean	SD
Pre-treatment	101	9.31	35.41	14.82	4.49
Post-treatment	101	12.44	38.09	17.49	4.51

Table 6: Mean and standard deviation of pretreatment, posttreatment measurements and the changes (*n* =101)

Variable (mm)	***Pre-treatment***		***Post-treatment***		***Changes***			
	Mean	***SD***	***Mean***	***SD***	***Mean***	***SD***	***Min***	***Max***
Lip thickness	12.00	2.05	12.29	2.05	0.29	0.67	0.00	1.00
U1 to SN-7° perpendicular	9.83	4.44	7.99	4.60	-1.83	3.09	-10.27	3.70
Ls to SN-7° perpendicular	21.84	4.64	20.29	4.95	-1.55	3.05	-10.87	4.40
U1 to VL	-6.43	2.79	-8.23	2.44	-1.80	1.54	-6.50	2.10
Ls to VL	5.57	2.64	4.06	2.38	-1.51	1.44	-6.40	1.60
Ratio of U1 to Ls in reference to SN-7° perpendicular	0.43	0.13	0.38	0.16	1.43	1.86	0.01	17.58
Ratio of U1 to Ls in reference to VL	2.53	4.93	5.90	12.88	1.40	1.10	0.00	8.00

Table 7: Correlation between change in maxillary incisor position and change in upper lip position

	SN-7° perpendicular	***VL***
Pearson correlation	0.003	-0.155
P	0.976	0.122

Table 8: Correlation between pre-treatment lip thickness and the ratio between change in maxillary incisor position and change in upper lip position

	SN-7° perpendicular	***VL***
Pearson correlation	0.949	0.884
Significance (2-tailed)	<0.001	<0.001

Table 9: Multivariate linear regression model for role of lip thickness, age, sex and the change in maxillary incisors position in prediction of the change in upper lip protrusion in reference to SN-7° perpendicular

Dependent variable (mm)	Model	R^2	*P*
Change in Ls to SN-7° perpendicular	1	0.016[a]	0.212
	2	0.035[b]	0.160
	3	0.057[c]	0.139
	4	0.906[d]	<0.001*

a. Predictors: (Constant), Pre-treatment lip thickness.
b. Predictors: (Constant), Pre-treatment lip thickness, Sex.
c. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment.
d. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment, Change in U1 to SN-7° perpendicular.
* Value significant at $P \leq 0.05$.

Table 10: Multivariate linear regression model for role of lip thickness, age, sex and change in maxillary incisor position in prediction of the change in upper lip protrusion in reference to VL

Dependent variable	Model	R^2	*P*
Change in Ls to VL	1[a]	0.001	0.708
	2[b]	0.034	0.071
	3[c]	0.035	0.768
	4[d]	0.787	<0.001*

a. Predictors: (Constant), Pre-treatment lip thickness.
b. Predictors: (Constant), Pre-treatment lip thickness, Sex.
c. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment.
d. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment, Change in U1 to VL.
* Value significant at $P \leq 0.05$.

Table 11: Lip thickness groups

Group	*n*	Lip thickness (mm)	
		Minimum	Maximum
1	25	8.00	10.50
2	26	10.60	11.80
3	25	11.90	13.30
4	25	13.50	16.50

Table 12: Multivariate linear regression for lip thickness groups to assess the role of lip thickness, age, sex and change in maxillary incisor position in prediction of the change in upper lip protrusion in reference to SN-7° perpendicular

Model	Group 1		Group 2		Group 3		Group 4	
	R^2	*P*	R^2	*P*	R^2	*P*	R^2	*P*
1	0.016[a]	0.550	0.074[a]	0.180	0.017[a]	0.536	0.000[a]	0.967
2	0.065[b]	0.291	0.082[b]	0.650	0.090[b]	0.196	0.061[b]	0.244
3	0.092[c]	0.443	0.091[c]	0.650	0.093[c]	0.825	0.076[c]	0.565
4	0.791[d]	<0.001*	0.654[d]	<0.001*	0.863[d]	<0.001*	0.827[d]	<0.001*

Dependent variable: Change in ls to SN-7° perpendicular.
a. Predictors: (Constant), Pre-treatment lip thickness.
b. Predictors: (Constant), Pre-treatment lip thickness, Sex.
c. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment.
d. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment, Change in U1 to VL.
* Value significant at $P \leq 0.05$.

