CHANGES RESULTING FROM BEGG ORTHODONTIC TREATMENT WITH EMPHASIS ON THE SOFT TISSUE PROFILE

VOLUME 1

TEXT

A report submitted in partial fulfilment for the degree of Master of Dental Surgery.

by

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TABLE OF CONTENTS

ERRATA and ADDENDA data have been inserted following the Bibliography in this volume.

VOLUME 2 : APPENDICES

Page

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Soft tissue changes in the region of the nose, lips and chin as a result of growth processes and/or orthodontic treatment have long been recognised. The Begg technique has been critisized for "dishing-in" the lip profiles of patients. However, relatively few studies have been made to quantify soft tissue changes, especially after Begg orthodontic treatment.

Studies of treatment effects on the soft tissue profile have used a wide range of methodologies in terms of measurement techniques and statistical analyses, yet there was universal agreement that there is a relationship between anterior tooth retraction and lip changes due to treatment. The observed changes were complicated by the effects of growth and soft tissue posturing. Mainly because of the effect of soft tissue posturing there was little consensus as to which lip posture was most suited to standardization of cephalograms in soft tissue studies.

A sample of 60 patients treated in the post-graduate orthodontic training programme at the University of Adelaide since 1969 was studied to provide information about the effects of growth, and especially Begg orthodontic treatment, on the soft tissue profile of the lower face. This sample comprised 30 males and 30 females of adolescent age, all of whom had a Class II, division I pattern of malocclusion. The sample selected on the basis of the cephalometric radiographs taken before treatment and at bands off. The mean times between radiographs was 1.9 years in males and 2.1 years in females. The radiographs were carefully selected according to strict criteria. The enlargement factor of 8.8%,

which was constant for all films, was compensated for in the calculation of linear variables.

Under standardised conditions 17 hard and 12 soft tissue landmarks were identified. The films were superimposed according to the procedure of Björk (1968) and Björk and Skieller (1983) in which stable structures of the anterior cranial base were used to transfer the reference system from the pre-treatment to the post-treatment film. A line joining reference points nasion and sella formed the X-axis and a perpendicular through point sella formed the Y-axis.

The landmarks and reference system were recorded using an electronic digitizer. The data was processed by the University of Adelaide Cyber 173 computer. The values of 48 linear variables (both horizontal and vertical), 10 dentoskeletal angles, and 8 soft tissue angles were calculated. All horizontal variables were perpendiculars from the landmarks to the Y-axis, and all vertical variables were measured as perpendiculars to the X-axis, such that changes due to both growth and treatment were observed.

The statistical analysis included replicability studies to determine the error of the method of tracing, superimposing and digitizing, and the error of digitizing only. For several variables the differences between the two sets of determinations were found to be significant at the $p < 0.1$ or $p < 0.5$ levels. In these instances the variables were considered to be less reliable. However, the mean difference between determinations was less than 0.5 mm for most linear variables and less than 1^{o} for most angular variables. The error of digitizing was negligible.

Student's t and Snedecor's F-ratio tests were calculated to assess the significance of differences between the sexes. Before treatment, there were very few variables with significant differences between the sexes. After treatment, however, there were many more significant differences. These were mainly found in the vertical location of hard and soft tissue profile landmarks, and indicated that on average the males grew significantly more in the vertical direction than females. Treatment responses did not show such a clear sex difference. The males had a significantly larger variance than the females for many variables which was due to the wider variation of growth experiences in the males.

On average, the nose grew downwards and forwards in both males and females. The tip of the nose grew forwards significantly more in males than females by 1.5 mm ($p < 0.01$). The soft tissue chin closely followed the underlying hard tissue chin and was largely unaffected directly by growth or treatment. The upper incisors were retracted, uprighted and moved downwards and backwards due to the combined effects of growth and treatment. The lower incisors were intruded, retracted slightly, and proclined approximately 5^{o} in both sexes. The upper lip increased in concavity after treatment, that is, it assumed a more curled profile. The upper lip retraction was greater lower down on the lip, away from the nose. The lower lip reduced in concavity after treatment as the upper incisors were retracted from the interlabial region. The lips moved towards a more closed position after treatment. The nasolabial angle opened by 5.2^{o} in females and 6.7^{o} in males after treatment. Only a small amount of mandibular plane opening was noted.

The upper lip retracted but did not follow the incisors in a 1:1 relationship. The ratio of 3.8:1 in females and 3:1 in males for upper incisor to upper lip retraction compared favorably with several studies and indicated less lip response to incisor retraction than most previous studies. A ratio of 2.5:1 has commonly been reported. The lower lip had less tendency to follow incisor retraction than the upper.

Correlation coefficients indicated a moderate correlation between upper lip and upper incisor retraction and lower lip and lower incisor retraction for all landmarks in these areas. These values confirmed those of the only other comprehensive study of soft tissue changes due to Begg orhtodontic treatment by De Laat in 1974. A complex relationship existed between dentoalveolar changes and soft tissue changes in the region of the lips as a result of treatment. The lip response varied according to factors such as growth, muscular tone, lip length and thickness, and a difficulty in recording a reproducible lip posture.

Z-scores were calculated for the variables for all subjects which allowed a study of individual cases and an appreciation of the great extent of individual variation that occurred in growth and treatment responses. Cases in which the soft tissue profile could be judged to be "dished-in" tended to have large noses and chins and/or considerable growth in these regions. Moreover, this was often more important in terms of the overall profile than the lip retraction per se.

STATEMENT

This report contains no material which has been accepted for the award of any other degree or diploma in any University. To the best of my knowledge and belief, it contains no material previously published except where due reference has been made in the text of the report.

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B.D.S.

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INTRODUCTION AND AIMS

Many types of orthodontic appliances are available to produce changes specifically aimed at the dento-alveolar complex. Soft tissue changes, especially in the region of the lips, which accompany these dento-skeletal corrections have long been recognized. However, until recently, scant attention has been directed towards quantifying these associated soft tissue changes. As a result a number of orthodontic techniques have been criticized for ruining or "dishing-in" facial profiles on an emotional rather than a scientific basis. The Begg technique has received such criticism. However, the number of studies which could be used in defence of the technique are few. No comprehensive studies are to be found in the orthodontic journals. Cangialosi and Meistrell (1982) studied changes only during the third (final) stage of treatment. De Laat (1974) published a small thesis reporting changes due to three orthodontic techniques, including Begg. The thesis of Werner (1968), cited by De Laat (1974), was the only other study of soft tissue changes due to the Begg technique. However, neither Werner (1968) or De Laat (1974) published their results in orthodontic journals. This would be a problem for those orthodontists using the Begg technique who wished to know how changing tooth positions could effect the soft tissue profile in order to help plan treatment and obtain optimum results.

Since Adelaide is the "home" of Begg technique it seemed appropriate that such a study should be based on patients treated in the post-graduate orthodontic programme of the University of Adelaide. This thesis is the first statistical survey of the Begg technique to be carried out in Australia.

Since its introduction in 1931 cephalometry has been the basis of a large number of studies of craniofacial growth and/or treatment. However, as has been the case with treatment studies, investigations of growth changes of the soft tissue profile have also been few. Much of the pioneering work was done by authors such as Burstone (1958, 1959) and Subtelny (1959, 1961). Authors such as Burstone (1967), Wisth and Böe (1975) and Hillesund et al. (1978) emphasized the problem of lip posture standardization in soft tissue studies.

The sample in the present study consisted of patients with a Class II, division I malocclusion who had been treated in the post-graduate training programme in orthodontics at the University of Adelaide using the Begg technique. Class II, division I cases were chosen since a consistent direction of upper incisor movement (retraction) would occur and the effect on the lips could be studied. The sample demonstrated changes due to the combined effects of growth and orthodontic treatment

The cephalometric radiographs, taken before and after treatment, were superimposed and landmarks representing various skeletal and soft tissue structures were identified. An electronic digitizer was used to record the coordinates of the landmarks and suitable computer programs enabled data, in the form of linear and angular measurements for each subject to be transmitted to the University of Adelaide Cyber 173 computer.

Replicability studies were made by conducting a series of double determinations in order to study the effect of bias on the results due to the error of tracing and superimposing, and digitizing, by repeating measurements on three separate occassions.

A detailed statistical analysis included the following:

(1) Basic descriptive statistics for all variables.

(2) Tests of significance for sex differences and error of the method.

(3) Correlation coefficients to help determine the relationship between the observed hard and soft tissue changes.

(4) Standard scores to study the pattern of change in individual subjects.

The analysis provided information on the following:

(1) The changes that occurred in the profile structures of the face due to growth and treatment.

(2) The relationship of the soft tissue changes and the underlying hard tissues, especially in the region of the lips.

(3) Sex differences.

(4) The effects of lip posture.

(5) The error of the method.

(6) Comparison with previous studies to determine:

(a) The success of treatment in terms of the changes produced.

(b) The relative effects of the Begg and other orthodontic techniques.

(7) Individual variation in growth and treatment responses.

Appendicies referred to in the text have all been included in a separate volume (Volume 2, Appendices).

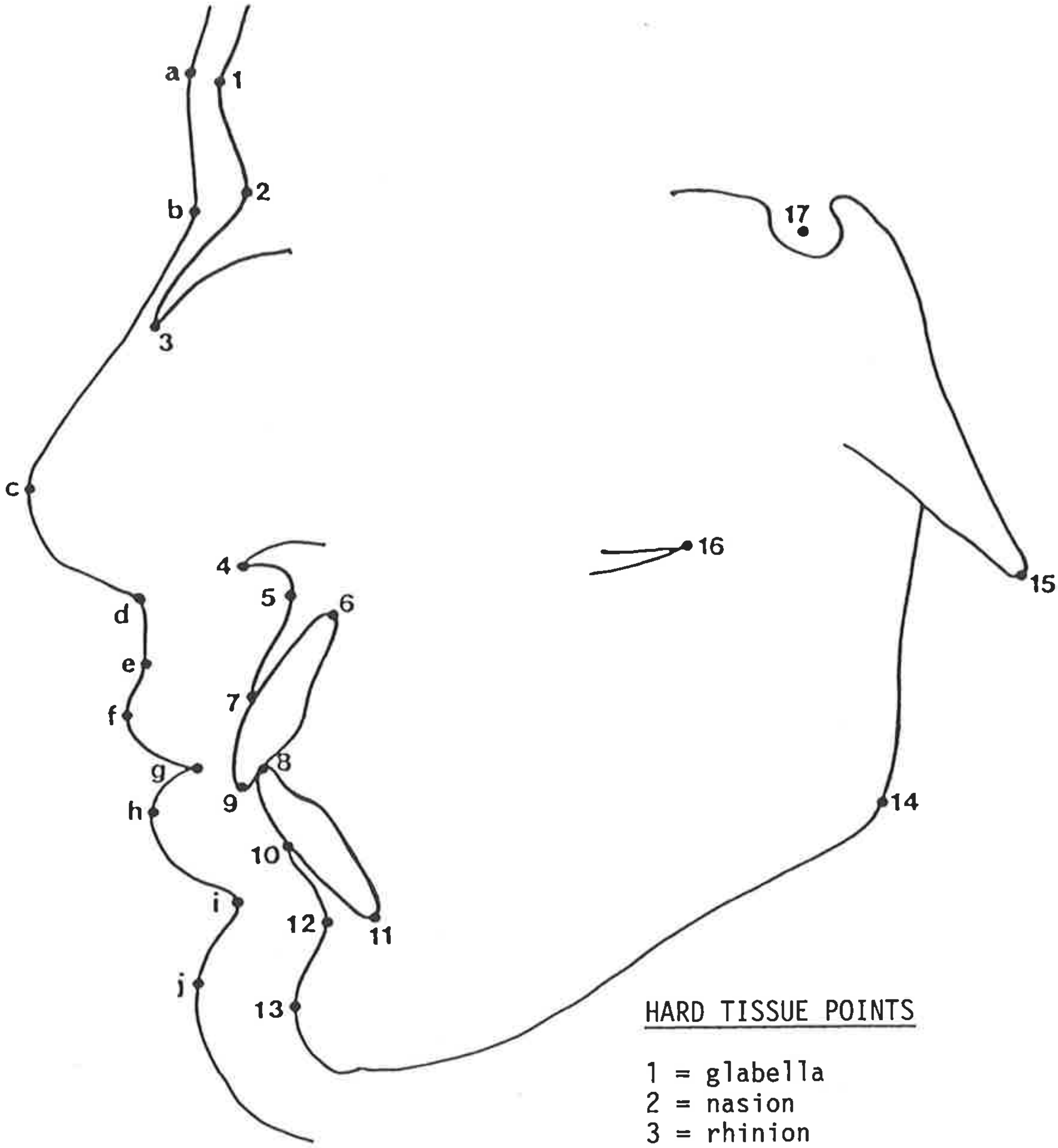
CHAPTER 1

LITERATURE REVIEW

1.1 INTRODUCTION

The review of literature deals primarily with the effects of growth and treatment on the soft tissue profile. In the progress report for the M.D.S. thesis (Farrer, 1983) some peripheral topics were reviewed ; general aspects of growth and development and facial form, growth of the maxilla and mandible, growth of the cranial base, growth prediction, and facial profile aesthetics were examined to provide a broader discussion base and as a background. These topics have been considered, where necessary, in the discussion chapter.

The landmarks referred to in this chapter are displayed in Figure 1.



HARD TISSUE POINTS

1 = glabella
2 = nasion
3 = rhinion
4 = anterior nasal spine
5 = A point
6 = root apex of upper incisor
7 = alveolar crest of maxilla
8 = incisal edge of lower incisor
9 = incisal edge of upper incisor
10 = alveolar crest of mandible
11 = root apex of lower incisor
12 = B point
13 = pogonion
14 = gonion
15 = basion
16 = posterior nasal spine
17 = sella
(bregma and sellion are not illustrated)

SOFT TISSUE POINTS

a = soft tissue glabella
b = soft tissue nasion
c = pronasale
d = subnasale
e = superior labial sulcus
f = labrale superius
g = stomion
h = labrale inferius
i = inferior labial sulcus
j = soft tissue pogonion

FIGURE 1. Landmarks referred to in the literature review.

1.2 METHODS OF CRANIOFACIAL SOFT TISSUE ANALYSIS

A. Cephalometrics

Several authors have referred to the early history and development of growth studies and cephalometric radiology. Lande (1952) considered that there have been three stages of study: (1) studies based on skull material; (2) anthropometric studies on living individuals; and (3) radiographic studies on living individuals. In 1947, Björk reviewed the earlier craniometric and anthropometric studies in some detail. Brodie (1949) and Nanda (1955) reviewed the early development of the radiographic cephalometric techniques. These authors cited the standardisation of a more precise method of cephalometric radiography by Broadbent (in the United States) and Hofrath (in Germany) in 1931 as having given rise to a fresh impetus to study the growth of the dentofacial region. Taylor (1969) noted the subsequent improvements to the technique.

Brodie (1955) proposed that the development of cephalometric radiography made it possible to follow the growth of the living individual in a cross-sectional, and longitudinal (or serial) manner. Further, Björk (1947) noted that this method allowed measurements on living subjects that could not otherwise be made. A major problem of the technique was believed by Björk (1947) to be distortion. The importance of head positioning (which was believed to be more accurate with ear-rods as developed by Broadbent in 1931 than with the type devised by Hofrath in 1931 without ear-rods), was also discussed.

Baumrind and Frantz (1971a) wrote that projection error resulted because a head film was a two-dimensional image of a three-dimensional object. The X-rays which produced the image were non-parallel and originated from a very small source such that head films were always distorted enlargements. Further distortion was caused by foreshortening of points lying on different planes and by radial displacement of all points and structures not on the central axis according to these authors.

Krogman (1958) stated that there were three types of cephalometric measures - linear, angular and positional. Linear measures were based on direct measures and were made in the mid-sagittal plane. These were preferred since only two planes of space were involved. The projected measures involved three planes of space and should therefore be avoided.

Steiner proposed in 1953 that cephalometrics was the most important of all contributions made so far in the study of craniofacial growth and development. He cautioned that there must be an awareness that the findings from radiographs were merely circumstantial evidence which must be accepted as such and co-ordinated with other evidence before it became useful. Graber (1958) and Salzmann (1964) considered that cephalometrics did not show the sites of growth, but contributed knowledge to the amount and direction of growth of the various structures of the skull. It also indicated a change in proportions and relations of the points, and the rate of growth. Cephalometrics was a quantative method for obtaining descriptive information on the dentofacial pattern at the time the radiograph was taken; it did not present information on the quality of growth and development. Qualitative information could be obtained from genetics, embryology, comparative anatomy, ontogenetics, physiology and pathology according to Salzmann (1964). To use cephalometrics intelligently, the subject's ethnic background, his skeletal, dental and physiologic age, the function and malfunction of the teeth and joints, and the soft tissue configuration must be taken into account.

Salzmann (1964) listed that cephalometrics provided information about:

(1) Dimensional relations of the craniofacial components;
(2) classification of skeletal and dental abnormalities with respect to the cranial base, skeletal pattern, soft tissue profile and inter- and intra-jaw and dentition relations;
(3) expression of growth and development responsible for the dentofacial pattern, congenital abnormalities, pathologic conditions or facial asymmetries;
(4) treatment planning;
(5) analysis of changes obtained in the hard and soft tissue contours by (a) orthodontic treatment, (b) growth, or (c) a combination of growth and orthodontic treatment;
(6) evaluation of the effectiveness of different orthodontic procedures;
(7) effectiveness of retention; and
(8) dentofacial changes after growth and treatment were complete.

Burstone (1958) listed the advantages of head films (especially for soft tissue studies) as:

(1) The record was approximately life size;

(2) the pose need not be held for a long period;

(3) the record contained vital skeletal information - to study the soft tissue profile only this one record was needed;

(4) the record was permanent and allowed measurements to be repeated;

(5) midline structures could be differentiated from more lateral contours (soft tissues);

(6) hard and soft tissue landmarks could be visualized and related; and

(7) the record could be studied at the leisure of the investigator.