Table 13: Multivariate linear regression for lip thickness groups to assess the role of lip thickness, age, sex and change in maxillary incisor position in prediction of the change in upper lip protrusion in reference to VL

Model	Group 1		Group 2		Group 3		Group 4	
	R^2	*P*	R^2	*P*	R^2	*P*	R^2	*P*
1	0.151[a]	0.055	0.035[a]	0.359	0.006[a]	0.721	0.020[a]	0.498
2	0.152[b]	0.877	0.080[b]	0.303	0.130[b]	0.090	0.046[b]	0.450
3	0.213[c]	0.214	0.087[c]	0.689	0.172[c]	0.315	0.067[c]	0.493
4	0.897[d]	<0.001*	0.905[d]	<0.001*	0.922[d]	<0.001*	0.934[d]	<0.001*

Dependent variable: Change in ls to VL.
a. Predictors: (Constant), Pre-treatment lip thickness.
b. Predictors: (Constant), Pre-treatment lip thickness, Sex.
c. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment.
d. Predictors: (Constant), Pre-treatment lip thickness, Sex, Age at pre-treatment, Change in U1 to VL.
* Value significant at $P \leq 0.05$.

Appendix B: Figures

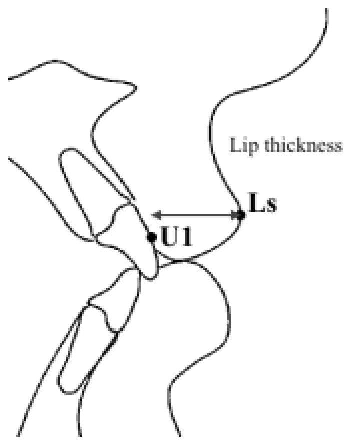


Figure 1: Upper lip thickness measured at the vermillion border (mm).

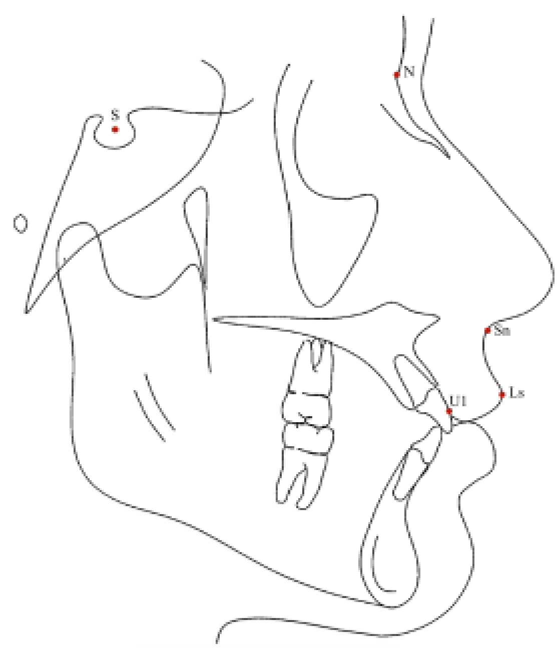
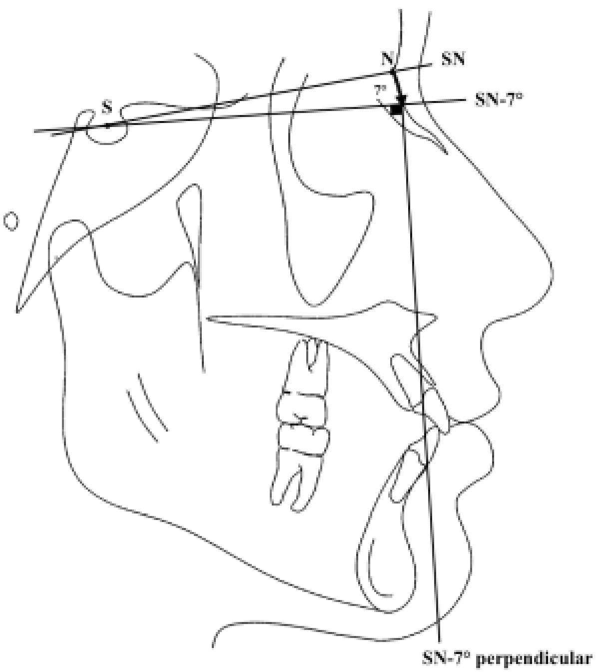
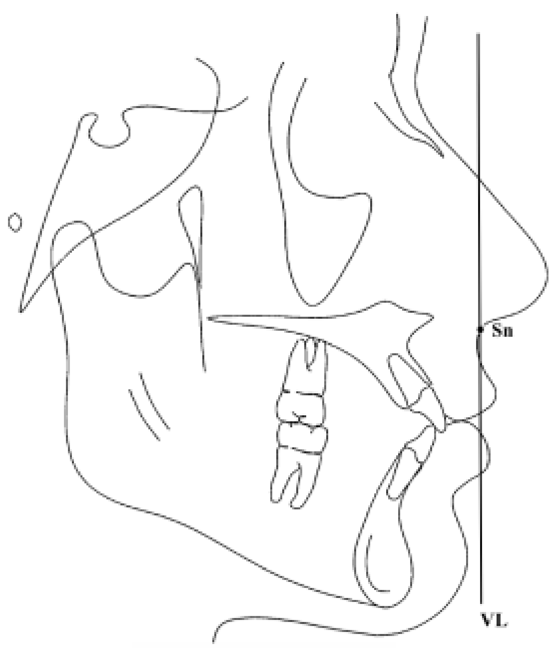