The disadvantages were noted as being:

(1) There were varying degrees of enlargement and distortion and;

(2) there could be difficulty in visualizing landmarks.

There is vast amount of literature concerned with descriptions of the "normal" dentoskeletal pattern and changes in the hard tissues due to growth and treatment. The soft tissue pattern, however, while long being recognized as an important factor in orthodontic analysis, diagnosis and treatment planning, has until more recent times been largely neglected from the point of view of quantitative analysis of pattern and growth, and or, treatment changes.

Burstone in 1958 considered that facial form could be abstracted into two planes of space, these were the frontal and the sagittal views. The mid-sagittal plane produced an outline commonly referred to as the profile. The profile was considered to be especially important since treatment changes were most readily seen in this aspect. The soft tissue or integumental profile of the lower face, as considered in the literature, consisted of the nose, lips and chin.

B. Other Methods

The soft tissue changes occuring with growth and orthodontic treatment have been studied most commonly using lateral cephalograms. The soft tissues of the face have also been studied using a simple constructed method using photographs (frontal planimetric approach) by Simonson (1968). Direct measurements of living subjects were made by Pelton and Elsasser (1955).

More sophisticated techniques involve the three dimensional analysis of the contours of the soft tissues. Stereo-photographs have been employed to produce contour maps in a technique named stereophotogrammetry. Savara (1965) explained the methodology involved and Burke and Beard (1967) reported some refinements to the technique to improve the accuracy. However, only a limited number of studies of the soft tissues of the face have been reported using stereophotogrammetry (Burke 1979, 1980 and Burke and Beard 1979). Research using this technique is still concerned mainly with technological refinement to allow further use in soft tissue (and other) studies for clinical application (Keefe et al. 1982). The disadvantages may be that the technique is expensive and time consuming, and relies on complex optical and plotting equipment (Madden and Karlan, 1979).

Madden and Karlan (1979) described the use of Moire photography for soft tissue facial examination. The technique was claimed to offer a rapid, inexpensive, one step process for recording contours. Other possible methods of three dimensional analysis, such as holography (Caulfield, 1970), have been proposed. The use of these methods also require further research and technological advances prior to realizing quantification and analyses for possible clinical application (Abbott, 1983).

1.3 GROWTH CHANGES OF THE HARD TISSUES OF THE FACIAL PROFILE

A vast number of studies have investigated the changes of the hard tissues of the facial profile. The mean, or average findings of mainly cephalometric studies have been briefly considered in this section. In particular, considerable individual variation in growth changes have been noted by all the authors cited.

There has been ample evidence that during facial growth, the lower face (mandible, usually measured from B point) moved forwards more than the upper (maxilla, usually measured from A point) in relation to the relatively stable cranial base, and that for all landmarks on the skeletal profile of the face the growth pattern was generally downwards and forwards and away from the cranial base. The maxilla was relatively constant in relation to the cranial base after 7 to 8 years of age, and mandibular growth continued until later. As a result, the overall skeletal profile convexity reduced with age. (For example, Hellman, 1927 and 1932, cited by Silverstein, 1954, Baum, 1961 and Taylor, 1969; Björk, 1947; Lande, 1952; Nanda, 1955; Downs, 1956; Subtleny, 1959 and Fosberg and Odenrick, 1979).

Basal prognathism of the jaws increased more than alveolar prognathism. Accordingly, the anterior teeth became less prominent in the profile such that profile convexity reduced with age, and the incisors tended to upright in relation to the jaw bases. (Björk, 1947; Shaeffer, 1949; Nanda, 1955 and Subtelny, 1959).

Björk (1947), Brodie (1953), Silverstein (1954), Nanda (1955) and De Kock et al. (1968) all found that occlusal and mandibular planes tended to reduce slightly, in the order of a few degrees, during growth.

The change of facial proportions with age was not constant, and no correlations were generally found between facial types at an earlier age, and the pattern of changes that occurred later (Lande, 1952 and Baber and Meredith, 1965). Pubertal growth spurts in facial dimensions have been identified. Moreover, different regions of the face have been found to change at different rates and at different times (Nanda, 1955; Subtelny, 1959 and Scott 1967).

Sex differences have been observed in the overall growth pattern of the face. In males, the circumpubertal increase in growth velocity of facial dimensions occurred later, progressed longer, and resulted in larger overall dimensions. Females generally experienced an earlier rise in growth velocity, with minimal changes after about 15 years of age. In contrast, males often showed significant growth changes even up to the age of 17 years. (For example, Nanda, 1955; Baum, 1961 and Downs, 1956). Males grew larger than females (Baum, 1961). Horowitz and Thompson (1964) considered that late growth of the chin was a secondary sex characteristic of males. Baum (1961) and Mauchamp and Sassouni (1973) determined that the female skeletal profile ultimately became flatter than the male. Subtelny (1959) however, observed no significant difference in profile convexity between the sexes. Baum (1961) cited the findings of several theses, and these points could be considered in summary:

(1) Males tended to grow more in all directions.

(2) Females attained their greatest amount of vertical growth at an earlier age than males.

(3) Males tended to attain relatively longer faces and females relatively deeper faces.

(4) Males developed less protrusive dentures than females due to incisor uprighting from 12-15 years.

(5) The convexity of the profile reduced (largely due to a greater relative mandibular compared with maxillary growth). The males maintained more convex faces than the females from 12-19 years due to continued maxillary and mandibullar growth in males, and reduced maxillary compared to mandibular growth in females.

(6) The faces of 12 year old males were significantly different to those of adult males, whereas the faces of females at 12 years were not significantly different from those of adult females except in size.

(7) Most of the female growth was earlier (8-13 years) than males (13-18 years). Females stopped growing after 15 years.

1.4 CHARACTERIZATION AND GROWTH OF THE SOFT TISSUES OF THE FACIAL PROFILE

A. Introduction

In 1958, Burstone wrote: "The facial objective of the orthodontist might be considered the achievement of the optimal in facial harmony consistent with the maximum in functional occlusion within the limitations of therapy". Consideration of the soft tissues of the face being important in obtaining the goals of function, aesthetics and stability of results in orthodontic treatment was well recognized in the literature (for example, Burstone 1959 and 1967, Bloom, 1961; Subtelny, 1961; Chaconas, 1969; Ricketts et al., 1979 and Holdaway, 1983).

Burstone (1958) noted that orthodontic treatment could produce desirable and undesirable changes in the external contours of the face. Burstone (1958) and Subtelny (1961) noted that improvement of the facial profile would occur with or without orthodontic treatment. Growth alone could produce changes in the contour of the face. Hershey in 1972 stated: "Understanding the response of the facial profile to orthodontic treatment involves an appreciation of the effects of both growth and treatment upon the hard and soft tissues of the face".

Burstone (1959) noted that the soft tissue redistribution during treatment could be in part postural, reflecting a change in the manner of lip closure, and in part the result of growth. It was also noted that malocclusions exhibited not only malocclusions of the teeth, but also facial disharmony. In part, this disharmony could be due to variation in the soft tissue mass and in many other instances the reverse would occur; that is soft tissue variation could mask a dentoskeletal discrepancy.

As with the hard tissues of the face, the soft tissues also showed variation. Burstone (1958) in one of the first extensive cephalometric studies of the soft tissues of the face in profile, stated that because of the variation, facial harmony could not be determined from skeletal and dental factors alone. Neger in 1959 also stressed the need to study the soft tissue profile as a seperate entity from the dentoskeletal analysis since changes in the dentoskeletal areas due to orthodontic treatment often showed little or no profile changes. Subtenly (1961) wrote that the soft tissue profile could not be correlated directly with the hard tissue profile and, therefore, it was important to know the changes occurring in the soft tissues due to growth; the soft tissues were not just a drape over the hard tissues.

Many authors of soft tissue studies (for example, Burstone, 1958; Neger, 1959; Bloom, 1961 and Hambleton, 1964) made the observation that compared to studies of the hard tissues, the soft tissues of the face had been little studied. Burstone (1958) noted that studies of the soft tissues in the orthodontic literature may have been meagre for two reasons:

(1) orthodontic treatment was concerned primarily with hard tissue manipulations; and

(2) there has been an assumption that if the teeth were arranged according to a given standard, the soft tissues would automatically drape in a maximally harmonious way.

Silverstein (1954) only studied changes of the bony profile (although he considered studying the soft tissue profile would be highly desirable), because he believed that the soft tissue profile could not be studied with the same exactness as the hard tissues. Lip posture was found to influence the reliability of cephalometric results (Wisth and Böe, 1975, and Hillesund et al., 1978).

B. Nose and Chin

The number of studies of nose growth were found to be small. Subtelny (1959, 1961) examined nose growth as part of in his study of the soft tissue profile. He found that the soft tissue over nasion tended to be thicker in males than females and tended to remain constant or reduce slightly in thickness with age. The nose length as measured from nasion to the nose tip increased the same amount in males and females (1 - 1.33 mm) but males at all ages tended to have greater nose lengths. The measures for the downward and forward growth of the nose did not show a reduced rate of growth with age as were typical of growth patterns for skeletal facial structures; there was considerable growth in the latter stages, at least into early adulthood, as well as the early growth stages. In males and females it was found that the average vertical growth increment was greater than the average horizontal growth increment, the tip of the nose progressively showed a more downward and forward position with age. In the horizontal growth there was a sex difference as females usually showed a greater increase in the depth of the nose than males from the facial plane (nasion-pogonion).

By superimposing on what was named the nasal bone line (nasion to A point registered at nasion), Subtenly (1959) wanted to check whether or not the nose grew with what were apparently constant and steady increments, and found that in male subjects growth spurts occurred at certain periods. In 12 of the 15 males a growth spurt occurred from 10-16 years with an average centred around 13-14 years. A growth spurt was evident in only 3 of the 15 female subjects and this centred around 12 years of age. The growth of the total profile of the nose was found to be closely related to the path of growth of the nasal bone. In cases where a growth spurt was found, both male and female, the nasal bone had a tendency to project and become inclined in a more forwards direction and frequently there was a concomitant humping or elevation in the profile of the bridge of the nose in the later growth stages. Otherwise the nose tended to maintain the same general contours.

Ricketts (1960a) found that the nose grew forwards at the rate of about 1 mm per year during treatment time for his 5 groups of 50 cases although there was great variation. Using measurements from anterior nasal spine to the nose tip he observed the greatest changes in boys at puberty.

Subtelny's (1959) 30 serial cases from 3 months to 18 years of age were used by Posen (1967) to make a detailed longitudinal study of nasal growth. The nasal bones as measured from nasion to rhinion were found to increase in length in an orderly way until 13 years when they reached 90% of their final growth and after this time there was little further growth. The growth pattern in males and females was the same. The angular relationship of the nasal bones to the cranial base (basion-nasion) increased from 1.5 to 17 years with a greater angular change in females from 6 to 16 years at which time the males were once again comparable to the females. Posen found that the growth of the external nose as measured from soft tissue nasion to pronasale was linear and regular with 81% occurring prior to 13 years and 91% at 16 years. The average nose length in males was greater at all ages than in females although this was not confirmed statistically. Nose depth as measured from the soft tissue facial plane (soft tissue nasion-soft tissue pogonion) increased in a regular and linear fashion and then slowed down at about 15 years, and increased again at 17 years. Larger average dimensions were observed in males.

Nose height measured from soft tissue nasion to a constructed point in the region of subnasale increased according to Posen (1967) in a linear and regular fashion from 3-13 years and became more irregular until 18 years of age; the mean values for males were greater than females at all ages. It was confirmed that the nose grew in a downward and forward direction.

The form and shape of the nasal and facial profiles as expressed by angular readings changed significantly from 13-18 years according to Posen's (1967) findings. The nasal dorsum and tip of the nose became approximately 13% more anteriorly placed in this time but did not keep pace with the nasal bone change which increased in its angular relation to the cranial base by approximately 30% from 13-18 years. It was found that this uneven growth expressed itself as a straightening of the nasal dorsum or possibly a humping of the nasal bridge. Nose depth increased 25%, height increased 13%, the nasal bone increased 10% in length and the dorsum increased 20% in length, and so after the age of 13 the nose became more prominent and the facial profile more convex. Therefore, It was concluded, what was a pleasing and harmonious profile at the age of 13 years may be completely changed at 18 years of age.

Posen (1967) found that males tended to have smaller angular and larger linear values than females, the higher angular values in females implied a higher degree of maturity toward ultimate nose shape and facial profile. The larger overall body size in males reflected itself in the linear dimensions and showed that maturity did not imply a larger size. No significant sex difference was found in the growth rate.

A detailed study of nose growth was also carried out by Chaconas in 1969. Kiser's 1960 thesis was cited in which the male nose was reported to be greater in depth, soft tissue height, length along the dorsum and size measured along the profile compared to females. The males also showed a greater antero-inferior position of the nasal bones during the period studied. The males demonstrated an increased soft tissue thickness between anterior nasal spine and subnasale from 13-16 years and in females this occurred from 10-13 years. The results suggested that there was continuous growth of the nose from 10-16 years and that males showed a slight increase from 13-16 years while the greatest period of nose growth in females occurred from 10-13 years. This was in agreement with the findings of previous authors.

Chaconas (1969) used angular and linear measures in 46 sets of annual serial radiographs from 10-16 years of age and divided the data according to age, sex and type of malocclusion. There were approximately equal sample sizes of Class I and Class II malocclusion, and number of males and females in each class. The total increase in nose size from 10-16 years was greater in males than in females. It was found in Class

I subjects that the nose tended to grow in a more forward direction whereas, in Class II subjects it exhibited a more downward growth direction. The trend was for Class I subjects to have a greater nasal depth although this was not statistically significant. The Class II subjects, he observed, may have more tendency to develop an elevated nose bridge. Chaconas found that it seemed to be the direction of growth of the nasal bones rather than the actual length that caused elevation of the nose bridge. This finding was supported by the study of Chaconas and Bartoff (1975). The results also indicated that a subject with a larger vertical dimension of the face also had larger nasal bones. The length of the nasal bones was less correlated with age than the other linear measures so that it seemed possible, according to Chaconas, that the growth of the nasal bones would already have taken place before the growth spurt of the soft tissue nose. This agreed with Posen's (1967) finding that the nasal bones had almost ceased growth at 13 years of age. The nasal shape was divided into three categories by Chaconas (1969). He found that nose shape tended to demonstrate the same general profile as that of the face; Class I/straight, Class II/convex and Class III/concave.

Chaconas (1969) investigated the correlations of various dimensions and found, for example, that growth of the length of the soft tissue nose correlated with the other linear nasal measures, with age, and with the angle sella-nasion-rhinion indicating that an increased nose length occurred with an increase in length of the nasal bones. The length of the nose correlated with length of the mandible. There was also a significant correlation found between length of the soft tissue dorsum of the nose and the thickness from A point to upper lip sulcus which, he proposed, indicated that as the nose grew the upper lip moved forwards with it. This was confirmed by the finding that nose depth correlated with all linear and angular nasal measurements as well as the angle sella-nasion-rhinion and the distance A point-upper lip sulcus. Nose depth also correlated with the distance pogonion-soft tissue pogonion and implied that a large nose was associated with a prominent chin. The nasal bones were found to move forwards with the maxilla and mandible. Chaconas (1969) found, as did other authors, that the nose contributed to the convexity of the soft tissue profile. The nose depth correlated negatively with the facial profile indicating a significant contribution to it.

Wisth (1975), who studied soft tissue growth in 33 females and 37 males from 4-10 years of age, also noted that an increased inclination of the nasal bones resulted in deviation of the bridge of the nose and a reduction of the "pugnose" of early childhood. The most significant effect of nasal growth on the profile was believed to be due to forward nose growth, which was noted to be about 1 mm per year, while the nose depth increased by only half this amount. Therefore, the nose tended to grow more in a downwards direction.

The change in thickness of the soft tissue of the chin was not often specifically referred to in the literature. Stoner et al., (1956) found that the movement of soft tissue pogonion forwards occurred to the same extent as the skeletal pogonion but did not refer to a change of thickness. Subtelny (1959) found that the soft tissue thickness over the chin increased with age, but was less than that overlying A point, and greater than the increase in thickness over nasion.

C. Lips

(i) Posture

Many authors have noted variations in lip pattern. For example, Hambleton (1964) observed many variations of lip imbalance as a result of underlying malocclusion, variation of tone, length and thickness of the lips. Burstone (1959) noted in his study of the soft tissue extension pattern that not all variation was due to a structural variation in the soft tissue mass, but that there was a considerable difference from a relaxed to a closed lip position.

The key reference on the pattern of lip posture was Burstone (1967) who proposed that there were two postural lip positions; relaxed lip position and closed lip position. In closed lip position the lips lightly touched to achieve an anterior oral seal with minimal muscle contraction. In Class II, division I cases with a significant overjet the closed position was noted to be where a light contact occurred between the lower lip and the upper incisors. The relaxed lip position was noted by Burstone to be where the lips were relaxed, apart, and hanging loosely with no effort made at lip contraction.

Schlossberg (1956) (cited by Burstone, 1967) used an electromyographic technique and noted the difference between relaxed and closed lip position. The role of mentalis muscle activity in producing an anterior seal in Class II, division I cases was noted. Burstone (1967) also cited some British literature which contained discussions of lip competence and incompetence (for example, Tulley, 1953). The two extremes of lip pattern, incompetent and redundant are illustrated in Figure 2.

Burstone (1967) discussed the two lip positions in some detail. It was noted that it was impossible to obtain an accurate record of relaxed lip position without an electromyographic technique, but that this should not discourage the use of this position which was considered to be useful. A clinical technique was described to obtain this position and lateral head radiographs were used to study its reproducibility. Using four radiographs taken by different operators of 10 subjects it was found that the mean deviation was 0.5 mm, being the average error produced by tracing measurement and patient positioning.