Figure 2: Hard and soft tissue cephalometric landmarks.



(A)



(B)

Figure 3: Cephalometric constructed reference lines. (A) constructed vertical line perpendicular to SN-7° below Nasion (B)VL: constructed vertical line passing through subnasale (Sn)

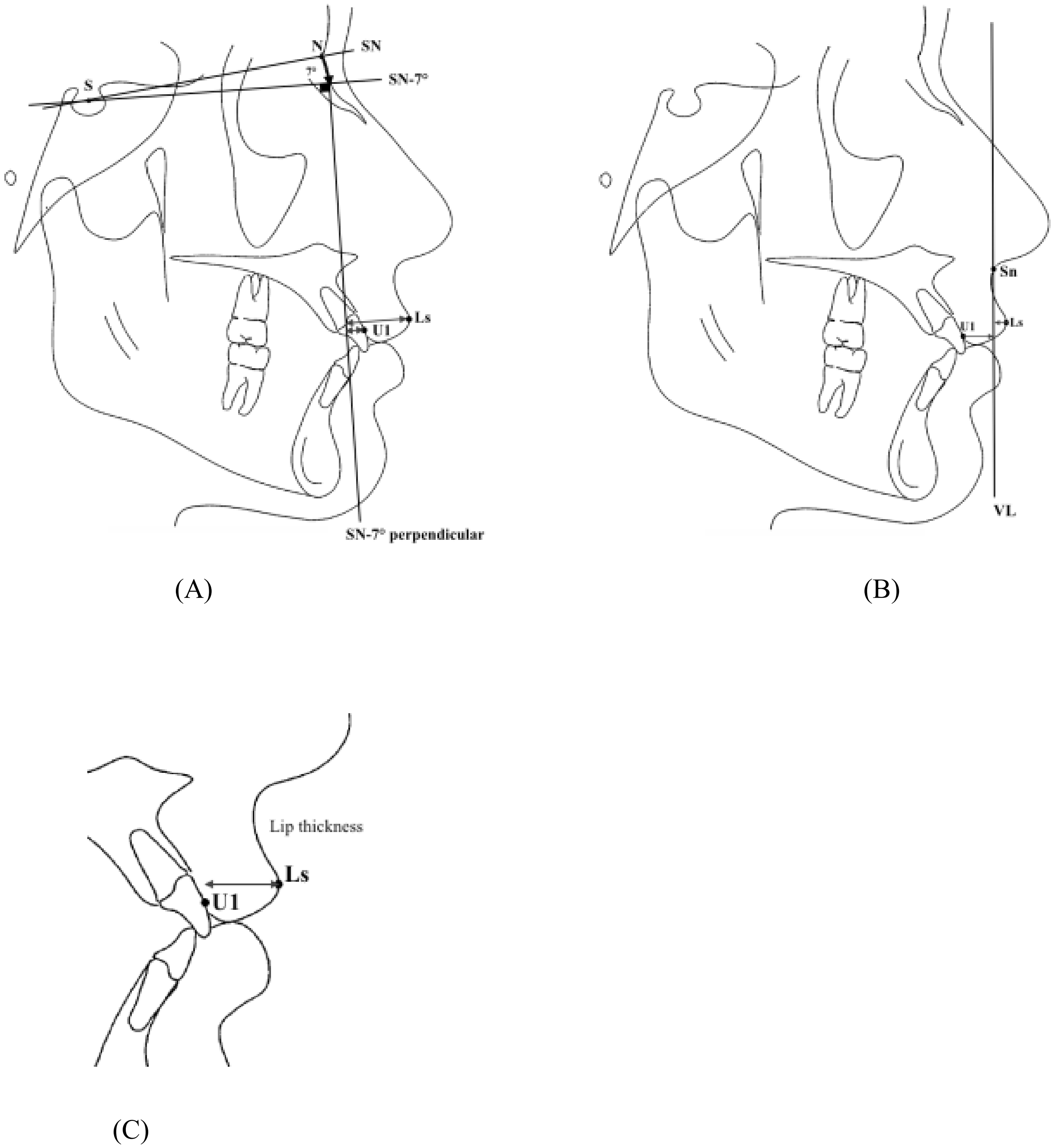
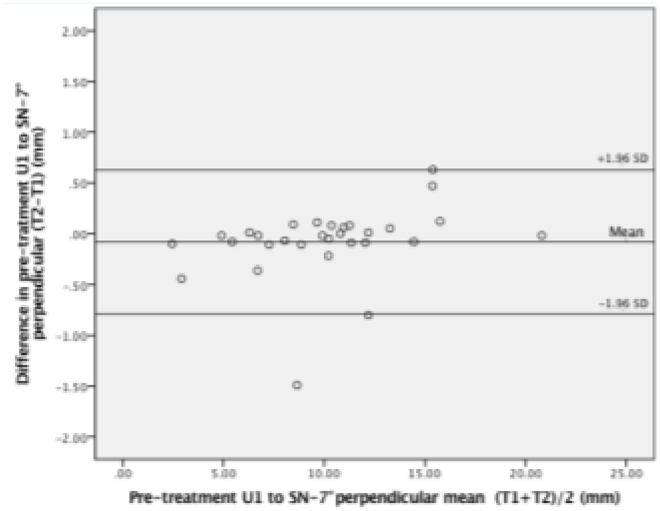
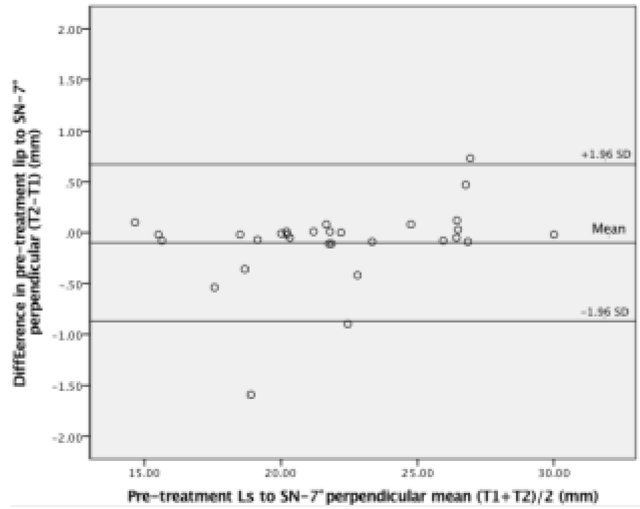
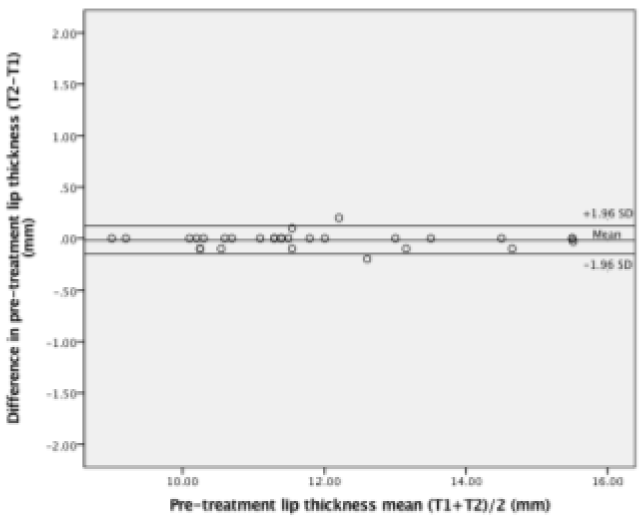
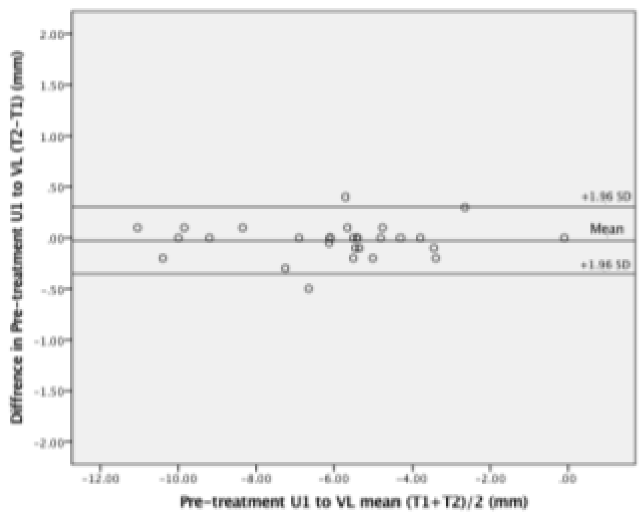