Like body posture, Burstone (1967) considered that relaxed lip posture was muscle determined and therefore could not have the reproducibility of hard tissue positions. The vertical characteristics of the relaxed lip position were described. The interlabial gap was, on average, 1.8 mm in centric occulusion and 3.7 mm in the rest position of the mandible. These figures were derived from a sample of 32 adolescents with "acceptable" faces. Therefore, it was noted, the normal interlabial gap was quite small and opened as the mandible opened, but there was considerable variation in people with malocclusions or facial disharmonies. Extreme conditions in which there was excessive space or lack of space was commonly observed. An inadequacy of lip length relative to the vertical dimension of the face was characterized by a large interlabial gap while if there was a redundancy of tissue in relation to the vertical dimension no labial gap was present. The average lip length in males was found to be 24 mm from stomion to subnasale, while in females it was 20 mm. Wider variation was found in

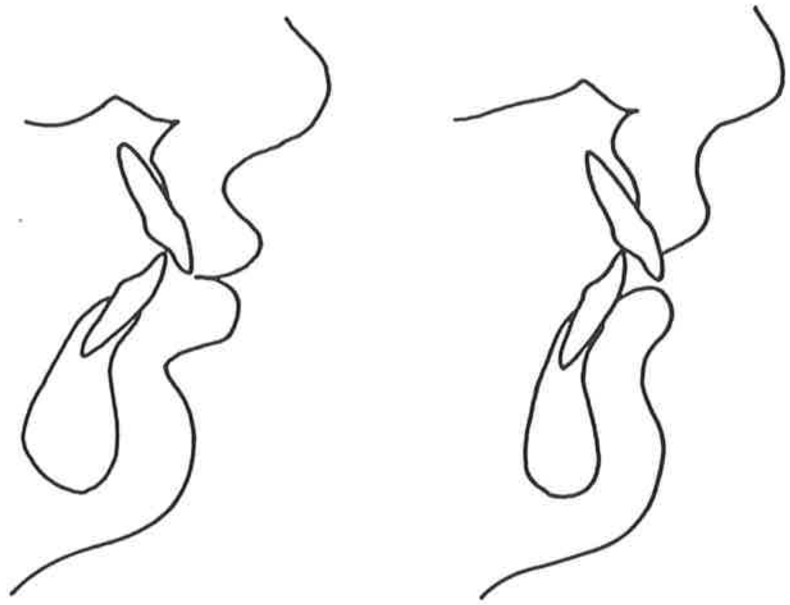


FIGURE 2. The two extremes of lip pattern: Redundant and incompetent.
(From Hershey, 1972)

cases of malocclusion especially Class II, division I cases. Burstone found that the upper lip in Class II, division I malocclusions was not significantly shorter than normal. In relation to the inferior aspect of the upper lip the incisors in Class II, division I malocclusions were found to be supra-erupted compared to normal. However, Burstone stated that this did not imply that there was not a large variation in lip length as well (Figure 3). The ratio of upper to lower lip lengths was found to be 1:2 (subnasale to stomion:stomion to soft tissue gnathion). The interlabial gap was believed to be dependent on many factors, including anterior skeletal height, dental protrusion, inherent lip length and lip posture.

To define the horizontal characteristics of the lips Burstone (1967) used a plane from subnasale to soft tissue pogonion. This plane was claimed to change little due to growth and treatment when radiographs were superimposed, providing the lips were in the rest position. It was also suggested that there was a greater standard deviation if the nose was included in any plane used for lip assessment, such as Ricketts' "E" line, but this was not to suggest that the nose was not important in profile analysis. On average the most anterior point on the upper lip was 3.5 mm forward of Burstone's reference plane while the most anterior aspect of the lower lip was 2.2 mm forwards (standard deviations were 1.4 and 1.6 mm respectively), with no sex difference. The upper lip had a greater angle in relation to the palatal plane in cases of incisor protrusion. The nasolabial angle was normally about 74^{o} and he found that it could be more obtuse in cases of incisor proclination after treatment. The anteroposterior position of the lip varied with lip thickness.

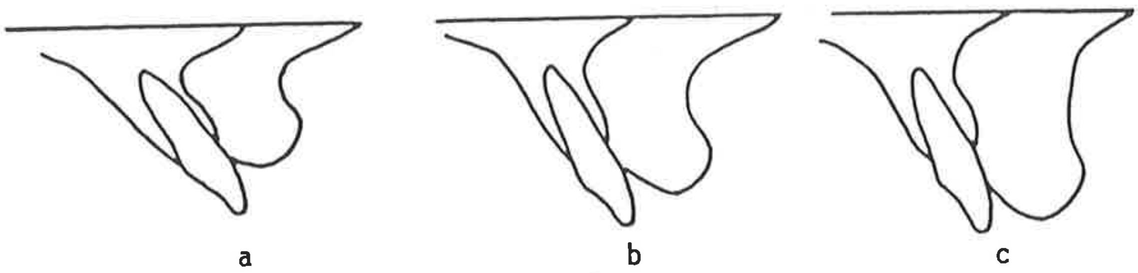


Figure 3A.

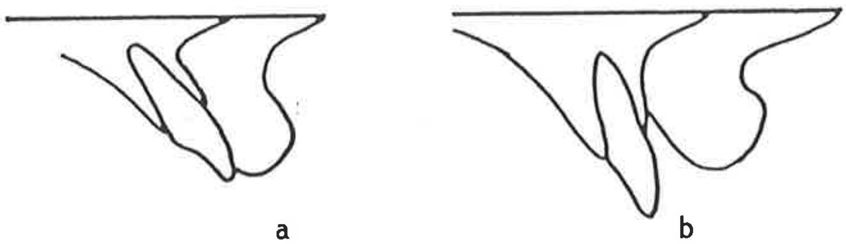


Figure 3B

FIGURE 3. Upper lip variation.

A. Variation in upper lip length (from subnasale to stomion) in three Class II, division I malocclusion cases:
a = 16 mm, b = 20 mm, c = 26 mm.

B. Variation of the upper lip line (from stomion to incisial edge) in two Class II, division I cases:
a = 2 mm, b = 8 mm

Lips in relaxed position.

(From Burstone, 1967)

Burstone (1967) believed that the role of the teeth in lip posture was still unanswered. He cited Robinson's 1960 thesis which investigated whether or not the teeth pushed the lips out into varying positions and whether or not the lip posture was independent of tooth position. Robinson used bite rims of varying thicknesses in edentulous young adults. The results suggested that the lips had a relaxed position that was independent of the teeth and alveolar process. With less support the lips did not fall back routinely into a retrusive position. However, there was considerable variation. Burstone concluded: "Although common experience tells us that lip posture can be influenced by tooth movement, it can now be postulated that there is a relaxed postural position of the lips which is independent, or partially independent, of tooth position". It was noted that the lips may have had a more retrusive or protrusive posture if different people were compared and that upper and lower lips could vary independently.This was noted to be an important consideration if treatment changes in the lips were to be considered.

The closed lip position, wrote Burstone (1967), was that position usually assumed during a person's daily activity and was produced with minimal muscular effort (which should be expected since the interlabial gap was usually small). It was found that the lower lip contributed to closure more than the upper, and both lips simultaneously flattened against the incisors. A small amount of mentalis muscle activity with some chin flattening may, or may not, have occurred with closure. In persons with malocclusions the pattern of lip closure exhibited greater variation. Burstone gave the example of a Class II, division I malocclusion with a large interlabial gap where considerable muscular effort was required to achieve lip closure. (Figure 4).

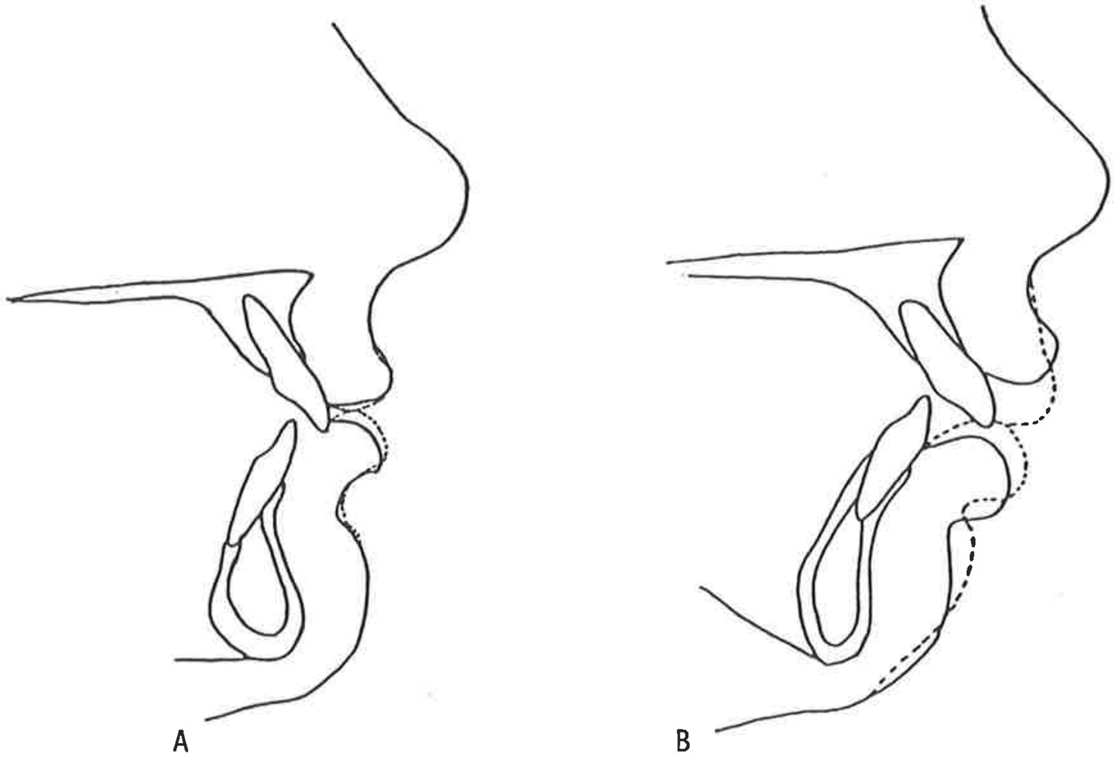


FIGURE 4. Lip closure from relaxed to closed lip position.

A. Normal closure. Minimal contraction is required. Lower lip contributes more to effect anterior seal. Larger than average interlabial gap is shown.

B. Abnormal closure in a Class II, division I case. Upper lip flattens and elongates, lower lip moves upward and forward with flattening of the chin area.

(From Burstone, 1967).

Burstone (1967) stated that the relaxed lip position was of fundamental importance in understanding the position of the lips when they were closed and that the relaxed position was more useful when trying to estimate how far the lips would move back due to treatment. It was concluded that the considerable variation seen in lip position demonstrated that treating to skeletal and soft tissue standards had questionable validity. One aim of orthodontic treatment should be to reduce the amount of lip closure required from the relaxed to the closed position.

Hershey (1972) found that the relaxed habitual pose of the lips was a reproducible position showing no significant difference at the 0.05 level using a t-test. However, this author did not define what was meant by a "relaxed habitual position". It could be assumed that this corresponded to Burstone's (1967) relaxed lip position.

In 1975, Wisth and Böe studied soft and hard tissue measurement reliability in cephalograms. The radiographs were taken with considerable emphasis being placed on the lips having been in a lightly closed position. It was found that while the hard and soft tissue points had the same general reliability in the same films, there was variation of soft tissue points noted in different films of the same subject, which was believed to be due to a change of facial expression. The error generally increased in the group with incompetent lips, but was significant for only two measures. The authors believed that this demonstrated the reliability of the closed lip position, even in people with incompetent lips. Since cephalometric analyses were based on cephalograms with teeth together, it was concluded that soft tissue measurements should also be related to a position with closed lips. This conclusion disagreed with Burstone's (1967) concepts of lip posture. However, Wisth and Boe agreed with Burstone that lip muscle activity was likely to be lower with the lips in the rest position and that displacement of the lips would occur with the teeth in occlusion.

Hillesund et al. (1978) believed that there was some confusion as to which lip position should be used in cephalometry. Relaxed, closed or no standardization of position was noted in the literature (see also appendix 3). The authors believed that the relaxed lip position described by Burstone (1967) offered many advantages, but that its stability and reproducibility were unknown. They studied 35 adolescents with increased overjet and a group of 32 adolescents with normal (1-3 mm) overjet. Radiographs were taken utilizing the relaxed and closed lip positions of Burstone (1967). Considerable variations of 1-1.5 mm could occur in the location of soft tissue landmarks on subsequent films in both lip positions with approximately equal reproducibility. This indicated the degree of accuracy that could be expected in studies of changes due to orthodontic treatment. It was concluded that cephalograms should be taken with the lips in a relaxed position since this provided the most correct reproduction of lip morphology and position in relation to underlying structures, even though the vertical position of the lower lip was noted to vary more in the relaxed compared to closed position. They proposed that the accuracy of the closed lip position was suitable for use in normal overjet cases, but that in cases of increased overjet the radiograph should be taken with relaxed lips. These conclusions supported Burstone's (1967) general findings.

Broch et al. (1981) found that the lips flattened from the relaxed to the closed lip position, especially in people with large overjets. In large overjet cases the upper and lower lip flattening was about 2.5 mm while in the normal overjet group the upper and lower lips flattened by approximately 1 and 1.5 mm respectively. They also confirmed that the interlabial gap increased with increased overjet. The reproducibility of relaxed lip position was found to be the same in the large and normal overjet groups.

By using correlations and stepwise linear regression, Saxby (1981) established a close dependence of the soft tissue facial profile on the underlying dento-skeletal framework. The sample size was not given. It was proposed that closer relationships could be established if the cases were analysed with the lips in a resting posture.

Oliver (1982) stated that habitual lip position was not useful in cephalometric studies since it was believed that emotional and neuro-muscular input into lip posture made it difficult to capture a relaxed lip posture repeatedly, especially under the conditions during which a cephalometric radiograph would be taken. Oliver preferred the use of a position where the lips were lightly closed, as described by Burstone (1967) and as preferred by Hershey (1972), Wisth and Boe (1975) and Holdaway (1983).

These studies have demonstrated that there was some concensus regarding the characteristics of lip posture, but that there was considerable disagreement as to which lip position best allowed evaluation of growth and treatment changes.

(ii) Growth Changes

Based on a study of 30 serial cases from 3 months to 18 years of age, Subtelny (1959, 1961) found the following with respect to the upper lip. (It should be noted that Subtelny did not specify whether or not the lip position was standardized during radiography). The soft tissue over A point increased in thickness with age by an average of about 5 mm from 3-18 years and this was greater than the increase in thickness over either nasion or pogonion. The length of the upper lip as measured from the most inferior point to a perpendicular to the palatal plane was the same in males and females at all ages. Lip length increased with age especially from 1-13 years and slowed down appreciably after 15 years. The growth curve was similar to that projected by Scammon et al. (1930) (cited by Subtelny, 1959) for muscle and other connective tissues. The thickness of the lip tended to increase more at the vermillion border region than over A point. This was regarded as a surprising finding since the increased length was more commonly recognized and the increased thickness was less obvious. Subtelny found the increased thickness at the vermillion region to be about the same as the increase in length. The lip continued to thicken in males after 14 years but in females after 14-15 years there was no further increase in thickness.

The upper lip was found to maintain a fairly constant relationship to the incisal edge of the upper incisors and the alveolar crest after the time of eruption of the central incisors, and Subtelny postulted that the vertical growth of the lip tended to keep pace with the alveolar growth or vice versa. The distance of the incisal edge to the inferior aspect of the upper lip as 4-4.5 mm (61-67% coverage of the central incisors) after 9 years of age.

With respect to the lower lip Subtenly (1959) found the following growth changes. The length of the lip was measured from the most superior point of the lip as a perpendicular to the mandibular plane. No sex differences were found at all ages in lip length. A rapid increase in length occurred from 1-6 years, followed by a slower increase, and then little change occurred from 15-16 years. The lower lip increased in thickness more at the vermillion region than in the area over B point. Stability of the relationship of the lip to the alveolar crest and incisal edge of the lower incisors was noted after 9 years, the lower lip covered the incisal one third of the crown of the upper central incisors. Subtelny noted that all changes were similar in nature to those of the upper lip.

Subtelny (1959) also studied the lip changes relative to the facial plane and found that the vermillion aspect of the lips tended to maintain a fairly constant postural relationship to the underlying teeth and alveolar bone; that is, as the teeth and alveolar bone uprighted with growth and approached the facial plane, the lips became more retruded also. In the fewer cases noted where the teeth became protruded, the lips did also. Thus it may be seen that the posture of the lips was strongly dependent on the position of the underlying dentoalveolar complex. Subtelny noted that this would be important from the orthodontic treatment point of view, in the possible profile changes that could occur with orthodontics. This finding differed from Robinson (1960) who introduced prostheses in non-growing subjects and produced sudden changes in lip support indicating some postural independence of the lips to the "teeth" (cited by Burstone, 1967). Subtelny, however, reported postural changes due to growth.

Burstone (1959) found that from adolescence (mean age of 14.7 years) to adulthood the lip contour changed very little. The protrusion of the upper lip from the sulcus tended to increase with age, while the curve of the lower lip showed a significant reduction in the young adult sample.

Ricketts (1960b) found that the lip convexity reduced consistently from the deciduous dentition through to the age of the full adult dentition since the lips retracted during this time. Ritchie (1962) in a study of males aged 9-12 years confirmed Subtenly's findings that the upper and lower lips tended to flatten or retrude with age. Chaconas and Bartroff (1975) found that the upper lip tended to grow forwards more than the lower lip.