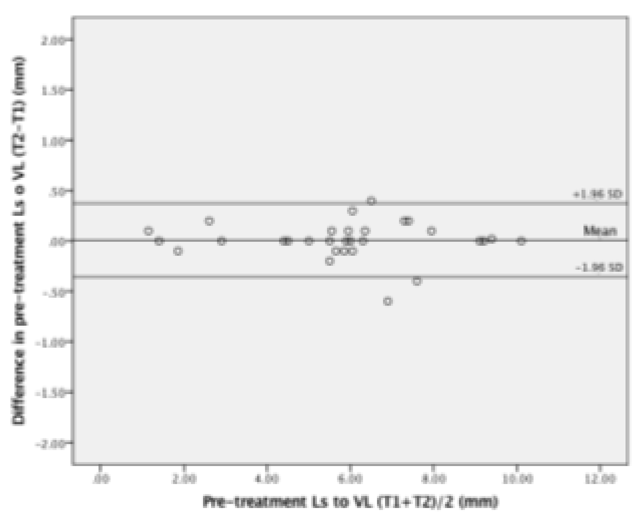
Figure 4: Linear cephalometric measurements (mm). Maxillary incisor position U1 and upper lip position Ls in reference to: (A) SN-7° perpendicular (B) VL, (C) upper lip thickness.

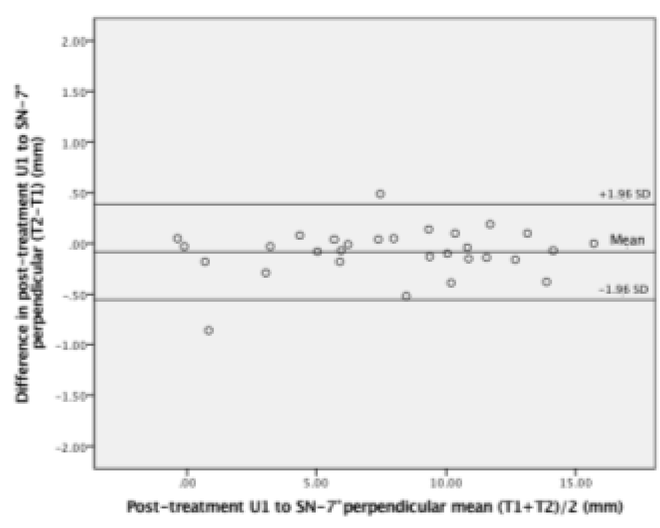

Difference in pre-tratment U1 to SN-7° perpendicular (T2-T1) (mm)
+1.96 SD
Mean
-1.96 SD
Pre-treatment U1 to SN-7° perpendicular mean (T1+T2)/2 (mm)


DiffEerence in pre-treatment lip to SN-7° perpendicular (T2-T1) (mm)
+1.96 SD
Mean
-1.96 SD
Pre-treatment Ls to SN-7° perpendicular mean (T1+T2)/2 (mm)


Difference in pre-treatment lip thickness (T2-T1) (mm)
+1.96 SD
Mean
-1.96 SD
Pre-treatment lip thickness mean (T1+T2)/2 (mm)


Diffrence in Pre-treatment U1 to VL (T2-T1) (mm)
+1.96 SD
Mean
+1.96 SD
Pre-treatment U1 to VL mean (T1+T2)/2 (mm)


Difference in pre-treatment Ls o VL (T2-T1) (mm)
+1.96 SD
Mean
-1.96 SD
Pre-treatment Ls to VL (T1+T2)/2 (mm)


Difference in post-treatment U1 to SN-7° perpendicular (T2-T1) (mm)
+1.96 SD
Mean
-1.96 SD
Post-treatment U1 to SN-7° perpendicular mean (T1+T2)/2 (mm)