In 1979, Vig and Cohen studied 50 cases serially from 4-20 years and studied lip lengths using a similar method to Subtelny (1959). They concluded that differential growth of the lips relative to skeletal structures was the rule rather than the exception. It was found that in proportional and absolute terms the upper lip grew more than the lower and that together the upper and lower lips grew to a significantly greater extent in absolute terms than the anterior face height. The amount of lip separation reduced and the relationship of the lower lip to the upper incisors was found to change between 9 and 13 years of age.

Simonson (1968) and Burke (1980) studied the lips from the frontal view. Simonson used a planimetric technique to measure the ratio of the area of the vermillion aspects of the lips to a defined area of the lower face between the nose and chin, and found that the mean ratio had little sex difference, that the ratio was constant in all age groups (spanning 7-30 years of age), and that there was no significant difference between the Class I and Class II groups. The small number of Class III subjects suggested a smaller ratio. Simonson concluded that there was a basic constancy in the ratio of lip area to lower face area irrespective of age and sex with a possible variation due to malocclusion.

Using the technique of stereophotogrammetry, Burke (1980) reported changes in lip shape in his study of like-sexed twins from 9-16 years. Anterior displacement of the lower lip was less than that of the upper. He also found that upper lip convexity was less than that of the lower and the convexity of both lips tended to increase over the period studied with more variation in the upper lip. It was concluded that the lower lip tended to protrude and increase in convexity whereas the upper lip was more variable showing flattening in some individuals and more variation in convexity changes. However, in relation to the rest of the profile, the interangular reference line (a line joining the angles of the lips) was noted to be displaced more posteriorly as the growth in width of the mouth took place. The relationship of the lips to growth changes in overjet were found to be variable by Burke (1980). Soft tissue posing error was an important limitation. Burke also commented that the sample was small and specific findings needed further investigation.

The differences in the overall soft tissue growth pattern found by the various authors varied most with relationship to lip profile growth changes. This may have been largely due to the problem of variation in lip posture as previously discussed.

D. Total Profile

Pelton and Elsasser (1955), in a cross-sectional study, took direct measurements of the soft tissue profile of 6,829 subjects and found that the jaws became more prognathic with age. The increase in mandibular prognathism was greater in females than in males, but the increase in mandibular prognathism was not as great as the increase in maxillary prognathism. This was in contrast to the findings reported earlier with respect to the skeletal profile. The total face height was found to increase markedly from 6-24 years with females reaching a plateau at around 15 years and males at about 18 years. They also found that the incisors retracted in relation to the profile. It was concluded that the growth pattern was generally downward and forward and that the profile convexity increased with age.

In 1959, Bowker and Meredith serially studied the relationship of five soft tissue points (nasion, pronasale, A point, B point and pogonion; the vermillion areas of the lips were not studied) to the facial plane in 48 children from 5-14 years of age. A small and insignificant sex difference was found in these linear measures at all ages (except for subnasale). The data was pooled and it was found that the only two variables to change in a statistically significant way were the distance to the tip of the nose and to superior labial sulcus. Correlation coefficients showed that there was not a strong association between the original size at any level at 5 years and the size increase in the next 9 years at that level. Changes in the profile at any one level were not found to be highly related to changes at other levels either. Vertical changes were assessed by projecting perpendiculars to the facial plane. It was found that the vertical distances increased with age at all levels with more vertical change in the period studied in the nasal region of the soft tissue profile than in the lip area. The total vertical change was significantly larger in males.

Burstone (1958) proposed a method to analyse the soft tissue profile based on angular relationships between points along the profile. Inclination angles were formed between various soft tissue planes and the palatal plane, and contour angles were formed between various soft tissue planes. Burstone produced mean values and standard deviations based on a sample of 40 young adults having "good or excellent faces" as chosen by a panel of artists. An analysis of growth changes was not undertaken in this study.

In 1959, Burstone studied the horizontal and vertical extensions of soft tissue profile points in relation to their underlying skeletal points. The young adult sample used in 1958 and a sample of 37 adolescents aged from 13.4 to 15.6 years, who also were judged to possess good or excellent facial form, were used. He found that the soft tissues inferior to subnasale were thicker than in the glabella region reflecting the high degree of development of the orbicularis oris complex. Considerable variation was found in these samples with the greatest variation occurring in the lower face, especially the lips. Burstone produced a grid diagram such that the profile values of a person could be compared, not to the means, but to determine whether or not the values varied uniformly from the means. It was noted that this variation was due to structural variation within the soft tissue mass, postural differences from a relaxed to a closed lip position, the choice of reference plane, and variation in the relative position of landmarks. Burstone looked at the sex differences and found that they were greater in the adult than in the adolescent sample. The soft tissue thicknesses were found to be greater in males from subnasale to menton, especially the upper lip. In females it was found that superior labial sulcus was lower in relation to A point, and stomion was lower in relation to the incisal edge of the upper incisors, compared with males.

Maturation changes were analysed by a cross-sectional comparison of the two groups. Superior labial sulcus was found to move more inferiorly with relation to subnasale with age. By using the method of his 1958 study, Burstone (1959) found that the lower facial, mandibular and interlabial inclinations were significantly greater in the adolescent group, which was explained partly by an increase in the mandibular prominence as a result of the maturation process. The prominence of the chin from the inferior labial sulcus showed an increase in the adult group. With reference to the contour angles of the face, it was found that only one showed a significant change; the total facial contour tended to flatten with age, that is, the face became less convex with maturation (this finding disagreed with Pelton and Elsasser, 1955). Several inclination angles however did change significantly. The labiomandibular contour (upper lip prominence-lower lip prominence-soft tissue pogonion) and maxillomandibular contour (subnasale-upper lip prominence-lower lip prominence-soft tissue pogonion) were found to remain relatively constant and therefore there was no marked flattening in the lower facial region in the post-adolescent period. Burstone noted that because this was a cross-sectional study, the changes noted could only be regarded as generalizations.

Subtelny (1959) provided what was probably the fullest analysis of soft tissue changes due to growth, according to Burke (1979). Subtelny studied 30 subjects from 3 months to 18 years of age. It was found that the soft tissue chin closely followed the skeletal chin and showed increased prognathism with age. The soft tissue chin was studied using the angle basion-soft tissue nasion-soft tissue pogonion. Using this angle, Subtelny found that the chin grew forwards rapidly from 6 months to 4 years, slowed down, and then increased again in males from 7 or 8 until 18 years with a smaller increase in females. He found that females from 6 months to 7 or 8 years were more prognathic than males while at 18 years the sexes were found to be equal. Females showed only a 1^{o} increase in soft tissue prognathism from 7 to 18 years whereas males showed a 4^{o} increase, demonstrating more late growth in males. These changes were also revealed in the skeletal measurements, and the mean trends were also generally noted in individual subjects.

Subtelny (1959) studied the soft tissue convexity in two ways. Soft tissue nasion-pronasale-soft tissue pogonion and soft tissue nasion-subnasale-soft tissue pogonion angles were used. In this way profile changes could be assessed with and without the influence of the nose. The convexity excluding the nose was found to change little from 6 months to 18 years, especially from 6 years to 18 years, and this was noted to be supported by a study of individual subjects. However, including the nose, there was a marked and continued increase in the profile convexity with age. This was in keeping with previous discussion on nose growth. Neither angles showed a significant sex difference. Baum (1961) postulated that Subtelny's finding of no sex difference in profile convexity including the nose, could have been due to greater forward chin growth in males, which tended to mask the greater forward nose growth that also occurred in males (as discussed previously).

Subtelny (1959) noted that the soft tissue convexity changed in an opposite way to that of the skeletal convexity; the skeletal convexity decreased with age, the soft tissue convexity increased (including the nose) and remained relatively stable (excluding the nose).

It was found by Subtelny (1959) that the increase in thickness of soft tissue in the maxillary region (over A point) was greater than over pogonion, where there was only a slight increase. Over nasion there was little change which explained why the soft tissue convexity excluding the nose remained relatively stable. The incisors uprighted, the lips followed and thickened with age, and also contributed to this effect. The bony chin grew forwards more, carrying the soft tissue chin with it, which itself grew less than the soft tissue overlying the maxilla which had less forward bony growth. It was also considered possible that the upper lip, due to its attachment to the nose, may have been affected in thickness and position by growth tendencies of the nose itself. Subtelny also found that the upper face increased in vertical height, mainly due to vertical growth of the nose rather than to upper lip growth.

Ritchie (1962) in a study of 33 males aged 9 to 12 years with excellent occlusion confirmed that the nose growth had a greater effect on the convexity of the soft tissue profile than forward chin growth. This was contrary to Baum's (1961) proposal. Flattening in the area of the upper and lower lips was also found to be important in producing profile changes. In 1964, Rudee studied 85 treated cases over an average period of 32 months (ages not provided). This study determined that the nose grew forwards twice as much as the chin, and the skeletal prognathism increased twice as much in males than females.

Subtelny (1961) concluded that the soft tisues did not directly follow the underlying skeletal profile during growth. The soft tissues above the maxillary dental base were found not to follow the underlying skeleton; the nose and soft tissue over A point continued to show progressively increased anterior prominence. In contrast to this the soft tissues of the lower face, beneath the maxillary dental base, closely reflected underlying modifications in the skeleton and denture. This, Subtelny postulated, was important from the orthodontic treatment point of view, since the teeth were moved and the lips could be expected to show a similar change. The soft tissue chin was also found to be directly dependent on the hard tissue chin. It was found that a consideration of nose growth was important since its forward growth could add to the impression that the lips were receding within the facial profile with treatment. (Figure 5). King (1960) in a study of Class II, division I treatment confirmed that soft tissue nasion and soft tissue pogonion closely followed the skeletal changes, and there was little change in soft tissue thickness in these areas.

Hambleton (1964) summarized the changes that occurred in the profile as:

(1) The maxilla became less convex in relation to the skeletal profile with age.

(2) The soft tissue over the maxilla thickened with age.

(3) The mandible grew forwards more and later in males than females.

(4) The soft tissue chin followed the skeletal chin forwards.

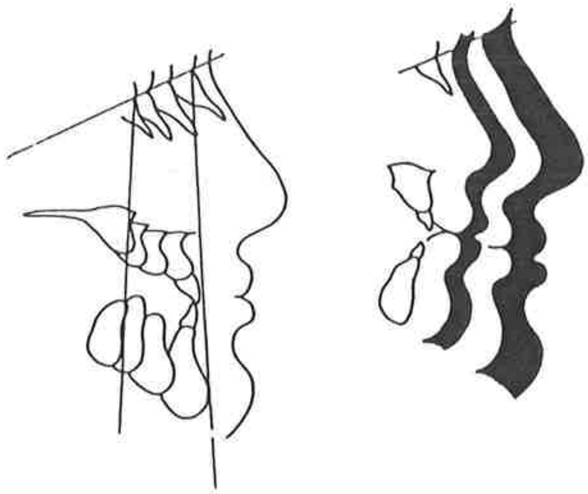


Figure 5A.

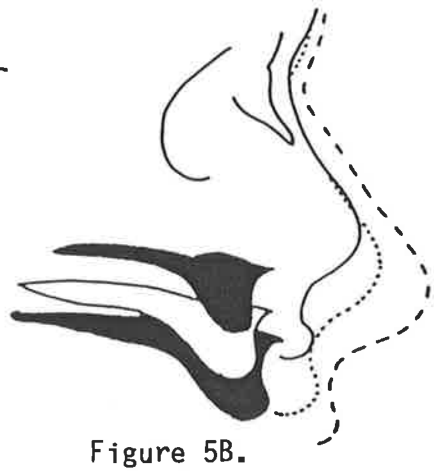


Figure 5B.

FIGURE 5. Soft tissue profile changes with growth.

A. Serial tracings depicting the forward positioning of the chin with the forward positioning of the skeletal chin and other facial changes.

B. Serial tracings superimposed on sella-nasion registering on nasion depicting the downward and forward growth of the nose at ages 5, 11, and 18 years.

(From Subtelny, 1961).

(5) The nose continued to grow downwards and forwards during adolescence.

(6) The lips lengthened and thickened in the vermillion region.

Merrifield (1966) cited Allessandra's (1959) and Barrett's (1959) theses as finding that the upper lip and sulcus, lower lip and sulcus and chin integuments were significantly thicker in males than in females and that the "E" line of Ricketts more closely approached the lips of males than females.

Posen (1967) examined changes of the angle basion-soft tissue nasion-soft tissue pogonion and found that there was a regular and smooth increase until 14 years. From 14 to 17 years there was no real increase in mandibular prognathism and this was found to closely follow the similar skeletal measure. It was found that the angle was greater in females and males until 15 years when the difference equalized. The profile measured from soft tissue nasion-pronasale-soft tissue pogonion became less convex on average until 11 years and from 11 to 16 years the profile became more convex with similar findings in males and females, except that the change that resulted in more convexity occurred about one year later in males than in females. Females had significantly more convex profiles from 10 until 14 years. The facial convexity was found to be stable after 16 years. It was concluded that the profile was significantly different at 13 and 18 years due to a forward chin movement of 10%, but mainly due to late growth of the nose. It must be noted that Posen used Subtelny's 1959 sample and therefore he confirmed Subtelny's findings and enlarged on certain aspects.

De Kock et al. (1968) noted that the recorded amount and direction of changes in the soft tissue profile varied according to the procedures used to study the changes and recommended multiple approaches to study the profile. In constrast to the previously cited literature, De Kock et al. used bregma-sellion as a reference line. They found that all soft tissue facial depths increased from 5 to 17 years in males and females. Females showed significantly less change from 14 to 17 years than during the previous three years. They also confirmed that facial depths for males were significantly larger than for females at all ages studied. The rank order of distance of points from the reference line did not change with age and remained, starting with the largest, as pronasale, labale superius, labale inferius, superior labial sulcus, soft tissue pogonion, inferior labial sulcus and subnasale. During each of the 3 year periods studied, the difference between the largest and smallest increased. They confirmed that pronasale increased in relation to all other points during childhood and adolescence. The upper lip depth was found to be greater than the lower lip, but between 5 and 11 years the lower lip increase was greater, and therefore the difference between the two lips was found to reduce. From 5 to 14 years they also found that the growth of the chin prominence was significant to the profile. Soft tissue pogonion increased in depth more than subnasale during this period. They also found that each of the measurements increased in variability over the period studied. For males the increase occurred from 5 to 14 years and for females from 5 to 11 years and this confirmed the earlier maturation of females. They found no association between the face depths at any age and the subsequent increase, but found a strong association between size at one age and size at another, which was stronger if the time interval was shorter. That is, a small face would not necessarily have a smaller increase than a large one, but small faces tended to remain small.

Mauchamp and Sassouni (1973) studied 51 cases from 7 to 18 years, divided according to sex and into deep bite, open bite and normal groups. No graphical or statistical significance was found between the different facial types. The female soft tissue profile (excluding the nose) was significantly straighter than the male (with an earlier growth spurt in females), but this sexual dimorphism was not as strong as for the skeletal profile. The profile tended to remain stable with age. The soft tissue increase at subnasale was found to be greater than at pogonion and all soft tissue thicknesses were greater in males. The skeletal open bite type was found to have greater soft tissue thickness than the deep bite type. The results showed the same general trends as Subtelny (1959), but differed in detail probably largely because Subtelny used glabella and soft tissue glabella rather than nasion and soft tissue nasion in his measurements. Angelle (1973) in a study of 11 females and 5 males at adolescence and early adulthood, and a treated group of 36 cases confirmed a tendency for increased nose and chin prominence due to growth which was greater in males.

In 1975, Chaconas and Bartroff studied 46 subjects yearly from 10 to 16 years of age, with various classes of malocclusions. Only soft tissue measurements were used and the reference line for linear measurements was a line between glabella and soft tissue pogonion. They confirmed many of the previous findings and reported the linear changes of profile points in some detail. Their results could be summarized as follows. The convexity of the profile including the nose increased with age. At age 10 males had less convex profiles than females, the classification of the occlusion was not important here. The convexity of the females remained stable after 13 years, males had a growth spurt between 12 and 15 years, and there was no sex difference in the convexity at 16 years. This was in contrast to Pelton and Elsasser (1955) who found that males ultimately had more convexity than females, but agreed with Subtelny (1959). Nose growth was found to increase linearly more than any other measurement. Males exhibited 1.5 to 2 times more growth of the nose and class of malocclusion was not important. Chaconas and Bartroff explained that the convexities were the same at 16 years due to a greater degree of vertical development in the male, which offset the effect of nose growth. The lower lip did not show as much change as the upper lip and the lip flattening previously reported was not observed. However, there was a reduction in the angular or proportional lip convexity from 10 to 16 years. They reported changes seemingly dependent on the class of the occlusion. However, no pattern was found, the results were often contrary to what they would have expected, and when the sample was broken down into sex and class only very small numbers were left in the groups. However, their general findings confirmed the results of previous investigations.

Wisth (1975) studied 33 females and 37 males from 4 to 10 years of age but excluded reference points on the vermillion area of the lips because excessive postural variation was expected. The results supported those of previous findings. He found the soft tissue changes in general seemed to follow the changes of the underlying hard tissues, and that the greatest difference occurred in the area of the alveolar processes. This was shown by the difference in behaviour of the sella-nasion-A point values which tended to decrease, while the sella-soft tissue-nasion-superior labial sulcus values tended to increase due to increased thickness of soft tissue over A point. The soft tissue over nasion was found to be relatively constant in thickness. The same was found to be true with relation to the soft tissue over B point with a flattening of the mental sulcus the result. The prognathism of the chin changed almost identically for both hard and soft tissues due to the change of soft tissue thickness over the chin being similarly as small as the change over nasion. The skeletal facial convexity was found to decrease in both sexes, while the soft tissue convexity, (excluding the nose) remained almost unchanged, largely due to the increased thickness of soft tissue over A point which tended to disguise the increased mandibular prognathism. The growth of the nose was believed to be responsible for the most dramatic effect on the profile. When the nose was included convexity increased. The greater vertical compared with horizontal growth of the nose changed the relationship of the nose to the chin and the nose length increased relatively more than face height. These features were in close agreement with those of Subtelny (1959).