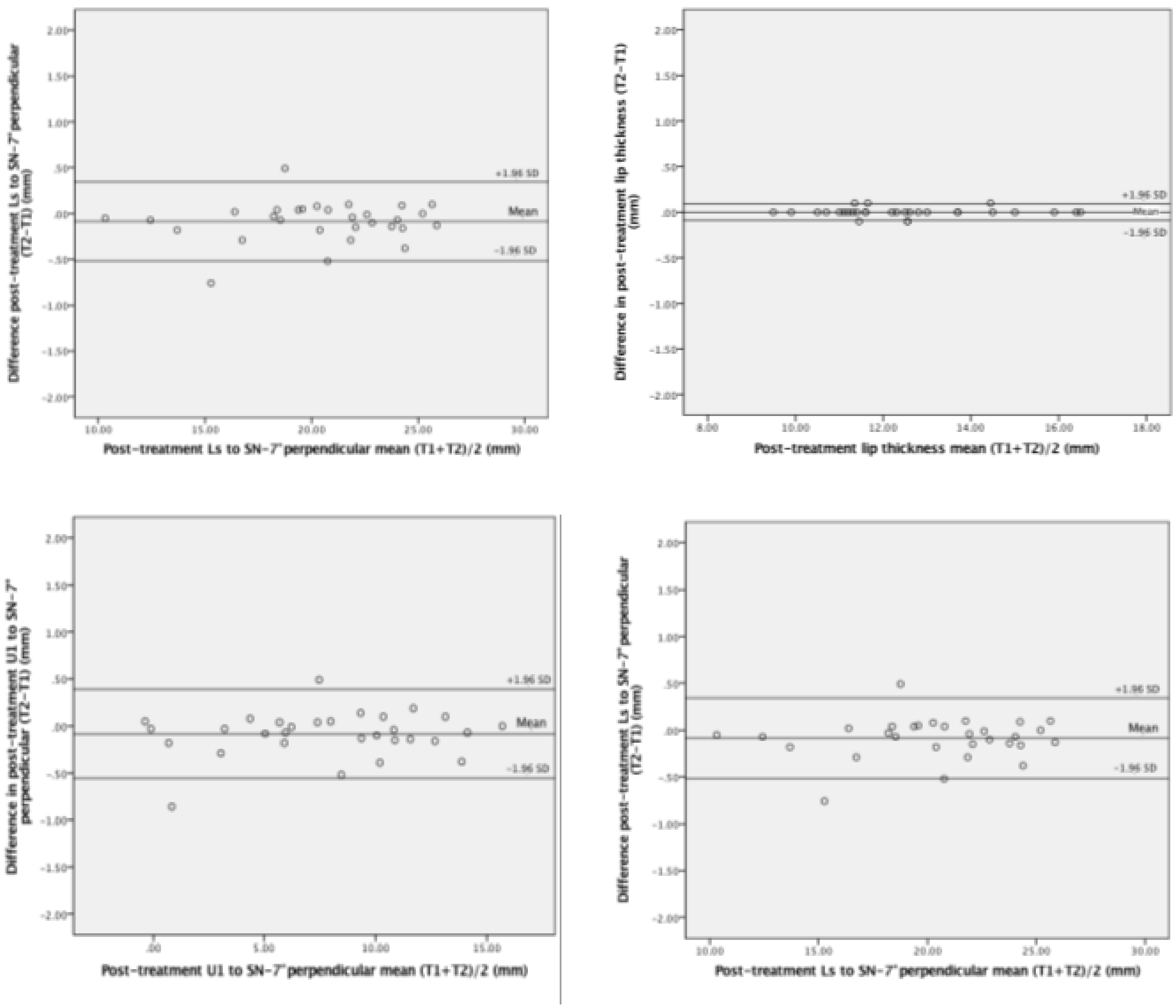


Figure 5: Bland-Altman plots for measurement of error of the method.

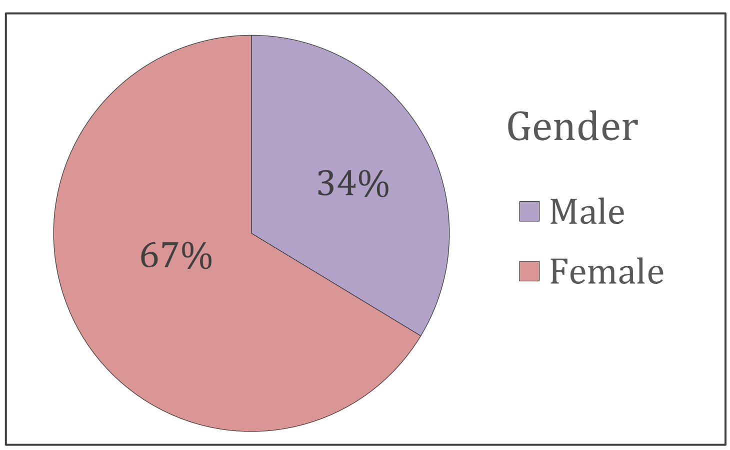
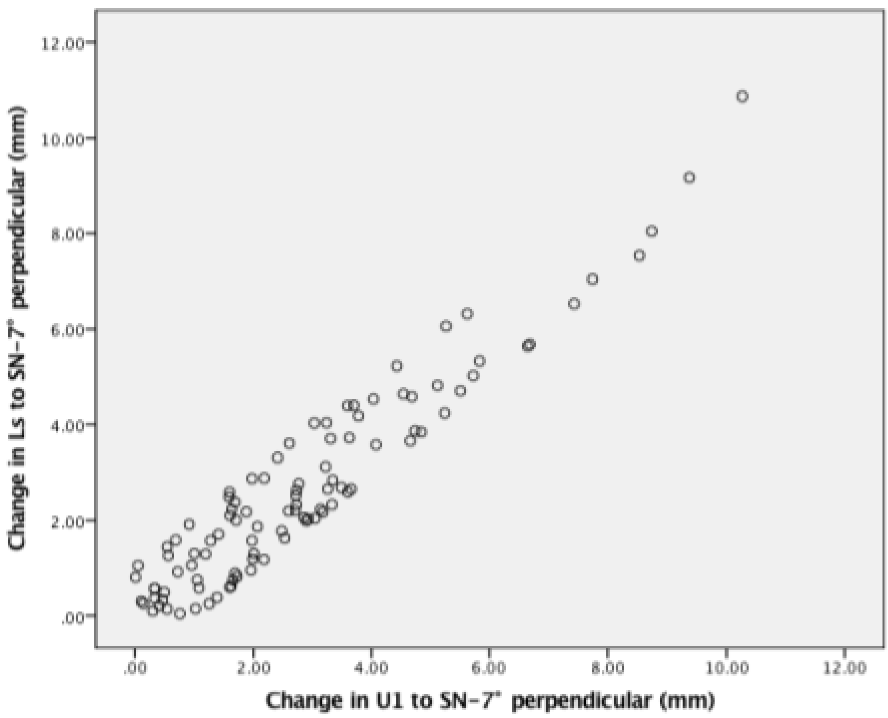
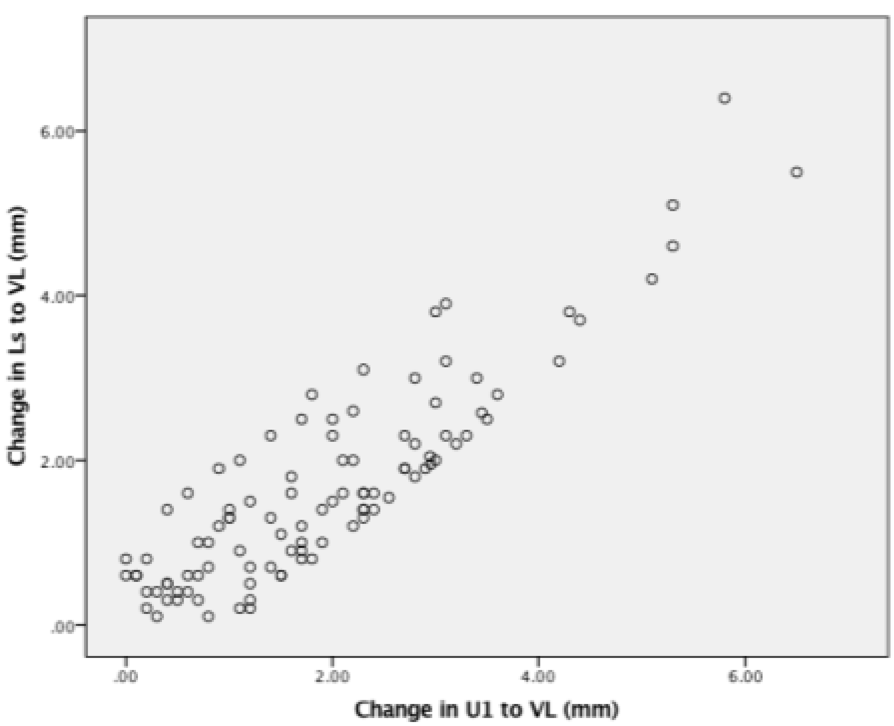


Figure 6: Gender distribution in the study sample (*n* = 101)