Fosberg and Odenrick (1979) found that the lips became more retrusive in relation to Ricketts' "E" line with growth, especially the upper lip. This was believed to be mainly due to forward nose growth.

Burke (1979, 1980) and Burke and Beard (1979) used a frontal approach and utilized stereoscopic pairs of facial photographs to produce a three dimensional contour map. An example of such a plot is shown in Figure 6. Burke (1979) supported the previous findings that there was considerable forward displacement of the nose tip, less at the mouth level and very little at the bridge of the nose. The contention that growth rates were differential, with the nose growing forwards faster than the lips was also confirmed. There was generally a higher

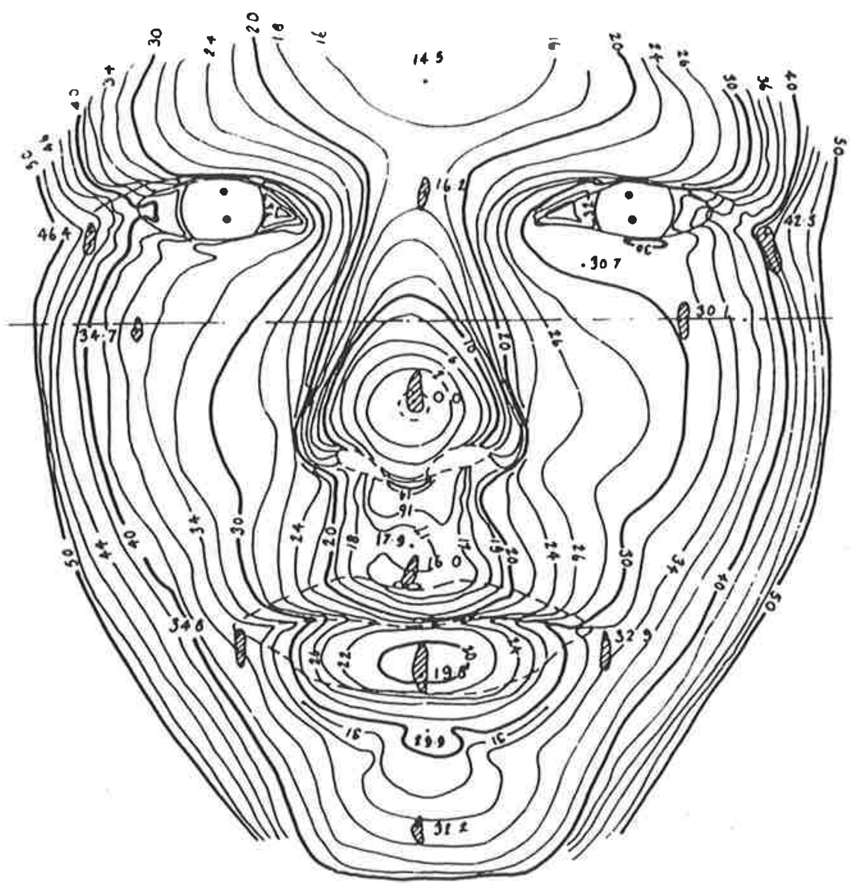


FIGURE 6. Example of a stereophotogrammetric facial contour plot.

(From Burke, 1979)

level of variance, as measured by the standard deviations of linear parameters, for the values at 12, 13 and 14 years for males and 11 and 12 years in females, which probably related to the variable ages at which the adolescent growth spurt commenced.

Burke and Beard (1979) found that the soft tissues of the face generally followed the skeletal growth rate of Scammon (1930), (cited by Burke and Beard, 1979), with a spurt in adolescence. The growth of the soft tissues was believed to be largely secondary to that of skeletal growth.

1.5 TREATMENT EFFECTS ON THE HARD TISSUES OF THE FACIAL PROFILE

The number of cephalometric studies of treatment effects on the hard tissues of the teeth and skeleton of the facial profile was found to be enormous. It is impossible to review them all, however some discussion of hard tissue changes would help provide a basis for a consideration of the soft tissue profile changes due to treatment. Discussion will be concerned mainly with the effects on the incisors and alveolar bone because these tissues were important in a consideration of the lip profile and its changes due to treatment. Changes occurring after treatment due to growth and/or relapse have been widely discussed in the literature, for example Levin (1977). However, only treatment effects will be considered.

Hellman (1931) (cited by Silverstein, 1954) found that orthodontic treatment produced changes by moving the teeth themselves, but had little effect on growth of the supporting bones. Skeletal changes seen at the end of treatment were believed to occur as a result of growth. Nance (1947) also supported this viewpoint.

In 1941 Brodie stated, "the most startling finding was an apparent inability to alter anything beyond the alveolar process" (this was widely referred to in the literature, for example, Nance, 1947; Riedel, 1950; Silverstein, 1954; Holdaway, 1956; and Neger, 1959). Ricketts (1960a) referred to Björk (1953) who made the point that there was no evidence from cephalometric research indicating that growth was influenced by orthodontic treatment. Ricketts (1960a) concluded that since there was no significant difference in the amount of growth between his treatment and non-treatment groups, there was no effect of treatment on mandibular growth. This was also found by Coben (1966).

Buchin (1957) believed that the current thinking was that orthodontic treatment did not effect growth, and wrote that this question could not be scientifically answered since there was a lack of standard control procedures.

In 1977, Cross investigated facial growth before, during and after orthodontic treatment. His conclusions were that individuals varied in their direction of facial growth and degree of response to orthodontic treatment, and that several cases had no change from their normal growth direction. Several other cases showed a deviation in direction associated with orthodontic treatment which was clockwise in nature (the profile faced to the right). The "clockwise response" noted by Cross (1977) referred to a retardation of the anterior maxilla, less forward movement of pogonion and a downward rotation of the occlusal and mandibular planes. These effects were widely reported in the literature.

The literature contained ample evidence that changes in the hard tissue profile and occlusal and mandibular planes could result from treatment. As with the growth studies, treatment responses also showed great individual variation. The studies of Silverstein (1954), Holdaway (1956), Stoner et al. (1956), Buchin (1957), Taylor (1969), Kimmons (1969), Pridemore (1969), Checkoff et al. (1971), Kottraba (1971), Barton (1973), Venezia (1973), De Laat (1974), Williams (1977), Cohen (1983), and others, reported a retraction or holding back of points A and B due to treatment, most often reported as a reduction in the angles sella-nasion-A point, sella-nasion-B point or A point-nasion-B point, or as a linear retraction with reference to a facial plane. The literature indicated that often the retraction of A point was more significant than that of B point. Often B point was found not to change. The concensus was that these changes were due more to incisor retraction rather than an effect on growth, since A point and B point were in the area of alveolar bone.

Changes of the occlusal and mandibular planes were noted in studies such as Silverstein (1954), Wylie (1955), Stoner et al. (1956), Ricketts (1960b), James (1968), Williams (1968), Kottraba (1971), Barton (1973), De Laat (1974) and Cross (1977). The changes noted were an increased steepness of these planes usually due to mandibular molar elevation. Burstone (1967) noted that a change of the mandibular position altered the relaxed lip posture.

The authors previously cited in this section found a significant retraction of the anterior teeth, especially the upper anteriors in Class II division I cases. Therefore as a result of the hard tissue changes, a straightening of the hard tissue profile was commonly recognized.

Mainly Begg studies have been cited in this section. Appropriate detail with respect to hard tissue treatment changes will be provided in the review of soft tissue treatment changes to follow.

1.6 TREATMENT EFFECTS ON THE SOFT TISSUES OF THE FACIAL PROFILE

A. Introduction

Unless otherwise indicated, the literature referred to concerned treatment effects due to edgewise appliances. However, studies cited in the previous section often found little or conflicting differences between hard tissue treatment effects using Begg and edgewise appliances. Studies of the effects of orthodontic treatment on the soft tissue profile were found to be comparatively recent. Only two studies, De Laat (1974) and Cangialosi and Meistrell (1982), were found to examine changes due to the Begg technique. Values provided in this section are means unless otherwise indicated.

Some details of the methodology of studies of soft tissue response to orthodontic treatment are provided in appendix 3. Some findings are presented in appendices 1 and 2.

B. Lips

Wylie (1955) found Tweed's edgewise treatment aimed for, and achieved, reduction of the profile in the region of the lips. However, he found that lingual movement of teeth was not always accompanied by a proportionate lip change (appendix 2).

In 1956, Stoner et al., studied 57 consecutive cases trated by Dr. Tweed and found that an improvement in lip contour occurred due to superior labial sulcus and inferior labial sulcus coming forwards, and the tips of the lips moving back. More lower lip than upper lip retraction was found, and it was believed that this was due to Tweed's concentration on the position of the lower incisors, an increased vertical dimension, or both. They correlated the angular change in the lower incisors (incisor-mandibular plane angle) with the amount of flattening of the lower lip and obtained a correlation value of -0.375, which they found to be small but significant at the 0.01 level, and concluded that there was a tendency for a large interincisal angular change to be accompanied by a large lip change (appendix 2). They also found some relationship between total lip retraction and the increased vertical dimension. No relationship was noted between the angular change of the lower incisors and the horizontal movement of the upper incisors. A small, but insignificant, relationship was found between the interincisal angle and lower lip retraction. It was conlcuded that the Frankfort-mandibular-incisor angle correlated only mildly with lip retraction. It should be noted that the Frankfort horizontal was used as a reference plane in this study in order to test Tweed's principles in relation to this plane.

Buchin (1957) found that the most significant treatment effect was a change in contour of the upper and lower lips permitting them to meet with less tension as a result of distal retraction of the anterior teeth. Cases were presented but no figures were given.

King (1960) studied 103 Class II, division I cases treated with head gear. For each 1 mm of upper incisor movement, the upper lip moved back approximately 0.5 mm except in thin lipped people where it tended to move back more, and in thick lipped people where it moved less (appendix 1).

Ricketts (1960b) stated that the upper lip thickened 1 mm for every 3 mm of retraction of the upper incisors depending on the amount of lip strain prior to treatment. The lower lip did not thicken but curved backwards or forwards and the soft tissue over B point tended to follow the behavior of the roots of the lower incisors. No studies or cases were cited as evidence.

In 1961, Bloom calculated correlation coefficients for the linear change of the upper and lower incisors to various landmarks (appendix 2). As the upper incisors changed so did the superior labial sulcus, upper lip and lower lip, and as the lower incisors changed so did inferior labial sulcus and the lower lip. It was also found that as the overbite and overjet changed, so did the upper and lower lips. It was noted that all of these correlation coefficients were between 0.73 and 0.93 which was far greater than the 0.01 level of significance. Consequently, it was concluded that this showed statistically that there was a very high relationship between the soft tissue changes and the orthodontically moved hard tissues. By the use of scatter diagrams it was found that the lower lip followed the lower incisors more than the upper lip followed the upper incisors. The range around the means showed a broad variation. The effect of large A point-nasion-B point angles, or the relationship of the upper incisors and lower lip were not investigated, and it was believed that these could also have had some bearing on the variation found in the predictability of the results. Environmental, hereditary and growth and development factors also needed to be more fully analysed in a consideration of the soft tissue response according to Bloom.

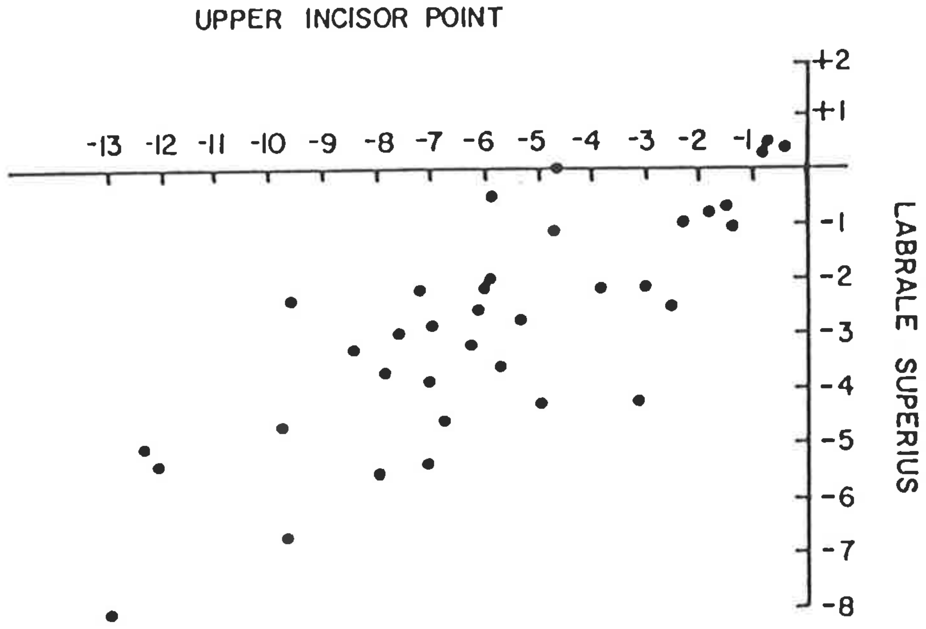
Subtelny (1961) believed that the lips were closely related to underlying structures and that only treatment, not growth, was able to alter the relationships of the lips to each other. In several case presentations to demonstrate the role of lip changes to overall changes in the soft tissue profile due to growth and treatment, Subtelny showed that a variable lip response could be produced.

In 1964, Rudee found a high degree of correlation between upper incisor and upper lip retraction, between lower incisor and lower lip retraction, and a moderate correlation between upper incisor and lower lip retraction (appendix 2). Ratios of upper incisor to upper lip retraction, lower incisor to lower lip retraction, and upper incisor to lower lip retraction were provided (appendix 1). It was concluded from the figures that the upper lip/upper incisor relation was the most influencial orthodontic treatment change. It was proposed that the values for the upper incisor compared favourably with those of Hasstedt's (1956) and O'Reilly's (1957) theses (cited by Rudee, 1964), including the variation in ratios (appendix 2). Fourteen of the 85 cases were reported to show a negative ratio of a small amount in relation to the upper lip/upper incisor. Hasstedt was cited as having reported a thickening of the upper lip with treatment, which disappeared in the retention and post-treatment period. Although the mean ratio of upper incisor to upper lip retraction was about 3:1 the mode was between 1:1 and 2:1. Therefore the average upper lip retraction was one third of the upper incisor retraction, but more upper lips retracted one half or an equal distance to the upper incisors. Rudee (1964) remarked that these collective findings showed that changes in facial contours and aesthetics were more related to the upper than the lower incisors. He refuted those formulae relating facial aesthetics to the position of the lower incisors and agreed with Angles' (1907) observation (cited by Rudee, 1964) that it was the upper incisors and not the lower incisors that established the curve of the lower lip. Rudee (1964) stated that there was a broad dispersion of results so that no finite conclusions could be drawn since, if combinations of extremes were applied to any one case, exaggerated results or results which tended to nullify each other and give negligible changes would result.

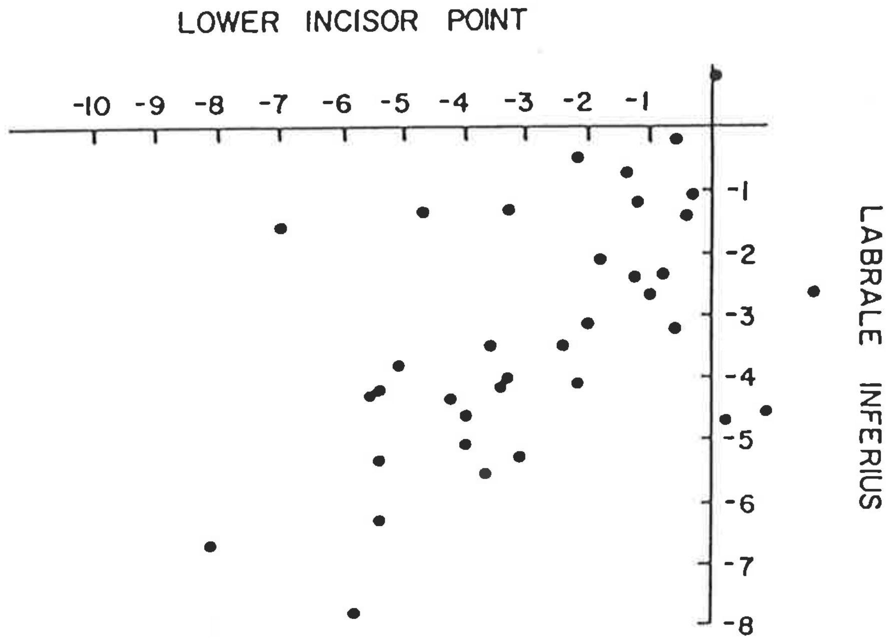
Burstone (1967) and Hillesund et al. (1978) proposed that the relaxed lip position was the best position from which to assess treatment changes of the lips. Burstone wrote that except for the influence of growth, the most dramatic facial changes following the retraction of teeth were seen in those cases in which there was a large or normal interlabial gap. If there was a redundancy, or potential redundancy of the lips, it was likely that they would not fall back following retraction of the incisors, and a case was presented where the upper incisors were retracted a large distance and yet the lips stayed where they were. The variability of lip pattern and response to treatment were pointed out and Burstone wrote: "If one considered malocclusions with and without interlabial gaps, it appears that no simple formula can be given for predicting the amount of lip displacement following retraction of the incisors, ..." This variation in response was noted by all authors and was considered to be important when considering the significance and interpretation of mean values.