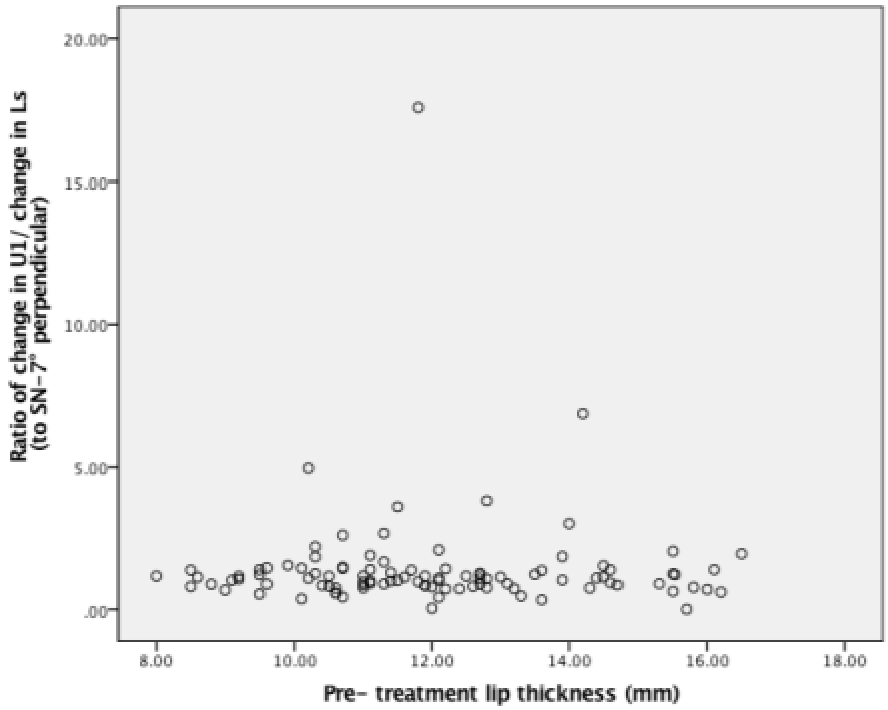


(A)

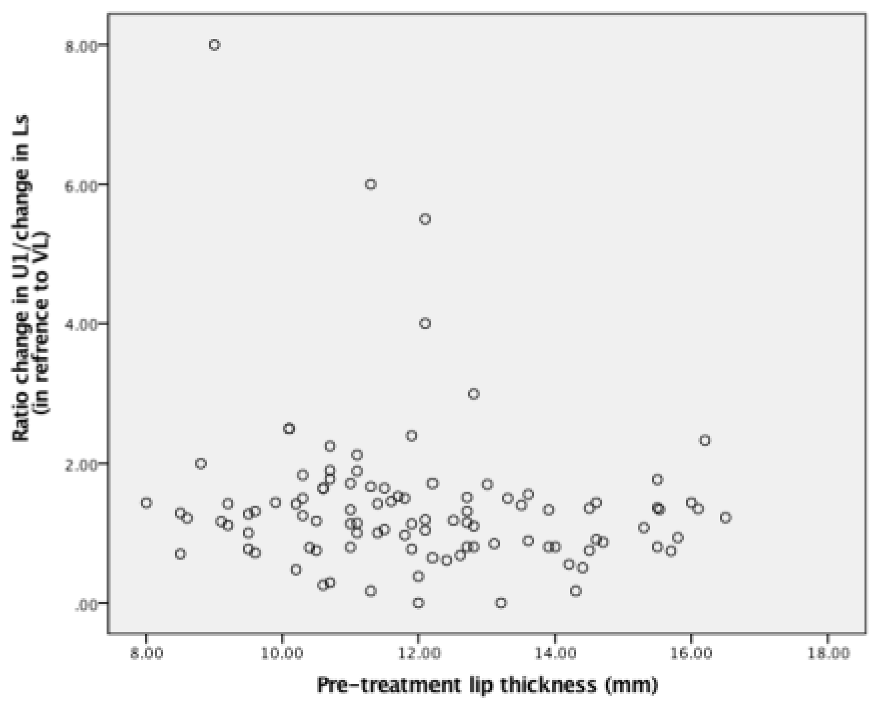


(B)

Figure 7: Scatterplots of change in maxillary incisors position and change in upper lip protrusion measured in reference to: (A) SN-7°perpendicular (B) VL.



(A)



(B)

Figure 8: Scatterplots of pretreatment lip thickness and the ratio between change in maxillary incisors position and change in upper lip protrusion measured in reference to: (A) SN-7° perpendicular (B) VL.