In 1972, Hershey studied linear changes in the area of the lips in 36 post-adolescent females to eliminate the influence of growth, and only studied cases in which incisors were retracted. It was found that all points showed a significant change at the 0.01 level, except A point which showed a significant change at the 0.05 level. There was slightly more posterior movement of the lower lip than the upper lip. Movement of the upper incisor showed a moderately strong correlation with change of the superior labial sulcus and labrale superius, and correlations relating the lower incisor to its overlying lip and sulcus were somewhat lower. Except for a moderate correlation between B point and inferior labial suclus, the remaining data showed weak correlation between the movement of hard and soft tissue landmarks (appendix 2). Scatter diagrams showed that a given hard tissue movement resulted in a soft tissue response which varied widely from subject to subject (Figure 7). The 12 cases that showed the most soft tissue response and the 12 that showed the least response were compared. It was discovered that as the magnitude of upper incisor retraction increased, the correlation with upper lip change increased, and the correlation with lower lip change decreased. More change in lip prominence per mm of sulcus movement occurred in the most change group for both the upper and lower lips.

Hershey's finding of increased variability of soft tissue response to increased tooth retraction suggested that the soft tissues may be self-supporting, or that gross tooth movement may not always mean that a marked reduction of the profile contour would occur. The possible factors that could be involved were discussed, such as the creation of a void between the lips and teeth, or that an actual increase in lip thickness could occur. However, Hershey could not determine the role of these factors. The multiple coefficient correlations showed that the



Response of the upper lip to retraction of the upper incisor (in millimeters).



Response of the lower lip to movement of the lower incisor (in millimeters).

FIGURE 7. Scatter diagrams depicting lip response to incisor retraction.

(From Hershey, 1972).

lower lip tended to be more self-supporting than the upper lip, according to Hershey. Therefore, either the lower lip was not as dependent on the position of the dentition, or it was dependent on some other factors. O'Reilly (1957) was cited by Hershey (1972) as supporting the former argument.

Hershey compared the amount of lip flattening in those cases with the least and those with the most incisor retraction. The ratio of labrale superius to superior labial sulcus was found to be 1.5:1 in the most upper incisor retraction group, and 1.3:1 in the least upper incisor retraction group, such that more flattening occurred in the most change group. The lower lip showed the same trend with a 2.2:1 labrale inferius: inferior labial sulcus ratio in the most lower incisor retraction group.

In order to determine whether or not the original lip morphology was a factor in the response of the soft tissues to treatment, Hershey (1972) compared only 10 patients with redundant lips and 10 with incompetent lips. No significant differences were found at the 0.05 level for any landmark movement between the two groups, especially for the upper lip. That lip morphology had little influence on the soft tissue response to treatment was unexpected and was in contrast to Burstone's (1967) findings.

Hershey (1972) also divided the sample into groups with Class I and Class II malocclusions and found that only superior labial sulcus showed a significant difference at the 0.05 level between these two groups. Labrale superius and superior labial sulcus tended to follow the upper incisors more closely in the Class II compared with the Class I group and both the upper and lower lips showed a much stronger correlation with the lower incisors in the Class I group (due to the distorted lip pattern in the Class II cases before treatment). In all 15 Class II cases the lower lip moved lingually more than the upper lip indicating that uniformly good results could not be expected. However, in 12 of the 15 cases superior labial sulcus moved lingually more than inferior labial sulcus which was found encouraging.

In agreement with Stoner et al. (1956), Hershey (1972) found that diagnostic schemes involving the use of the lower incisors and prediction of profile change due to lower incisor retraction were disappointing due to the correlation coefficients determined. Rules relating a given amount of incisor retraction to a certain amount of lip retraction were only valuable in the broadest sense and may have had little value when applied to the individual subject.

Point A retracted on average only 0.3 mm in relation to the average upper incisor retraction of 5.8 mm and Hershey (1972) commented that this retraction was lower than previously stated in numerous case reports.

Hershey (1972) concluded that lip position was not highly correlated with incisor position. Other variables may have been involved other than retraction, such as; the original force per unit area exerted by the lips, variations in the soft tissues themselves (for example, the amount of muscle or adipose tissue), changes in the intercanine width altering buccinator muscle tension, or the actual area of lip to tooth contact. This supported the contentions of Salzmann (1964) that factors such as muscle size, tonicity, habits and psychomotor involvements were important variables in the relationship between lip and incisor retraction.

Anderson et al. (1973) evaluated the effect of growth and treatment, and changes 10 years post-retention. These authors considered that growth at nasion and pogonion must be recognised when considering results in relation to the facial plane since significant upper incisor retraction was noted which tended to relapse in relation to the maxillary superimposition, but showed continued retraction in relation to the facial plane due to growth at nasion and pogonion with forward positioning of the facial plane.

As expected, Anderson et al. (1973) found that there was more upper incisor retraction in cases of larger overjet. The lower incisors retracted to a lesser extent, especially in the small overjet group. This relationship continued to some extent after treatment. It was found that the upper lip retracted due to treatment, and that this was directly proportional to the amount of upper incisor retraction for the large overjet group. However, the small overjet group showed an inconsistent regression pattern with low correlation (appendix 2). The upper lip was also found to thicken during treatment as it retracted and this was in direct proportion to the amount of upper incisor retraction. Hasstedt (1956) was cited as supporting this finding. Ricketts (1960a) found a thickness: retraction ratio of 1:3, Anderson et al. (1973) reported a 1:1.5 ratio. This thickening was found to remain 10 years post-retention in all groups with some recovery toward the original value in females and in the small overjet group. A small amount of thickening was noted in the soft tissue over A point which was larger in males (1.4 mm) and thickening continued after treatment (1.9 mm).

Females showed a reduction in thickness over A point after treatment (1.5 mm) with a reduction of 1 mm after 10 years. It was suggested that orthodontic treatment had only a minimal effect on the soft tissue thickness over A point and that these changes largely reflected growth changes.

The amount of lower lip retraction was found to be similar for all groups by Anderson et al. (1973). There was a significant relationship between lower lips and lower incisor retraction which showed a higher correlation in the large overjet group. Ten years post-retention it was found that the lower lip had retracted more than the lower incisor which led Anderson et al., (1973) to conclude that the lingual re-positioning of the lower lip depended upon changes in both the upper and lower incisors, and that in cases with a large upper incisor protrusion the lower lip was maintained in a forward position by the upper incisors. No significant changes were found in the thickness of the lower lip after treatment or 10 years later. No treatment effect was noted in relation to B point.

Angelle (1973) in a study of growth, treatment, and post-retention effects in an untreated control group and in a treated group, found a smaller amount of upper lip retrusion than previous studies, particularly in males. Both the upper and lower lips tended to increase in thickness due to treatment and this was greater in males; a similar increase was not observed in the untreated control group. After treatment the upper lip had a tendency to reduce in thickness, and this was more marked in females. The upper lip seemed to have had a tendency to maintain its anteroposterior position and did not follow the anterior teeth. The increase in upper lip length was the same for treated and control groups.

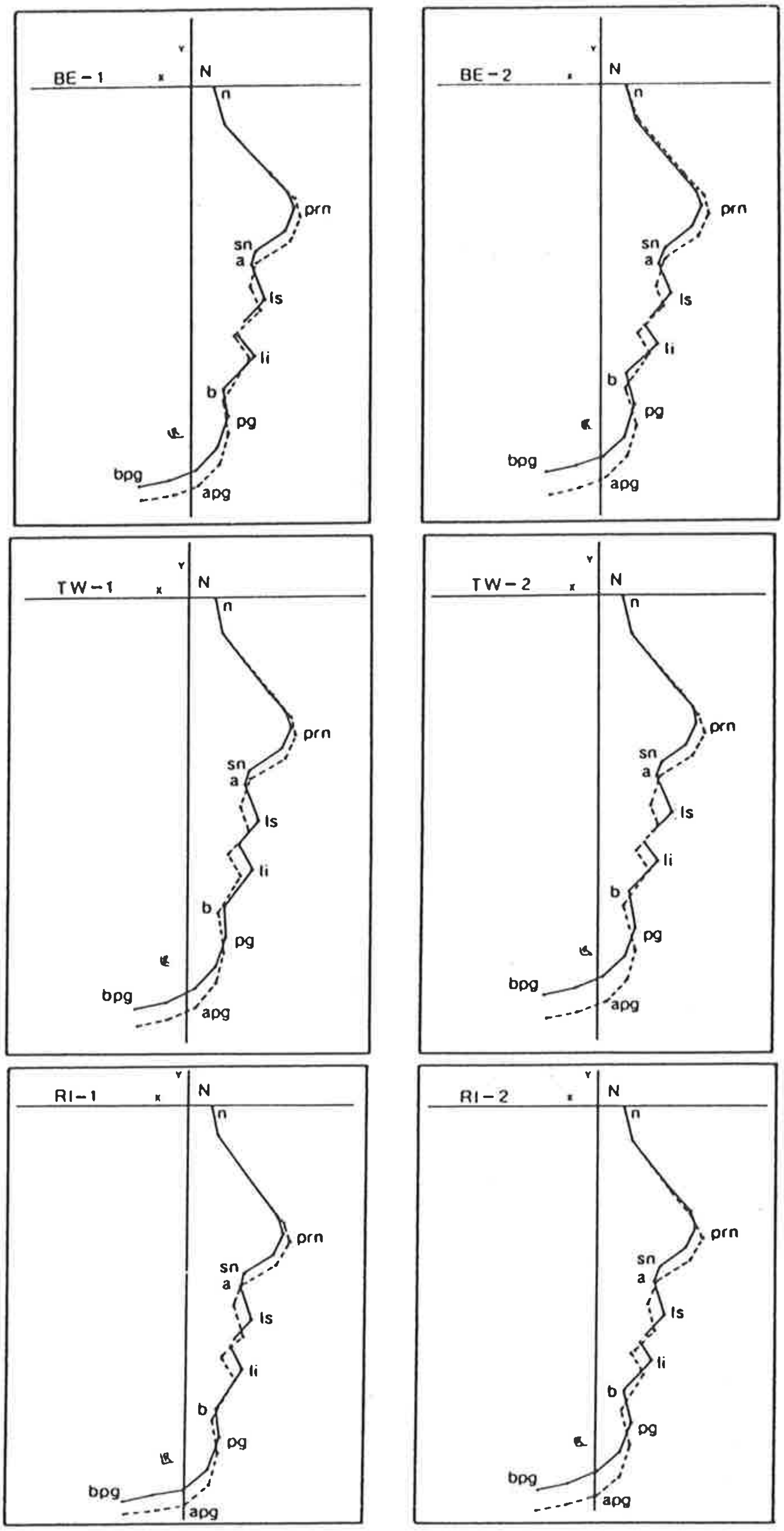
The behaviour of the lower lip was noted by Angelle (1973) to be similar to the upper lip. However, a marked retrusion was noted in females, while in males the lower lip tended to become more protrusive. The control group was reported to show an even greater protrusion for the male lower lip. Angelle's sample size for the control group consisted of only 5 males and 11 females and measurements were related to the palatal plane, and in particular anterior nasal spine.

De Laat (1974) made a comprehensive study of cephalometric changes due to orthodontic treatment, and included soft tissue profile changes and changes in facial aesthetics, in three groups of 50 patients treated according to the Begg, Riedel edgewise and Tweed edgewise techniques. Each group was further divided into 20 Class I cases (9 males and 11 females) and 30 Class II cases (11 males and 19 females).

Only one previous study of the soft tissue changes due to Begg treatment, the thesis of Werner (1968) was found by De Laat (1974). Regarding the Begg technique, statistically significant changes were localized to the dentoalveolar area and the overlying soft tissues. De Laat believed that this was due to the use of only intra-oral forces over a relatively short time, which would be too short to influence growth permanently. No significant differences in the overall measurements were found between Class I and Class II cases except in the rotation of the occlusal plane and in the retraction of the crown of the upper incisors, which were greater in the Class II group.

A change in skeletal convexity due to retraction of the upper incisors, significant lip retraction, and minimal effects of treatment on growth were also found in the Riedel and Tweed edgewise groups. The general findings were therefore similar to those noted in the Begg sample. In comparing the three groups further, De Laat (1974) found that there was no significant difference in the retraction of the upper incisors between the groups in Class I cases. In the Class II cases however, the Tweed group showed significantly more retraction of the crowns and apices of the upper incisors and A point, with a greater A point-nasion-B point reduction, than in the Begg group. The difference was attributed to the mechanics involved, such as the use of head-gears in the Tweed group. It was also found that the Tweed groups were the only cases to show a significant retraction of the crown of the lower incisors and, therefore, the lower incisors uprighted. Retraction of B point was less in the Begg group than in the edgewise groups, which was found difficult to explain, except that growth influences may have been involved. The soft tissue profile changes were compared, and De Laat found that in the Class I cases the only differences were found in superior labial sulcus, where retraction was noted in the edgewise but not in the Begg groups. In the Class II groups there was significantly more retraction of the upper lip in the Tweed group and upper lip uprighting in the Riedel group compared to the Begg group, and a greater retraction of the superior labial sulcus in the Tweed than in the Begg group. De Laat concluded that the differences between Class I and Class II groups were quantitative rather than qualitative with greater retraction in the maxillary area for Class II cases. This was also true for the different techniques with more distal retraction, and in the Tweed groups especially. The Begg and Tweed techniques were overall found to be the most divergent in terms of the changes produced. (Figure 8).

From a consideration of the changes produced De Laat (1974) then wanted to determine whether or not the retraction of the lips was related to retraction of the dentition. To do this coefficients for the six subgroups were calculated, and then all the data for these groups was combined into a sample size of 150, and combined correlation coefficients were calculated for horizontal changes of the lips and dentoalveolar areas (appendix 2). There was a significant correlation between upper incisor retraction and retraction of the upper lip, retraction of the lower incisors and retraction of the lower lip, and between retraction of the upper incisors and the lower lip. This agreed with the authors previously cited. It was also found that the retraction of the upper and lower incisor root apices were correlated with retraction of the respective alveolar area, and less so, but still significantly, with retraction of the respective lip convexities. Since the horizontal movements of the apices of the incisors correlated with the movement of the deepest concavities of the lips, De Laat suggested that torquing procedures would have an influence on the contour and positions of the lips. The influence of treatment on the soft tissue over A and B points was in contrast with the findings of Anderson et al. (1973). He concluded that strong positive correlations existed between the horizontal movements of the incisors and lips. The lower lip position was influenced by the upper and lower incisors and the upper lip, whereas the upper incisor played the major role in the position of the upper lip. The position of the lower incisors and lower lip had hardly any influence on the upper lip.



Class I groups   Class II, division I groups

FIGURE 8. Soft tissue profile response to orthodontic treatment.

BE = Begg treated, TW = Tweed edgewise treated,
RI = Riedel edgewise treated. (From De Laat, 1974).

The relationship of the amount of crowding (as measured on study models) in the lower arch and the amount of lower incisor retraction was examined by De Laat (1974). More crowding resulted in less lower incisor retraction and less lower lip retraction. There was only an indirect relationship between the amount of crowding and the amount of lower lip retraction. The differences in values for the correlations between the six subgroups can be seen in Table 1.

In 1974, Garner studied soft tissue changes in a small sample of Negro patients. He found that the lips were 50% thicker and were also longer in Negroes compared with Caucasians using Burstone's (1958) standards. Garner found the results to be similar to previous findings. Great individual variation was noted. In the male sample (only 6 cases) he noted a tendency for the lower lip to move forwards, a finding that was attributed to greater growth in the male sample than in the female sample (10 cases). It was concluded that due to variation, predictability was poor (appendix 1).

Wisth (1974) studied changes in 60 males who were aged between 11 and 12 before treatment. The sample was divided into small (3-4 mm) and large (8-10 mm) overjet groups in which it was noted that the greatest difference was in the amount of protrusion of the upper incisors, the lower incisors had about the same position. This was done in an attempt at better standardization of the method. The lower lip was found to have had significantly more thickness and more protrusion in the group with large overjet and the upper lip morphology was similar in both groups. Wisth suggested that this demonstrated that the soft tissue may mask hard tissue differences. During treatment the change in lip morphology was found to be greater in the larger overjet group but large variation

	BE-1	RI-1	TW-1	BE-2	RI-2	TW-2	Comb.
Isl - ls	.41	$.62^{+}$	$.65^{+}$	$.59^{++}$	$.67^{++}$	$.52^{+}$	$.59^{++}$
Iil - li	$.63^{+}$	.54	.55	$.53^{+}$	$.53^{+}$	$.73^{++}$	$.59^{++}$
Isl - li	.17	$.62^{+}$	$.63^{+}$	-.10	$.53^{+}$	.43	$.39^{++}$
Rs - A	$.58^{+}$	$.63^{+}$	$.82^{++}$	$.48^{+}$	$.81^{++}$	$.70^{++}$	$.69^{++}$
A - a	.45	.55	.35	$.68^{++}$	$.49^{+}$	$.51^{+}$	$.53^{++}$
Rs - a	.36	.25	.50	$.58^{++}$	$.49^{+}$	.33	$.44^{++}$
Ri - B	.16	.32	$.58^{+}$	.44	.41	$.69^{++}$	$.47^{++}$
B - b	.05	.25	.53	$.57^{+}$	$.54^{+}$	$.80^{++}$	$.53^{++}$
Ri - b	.51	.32	$.73^{++}$	.28	.30	$.49^{+}$	$.44^{++}$
Iil - ALD	$-.86^{++}$	-.35	-.45	$-.56^{+}$	$-.78^{++}$	-.47	$-.62^{++}$
li - ALD	-.58	-.20	-.35	-.30	-.46	$-.52^{+}$	$-.42^{++}$

TABLE 1. The coefficients of the correlations between the horizontal changes in position of selected measuring points located on the lips, the incisors and the anterior alveolar borders. (+ = $0.001 < P < 0.01$; ++ = $P < 0.001$)

(From De Laat, 1974).

BE = Begg Group
RI = Riedel Group
TW = Tweed Group
-1 = Class I
-2 = Class II, division I
Comb = Combined

Isl = incisal edge $\underline{1}$
Iil = incisal edge $\overline{1}$
ls = labrale superius
li = labrale inferius
Rs = root apex $\underline{1}$
Ri = root apex $\overline{1}$
A = A point
B = B point
a = superior labial sulcus
b = inferior labial sulcus
ALD = arch length deficiency

was noted in both groups. The upper and lower lips were found to retract more in the large overjet group. This was associated with a greater retraction of the upper and lower incisors, however, the range of variation was also greater. The upper lip response was found to be more related to the degree of incisor retraction in the small overjet group. In the large overjet group the upper and lower lip responses were about the same. The lower lip morphology after treatment remained more acute, with a deeper sulcus in the large overjet group, whereas the protrusion angle of the upper and lower lips no longer differed significantly.

The upper lip thickness was noted by Wisth (1974) to increase during treatment, more so in the large overjet group, but not significantly. Moreover, no direct relationship between the amount of thickness increase and amount of incisor retraction was found as Anderson et al. had done in 1973. Wisth believed this change was due to growth and that treatment had little effect on the position of the superior labial sulcus. The ratio of increase in the large overjet group agreed with Ricketts' (1960b) 1:3 ratio, whereas in the small overjet group the ratio was found to be 1:2. Wisth found no significant increase in lower lip thickness (a tendency to increase was observed in the small overjet group) which agreed with Ricketts (1960b) and Anderson et al., (1973). The superior labial sulcus thickening was believed to have been independent of treatment and occurred due to growth.

Because of the greater variability in lip response to incisor retraction in the large overjet group, Wisth (1974) found that the changes in the small overjet group were more predictable, which disagreed with Hershey (1972). Wisth agreed with previous authors that the lower lip response was dependent on the upper incisor retraction.

Further, it was remarked that increased upper incisor retraction generally resulted in a reduced upper lip response and an increased lower lip response (appendix 1).

Huggins and McBride (1975) studied the soft tissue changes due to overjet reduction in 33 Class II, division I cases. The range of overjet was from 3 to 12 mm with a mean of 7 mm. The upper and lower lips were found to be nearer the facial plane due to treatment. Correlation coefficients were calculated in a different way to previous authors, by relating the interincisial angle change and soft tissue changes. In females with a Class I or Class II dental base there was a relationship between the retraction of the upper incisors and a reduction in prominence of the lower lip. There was also a correlation between the retraction of the upper incisors and the decrease in prominence of the upper lip in females with a Class I skeletal base. However, no correlation was found between the change of interincisal angle and change in lip position in the other groups studied although the clinical impression of these authors was that there was a distinct relationship. These authors believed that continuing mandibular growth in the male could have had a bearing on these findings (appendix 2).

Roos (1977) studied horizontal retraction in 30 Class II cases with a mean overjet of 9.5 mm and mean overbite of 4.2 mm. The incisors, A point, superior labial sulcus, inferior labial sulcus, and the upper and lower lips were significantly more posterior in relation to the reference line after treatment. The correlation between the retraction of hard and soft tissue points was relatively high with respect to A point, the incisal edge of the lower incisors and B point, and their respective soft tissue points (superior labial sulcus, labrale inferius, inferior labial sulcus). However, the correlation between the retraction of the incisal edge of the upper incisor and superior labial sulcus or inferior labial sulcus was relatively poor (appendix 2). The upper lip measured at superior labial sulcus was significantly thicker, and the lower lip measured at inferior labial sulcus was significantly thinner after treatment. That the upper lip thickened agreed with Ricketts (1960b), Anderson et al., (1973) and Wisth (1974). However, the thinning of the lower lip disagreed with the findings of these authors who found no change except for Wisth (1974) who noted some tendency to increase in cases of small overjet.

Roos (1977) found that the ratios for lip and incisor retraction agreed with previous authors. The ratios showed that the soft tissue overlying the lower incisor, A point and B point showed almost the same amount of retraction, whereas the retraction of the upper incisor resulted in a much smaller upper lip response (appendix 1). It was also found that the greater the hard tissue retraction, the smaller was the relative retraction of the corresponding soft tissue point. These results showed that the soft tissue profile did not, in all respects, reflect changes in the underlying skeletal profile due to orthodontic treatment, and large individual variations in response were noted.

Jacobs (1978) studied the vertical changes in the lips relative to upper incisor retraction in order to study closure of the interlabial gap. The sample consisted of 20 patients with a Class II, division I malocclusions and a normal mandibular plane angle. In the vertical dimension, positional changes in the upper incisor ranged from a -2.0 mm of intrusion to a +4.5 mm of relative extrusion and the upper incisors were retracted from 4 to 10 mm. Reduction of the interlabial gap ranged from 0 to -6.0 mm. No significant correlation could be found between the amount of maxillary incisor retraction and the vertical closure of the interlabial gap, or between the vertical movement of the upper incisors and the closure of the interlabial gap. However, by combining both sets of measurements, a significant multiple correlation coefficient of 0.94 was obtained. If no vertical change of the upper incisor occurred with its retrusion it was found that the interlabial gap closed approximately 1mm for each 2 mm of retraction. If, however, intrusion occurred there was more interlabial gap closure per mm of retraction and proportionately more relative to the amount of intrusion that occurred. The converse was noted if extrusion occurred. The vertical and horizontal change of the upper incisors was highly correlated with the vertical change in the upper and lower lips ($r = 0.70$ and 0.82 respectively) (appendix 2).

Jacobs (1978) concluded that it was possible to predict the closure of the interlabial gap within the limits of reasonable error. It was claimed that the reasons that the vertical upper incisor movement effected upper lip lengthening could only be conjectured; a decreased upper lip support was suggested. The lower lip may move vertically and horizontally due to upper incisor intrusion due to reduced support, and conversely, extrusion would place more influence on the lower lip with less change horizontally and vertically. It was noted that the amount of lip strain may also be important in the response to upper incisor movement.

Koch et al. (1979) studied soft tissue changes due to treatment in a total of 113 Class II, division I and Class III cases divided into four groups on the basis of classification, extraction or non-extraction treatment, or treatment with edgewise appliances and/or functional appliances. The post-treatment radiograph was taken one-year post-retention. A control group of 17 untreated Class II, division I cases was also studied. It was found that the lips retracted with incisor retraction and that upper incisor retraction resulted in more retrusion of the lower than the upper lip.

Stromboni (1979) studied 33, Class II, division I cases with a skeletal open bite treated with Bimler functional appliances. The upper lip was found to retract 0.5 mm for every 1 mm of upper incisor retraction and superior labial sulcus was found not to have been influenced by treatment. The lower lip also retruded with treatment. Lip and incisor retractions were greater in non-extraction cases, since the upper lip lengthened by becoming more stretched, more so in the non-extraction group. Only means and standard deviations were provided.

Broch et al. (1981) proposed that the lip flattening observed from relaxed to closed lip position, which was greater in large overjet cases, could camouflage the response of the lips to incisor retraction. It was also proposed that this would help explain the increased lip thickness observed by several authors subsequent to upper incisor retraction.

In 1981, La Mastra studied 40 Class II, division I cases and reported that A point, superior labial sulcus, B point and inferior labial sulcus all retracted during treatment. Ratios were calculated between A point and B point retraction and the respective soft tissue points. The results compared favourably with those already cited (appendix 1).

Cangialosi and Meistrell (1982) studied 18 cases using radiographs taken before and after the third stage (that is, after incisor torquing) of the Begg technique to determine the change that occurred in the upper incisor, A point, and superior labial sulcus. In relation to the nasion-pogonion plane the following changes were noted. The apex of the upper incisor moved posteriorly in all but one case with a mean of 3.5 mm. A point moved posteriorly in all cases with a mean of 1.7 mm. Superior labial sulcus moved posteriorly in all cases with a mean of 1.97 mm. The incisal edge of the upper incisor moved forwards in most cases with a mean of 1.62 mm. The incisal edge of the upper central incisor moved downwards in most cases with a mean of 1.27 mm. Labrale superius moved forwards in 5 and backwards in 9 cases, the mean change was 0.38 mm posteriorly which was not statistically significant. These results have been reported in some detail since this was only the second Begg study in the literature, and since it showed the changes as a result of the incisor torquing stage of Begg treatment. Remodelling of superior labial sulcus was shown to have little correlation to changes at A point and the change was, therefore, found to be unpredictable. No correlation between soft and hard tissue movements were found to be significant in this study and it was concluded that there was no predictablity between hard and soft tissue changes (appendix 2).

Lo and Hunter (1982) studied 50 treated and 43 non-treated Class II, division I malocclusions with a minimum overjet of 3 mm (average approximately 7 mm) for the treated group before treatment, and a minimum of 4 mm (average approximately 6 mm) in the untreated group. In the untreated group the nasolabial angle did not change with age. Neither of the components (nose or upper lip) changed either. No skeletal landmark change was found to be correlated with the nasolabial angle. In the treated group all landmark changes correlated significantly with changes in the nasolabial angle. Stepwise multiple regression analysis revealed that the most important of these were, in order: incisal edge of upper incisor, lower face height, mandibular plane angle, and A point. Other landmarks showed lower correlations. The nasolabial angle, therefore, was found to increase with the amount of upper incisor retraction which seemed to be a linear relationship where a 1 mm retraction of the upper incisor produced a 1.63^{o} increase of the nasolabial angle. High correlations were found between upper incisor retraction and the retraction of labrale superius. Significant correlations were also noted between the upper incisor retraction and retraction of superior labial sulcus and inferior labial sulcus. No correlation between upper incisor retraction and labrale inferius retraction was noted, which differed from the general findings of previous authors. Change at A point correlated significantly with change at superior labial sulcus but upper lip thickness did not correlate with incisor retraction, while lower lip thickness did. No significant differences were noted at the 0.05 level according to whether the cases were treated extraction or non-extraction. The mean ratio of retraction of the incisal edge of the upper incisor and labrale superius was approximately 2.5:1 which was in agreement with previous findings (appendices 1 and 2).

Oliver (1982) studied the influence of upper lip thickness and strain on the upper lip response to incisor retraction in 40 Class II, division I cases. Point A was not used since it was believed through a personal communication with West (1980), that the drape of the lip overlying A point was modified by the attachment of nasal structures at anterior nasal spine, and that it was only at a level of 2 to 3 mm below

A point that this influence did not exist. A constructed point lower down on the alveolar bone which was named K point was used. The lip strain was calculated using a constructed method of subtracting upper lip thickness at the level of labrale superius from lip thickness at the region of K point and superior labial sulcus. Holdaway (1980) (cited by Oliver, 1982) found that the upper lip did not follow the upper incisor retraction until the factor of lip strain had been eliminated (which Holdaway calculated in a similar way). Holdaway was cited to have believed that a 1 mm lip strain, or taper was normal for a person with an orthognathic profile. Lip thickness was determined by placing those in the lower 25% into the thin lip group while those in the upper 25% were placed into the thick lip group.

Using these factors of lip strain and thickness, Oliver (1982) statistically evaluated the upper lip response to upper incisor retraction. There were significant sex differences in treatment, with osseous changes and soft tissue changes being significantly greater in males at the 0.01 level. Upper incisor uprighting was significantly greater in females at the 0.01 level. It was believed that the sex differences could be due to expected differences in growth, differentiation and maturation patterns between the two sexes at this age group.

A significant correlation was found by Oliver (1982) between general hard and soft tissue responses in males and females. This correlation was stronger in the group with thin lips, while the group with thick lips showed no significant correlation between hard and soft tissue changes. Significant correlations were found between upper incisor retraction and retraction of labrale superius in both sexes. The correlation which was stronger in the high lip strain group, but there was no significant correlation in the group with lower lip strain.

Prior to treatment there was no significant difference between the skeletal, dental and soft tissue positions in males and females, while after growth and treatment the soft tissue position alone showed a significant difference and showed growth differences between the two sexes. Oliver (1982) agreed with the findings of Baum (1961) that males and females had different patterns of maturation. The significantly greater soft tissue changes in males was therefore believed to be due to their greater growth tendency. This also explained why lip strain significantly decreased in females with upper incisor retraction.

Oliver (1982) proposed that his results supported the hypothesis that the soft tissue varied in thickness, length and postural tone causing the response of soft tissue to hard tissue retraction to be different in a person with thick lips as compared to a person with thin lips. However, it was believed that the results could not be used for prediction because of methodological problems, such as a small sample size, inability to separate growth and treatment effects, and because lip tone could be more accurately measured by lip strain gauges and electromyographic techniques than using a constructed method. The lower lip and incisors were not studied (appendix 2).

Rains and Nanda (1982) believed that the relationship between incisor retraction and lip adaptation was still controversial. They studied the soft tissue response to upper incisor retraction in a late adolescent/early adult group of 30 females to eliminate the effects of growth. These authors believed that the approach of most other investigators, while not eliminating the effects of growth, also used a too simplistic approach with the use of simple ratios to predict treatment responses. Rains and Nanda aimed to use a more sophisticated approach. The relaxed lip position of Burstone (1967) was used since these authors believed that Burstone showed it to be the best posture for cephalometric evaluation. It was proposed that using this lip posture some of the variablity of lip strain due to closure would be removed, especially in cases of large overjets. It was also believed that a more careful selection of patients would remove some of the variables that would have influenced the results of previous studies. For example, Vig and Cohen (1979) and Subtelny (1961) had shown that marked lip changes could occur due to growth in early adolescence.

Scatter diagrams were produced by Rains and Nanda (1982) which showed that the soft tissue response could vary widely for a given amount of tooth movement. The lower lip was found to be more variable than the upper to a difference in upper incisor retraction. The retraction of labrale superius became more variable as upper incisor retraction increased. These results showed that dental movement, especially of the lower incisors, did not correlate well with changes of the lips. A moderate correlation was found for the response of labrale superius to upper incisor retraction, but the response of superior labial sulcus was more complex and related more to change in labrale superius than to other changes. No significant correlation was found between lower incisor movement and response of the lower lip. Mandibular rotation was found to have a greater influence on lower lip response than incisor movement. A complex interaction was proposed to exist between dental movement, mandibular rotation, and the lips, as well as a complex relationship within the soft tissues themselves.

Waldman (1982) believed that Class II, division I cases with obtuse nasolabial angles were likely to finish with a "dished-in" look if care was not taken to avoid excessive retraction of the anterior teeth. No significant correlation between retraction of the upper incisor and change in the nasolabial angle were found by Waldman (1982) but there was a significant correlation between the retraction of the upper incisor and the retraction of labrale superius. However, it was deduced that this ratio indicated less effect on the soft tissues than previously reported (appendix 1). Neither was there a correlation between retraction of labrale superius and change of the nasolabial angle. However, a significant correlation between change in angle of the upper incisors and change in the nasolabial angle were noted. It was believed that this sample was too small to statistically assess the relationship between lip thickness and the soft tissue response. A steep palate pre-treatment was found to be associated with a large nasolabial angle which, Waldman believed, served as a warning to avoid excessive incisor retraction. The non-significant correlations were explained by Waldman (1982) as being due to other factors, such as growth, soft tissue consistency and musculature, and other variables that effected the physical form of the face.

Yap (1982) studied treatment changes in 30 growing Class II, division I patients and found that horizontal changes of the upper incisor significantly contributed to the change of the upper and lower lip sulci and convexity of the upper lip, thus influencing the soft tissue profile. Changes in the nasolabial angle could not be predicted accurately. Yap believed that the study could have been sample dependent.

In 1983 Holdaway described a comprehensive cephalometric soft tissue analysis using various soft and hard tissue measurements. The method and values were derived from the author's experience in clinical practise. No studies were cited to support Holdaways findings which were designed to provide a normal or acceptable range of variation for facial harmony related to variations in skeletal convexity. Case examples were discussed to illustrate the results. Most of the discussion involved the upper (and not the lower) lip. The usual soft tissue thickness over A point was 14-16 mm in adolescents. The soft tissue tended to follow the retraction of A point and thickness did not change. The normal upper lip thickness at the vermillion was 13-15 mm. Therefore, the upper lip should have a taper of about 1 mm from the sulcus region to the vermillion. An excess taper often resulted when lip strain (for example, over proclined incisors) was present, while the opposite situation often resulted from a reduced lower face height and lip redundancy.

As a result of varying lip thicknesses and strain, Holdaway (1983) found that the upper lip tended to follow a certain pattern in response to incisor retraction in adolescents. When there was lip taper (such as over protruded incisors) the vermillion tended to thicken as the lip followed the incisor retraction until the thickness approached that over A point (within 1 mm). After lip taper was eliminated further lingual movement of the incisor did not result in lip movement in a 1:1 ratio. However, when the thickness of tissue over A point was not in the normal range the response varied. For thin lips (9-10 mm over A point) the lip tended to follow the incisor immediately and retained its taper. For thick lips (18-20 mm over A point) there was often no lip movement with incisor retraction. Adults tended to show a different response. Holdaway believed that the lip response to treatment changed after growth had ceased. Adults tended to follow a similar pattern to thin-lipped adolescents, except that if excessive taper or strain was present, this would tend to remain. In such cases it was almost impossible to reduce the overjet and still have adequate upper lip curl.

Holdaway (1983) found that the upper lip thickening that occurred at the vermillion due to treatment tended to return to the original measurement after a period of "adaption" during retention (considered to be a minimum of 5 years). The exceptions were patients with thick lips and older patients with excessive lip taper. This should therefore be allowed for in treatment planning to avoid over-retraction of the incisors and later worsening the lip profile as the lips (especially the upper) caught up. Holdaway advised caution in cases with an already excessive labiomental fold and an excessive chin since lingual retraction of the lower incisor root and B point could worsen the lip profile.

Chang (1983) studied 52 adolescent and young Chinese patients divided into groups on the basis of extraction or non-extraction and protractive or retractive movement of the incisors. The soft tissue response was found to vary widely with a given amount of tooth movement. The predictability of the lower lip-to-incisor relationship was found to exhibit statistically stronger correlations when compared with the upper lip-to-incisor relationship.

Abdel Kader (1983) studied vertical lip height in relation to dental height, overjet and overbite in a sample of 22 males with Class II, Division 1 malocclusions and extraction of four first premolars. Although vertical dental height increased significantly after treatment (mean, 0.61 mm), the vertical lip height (as measured from labale superius to labrale inferius projected onto the nasion-pogonion plane) was found to increase (by a mean of only 0.05 mm), but this was insignificant and disagreed with the finding of Jacobs (1978). A statistically insignificant correlation was found between vertical lip height and vertical dental height. Abdel Kader believed that lip height increased as a result of the relaxation of stretched lips as the overbite and overjet was reduced (a statistically significant relationship was found between lip height and overjet reduction). Due to the small sample size and insignificance of many of the changes, the results of this study would appear to be inconclusive.

C. Nose and Chin

Subtelny (1961) wrote that changes in the basic position of the soft tissues of the nose occurred primarily as a function of growth and that there was little that could be done by the orthodontist to alter it.

Most authors who studied treatment changes studied only the soft tissues in the region of the lips. Specific reference to the nose was rarely made. Angelle (1973) believed that nose changes observed in the growing patient were due to growth alone. Lo and Hunter (1982) believed that approximately 90% of change in the nasolabial angle was due to change at the vermillion border of the upper lip. The other 10% was believed to be due to an increase in slope along the columella border of the nose and that when the upper lip followed the incisors, it actually pulled the subnasale area forward and downward slightly, thus causing this increased slope at the lower nasal border. Oliver (1982) believed that the nose influenced the drape of the upper lip due to attachment to anterior nasal spine and, therefore, chose hard and soft tissue points further inferiorly to study treatment changes. Apparently he did not believe that the superior lip and inferior nasal structures would be influenced by treatment. However, Ricketts et al. (1979) believed that treatment could influence the nose but cited no evidence to support his contention, and did not elaborate on the pattern of change.

Subtelny (1961) believed that changes in the soft tissue chin occurred as a result of growth and that there was little that the orthodontist could have done with it. Subtelny did not believe that mandibular growth could be controlled with appliances. Ricketts (1960b) and Ricketts et al. (1979) believed that an increase of soft tissue thickness over the chin could occur due to treatment with a loss of lip strain and relaxation of the mentalis muscle. However, Stoner et al. (1956), Anderson et al. (1973), Angelle (1973), De Laat (1974), Wisth (1974) and Stromboni (1979) all provided evidence that treatment did not influence the soft tissue overlying the chin, and that changes observed in the growing patient occurred as a result of growth.

D. Total Profile

Studies such as Wylie (1955), Stoner et al. (1956), Anderson et al. (1973), De Laat (1974), and others noted that overall the soft tissue profile straightened with treatment. Stoner (1956) believed that this involved four main changes: a reduction in lip prominence in relation to the rest of the face, a reduction in the curve beneath the lower lip, vertical face lengthening tending to flatten the profile, and forward chin movement. Lip retraction in relation to chin movement was greater in Class II compared with Class I cases. Subtelny (1961) believed that treatment effects were centred around the lips and had a dramatic effect on the profile, while in the growing patient growth changes encompassed a larger aspect of the soft tissue profile; the nose, chin and lips. Rudee (1964) and Branoff (1971) also referred to the importance of chin and nose growth. Rudee found that lip retraction occurred to a similar extent as forward chin growth and to about half the extent of forward nose growth. Variation in all of these factors was noted. In his study of Begg patients, De Laat (1974) found that the most significant change in the profile after treatment was that the convexities of the lips reduced.

CHAPTER 2

MATERIALS AND METHODS

2.1 SELECTION OF SUBJECTS

The sample consists of the orthodontic records of 30 male and 30 female patients treated in the post-graduate Master's degree programme in Orthodontics at the University of Adelaide since 1969. All patients were Caucasians of European origin who had been treated with full banded appliances using the Begg light-wire tehnique (described by Begg and Kesling 1977). The records collected included the hospital case notes, post-graduate treatment folders (written by the operator), study models and cephalometric radiographs taken before and after orthodontic treatment.

All patients had an Angle Class II, division I pattern of malocclusion. In all cases there was some degree of upper incisor proclination. The molar and canine relationships, however, were not always Class II (Table 2A). The cases included both extraction and non-extraction treatments (Table 2B). The skeletal pattern was not used as a selection criterion, except that no cases received orthognathic surgery of any kind.

The sample was selected as randomly as possible from approximately 230 possible cases, identified by reference to the post-graduate operators' treatment folder.

SAMPLE	CLASS II, DIVISION I INCISORS	CLASS II, DIVISION I BUCCAL	CLASS II, DIVISION I SUB-DIVISION	CLASS I BUCCAL
MALES	30	22	3	5
FEMALES	30	23	5	2
TOTAL	60	45	8	7

Table 2A. Distribution of subjects according to the pattern of malocclusion.

SAMPLE	SAMPLE SIZE	EXTRACTION OF FOUR FIRST PREMOLARS	NO EXTRACTIONS	OTHER
MALES	30	17	6	7
FEMALES	30	17	10	3
TOTAL	60	34	16	10

Table 2B. Distribution of subjects according to the pattern of tooth extraction.

TABLE 2. Sample composition.

The cases were selected on the basis of the following features:

1. Complete records; primarily the presence of before and after treatment cephalograms.
2. Class II, division I pattern of malocclusion (all cases had some degree of increased overjet).
3. Ages at beggining of treatment was approximately between 11 to 16 years; adolescents in this category could be expected to have some degree of growth potential.
4. Quality of the cephalograms.
   a. Teeth in centric occlusion.
   b. Minimal lip strain. The lip position could not be standardized as only retrospective records were available. Compromises were necessary in order to obtain the desired sample size. Lip pattern variations included cases with some slight strain, lips relaxed and wide apart, and lips together and at rest. The problems of lip posture and variation have been alluded to in chapter 2.4C(i). The selection on the basis of soft tissue pattern could not be fully objective or random.
   c. No orthodontic appliances in place, these would likely alter the soft tissue posture.
   d. Good overall quality; completeness of image, adequate contrast for landmark identification.
   e. Satisfactory post-treatment occlusion. Of necessity a largely subjective criterion, based largely on the incisor relationship. Usually an

edge-to-edge or near edge-to-edge incisor relationship was observed.

2.2 RADIOGRAPHY

All radiographs were exposed in the Radiology Unit of the Adelaide Dental Hospital. The cephalostat was of standard design (Lumex, Copenhagen) comprising a film holder, head-holder with plastic ear-rods, aluminium wedge for soft tissue imaging and light beam for head positioning. The distances from the source to the mid-sagittal plane and from the mid-sagittal to the film plane were standardized so that the enlargement of the radiographic image in the mid-sagittal plane was a constant 8.8%. (Figure 9)

Intensifying screens were used in order to reduce dosage, and a grid was used to reduce the effect of secondary irradiation on the image. Various Kodak brand films were used and exposures were according to the film specifications. The film processing was standardized according to the film type by using an automatic processor for all films.

The radiographic procedure has been standardized as much as is possible, however, the Radiology Unit of the Adelaide Dental Hospital has a large staff turnover for teaching purposes.

The steps taken were:

1. Film loaded in holder.
2. Patient positioned in a standing position, looking straight ahead. Ear-rods placed in external auditory

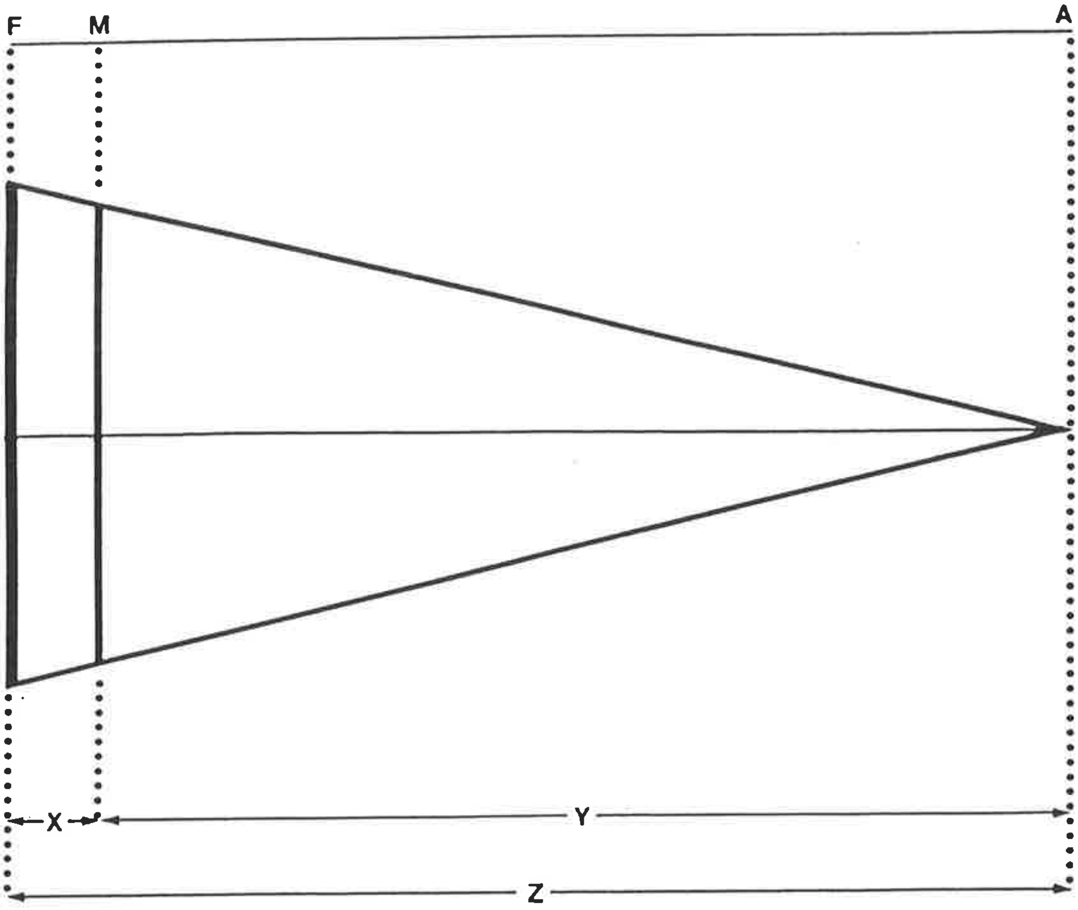


FIGURE 9. Calculation of the enlargement factor for points lying on the mid-sagittal plane. (X, Y, Z drawn to scale).

F = Film plane

M = Mid-sagittal plane

A = Focus

X = 160 mm

Y = 1818 mm

Z = 1978 mm

E = Enlargement Factor

$$E = 100 \times \left[\frac{Z}{Y} - 1\right]$$

$$= 100 \times \left[\frac{1978}{1818} - 1\right]$$

$$= \underline{8.8\%}$$

meatus, head holder adjusted upwards such that the rods exerted pressure against the superior margins of the cartilaginous meatus and the cervical spine was stretched.

3. Aluminium wedge positioned, profile completeness checked using light beam.
4. Mid-sagittal plane of the face checked in relation to the mid-sagittal plane of the head holder by using the vertical light beam.
5. Vertical head inclination adjusted to the Frankfort horizontal using horizontal light beam (at infra-orbital region).
6. Patient instructed to close teeth into centric occulusion.
7. The lip position was not standardized (the patient may have been instructed to relax their lips).
8. Exposure made.

2.3 PILOT STUDY

In order to learn the techniques involved and to eliminate any problems, the procedures listed from 2.4 to 2.9 were initially carried out using a small sample of 12 subjects (24 tracings).

2.4 TRACING AND SUPERIMPOSITION

All radiographs were traced under standardized conditions in a darkened room using a viewing screen with a light of variable intensity with curtains to reduce screen size. In addition, pieces of cardboard were used to further reduce the area of interest to facilitate landmark identification. Tracings were made with a 0.3 mm "H" clutch pencil on transparent drafting paper. The two films for each subject were viewed together. The radiographs were superimposed using the standard procedure described by Björk (1968) and in more detail by Björk and Skieller (1983) (appendix 7 and Figure 10).

The landmarks traced, symbols used, and their definitions appear in appendices 4 and 5 and Figure a of appendix 4. Where possible, landmarks located in the mid-sagittal plane have been selected. The standardized method used to identify landmarks appears in Appendix 6.

Superimposition allowed the transfer of the refence planes of the first (pre-treatment) film to the second (post-treatment) film based on the stable structures of the anterior cranial base.

The structures upon which the superimpositions were based were as follows:

1. anterior wall of sella turcica
2. anterior contours of the middle cranial fossae
3. inner surface of the frontal bone
4. contour of the cribriform plate
5. bony trabeculae, especially of the ethmoid bone

(Björk 1968, Björk and Skieller 1983, Chapter 4.3B).

These structures are depicted diagramatically in Figure 10.

This method of superimposition allowed facial growth changes to be studied in relation to the cranial base. The reference planes selected

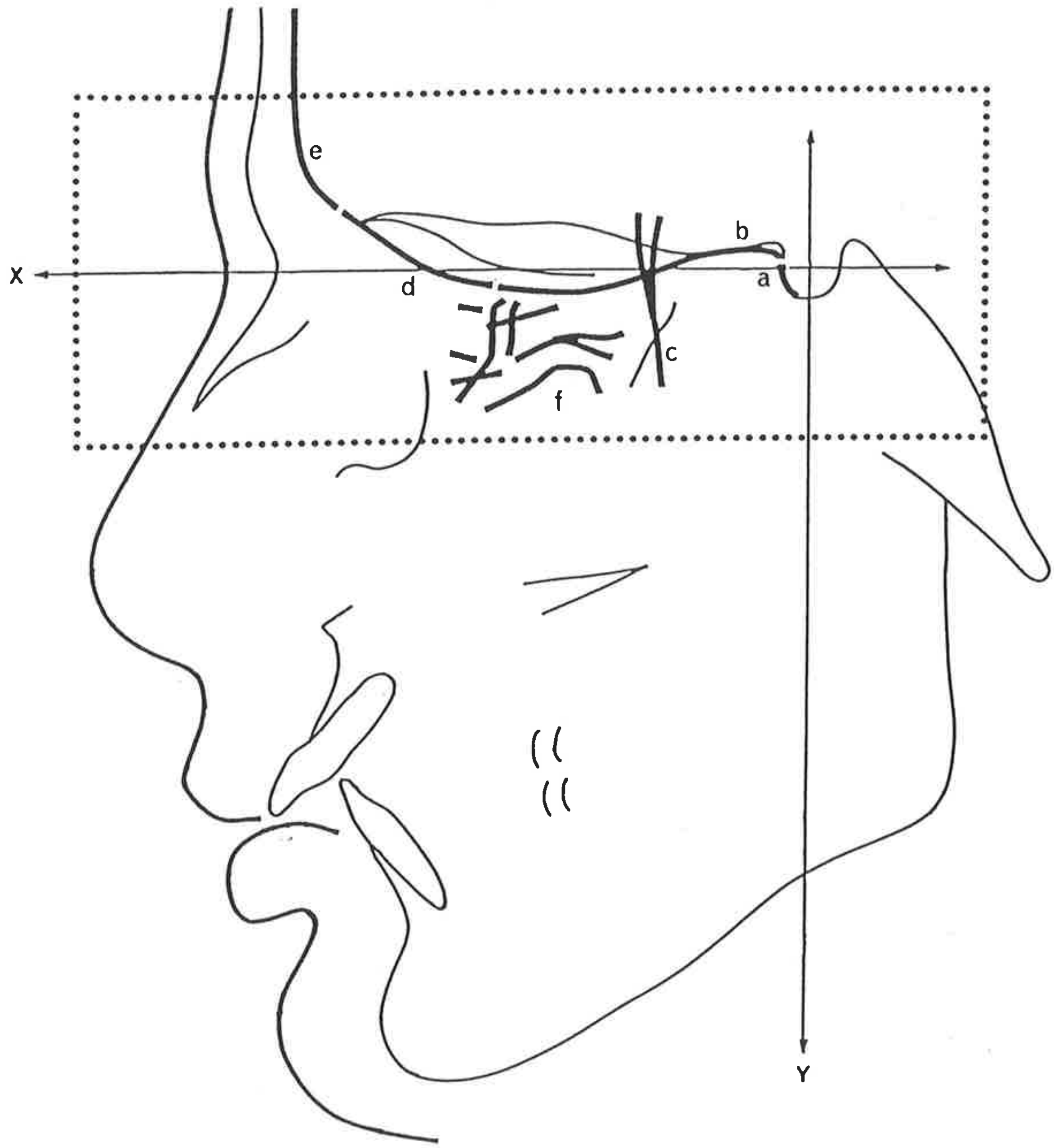


FIGURE 10. Principal structures used for cranial base superimposition.

a. anterior wall of sella turcica.
b. planum sphenoidale.
c. anterior contours of the middle cranial fossa.
d. contour of the cribriform plate.
e. inner surface of the frontal bone.
f. bony trabeculations of the ethmoid bone.

(Derived from Björk, 1968 and Björk and Skieller, 1983).

were nasion-sella (of the first film, transferred via superimposition to the second film) which formed the x-axis, and a perpendicular to nasion-sella through sella (first film transferred to second) which formed the y-axis of the cartesian coordinate system with sella at the origin. After tracing the first film and superimposing to transfer the reference system to the second film the landmarks of the second film were traced. The pre-treatment sella was registered on the post-treatment film; that is, sella on the second film was not traced.

In addition to the 120 tracings (60 subjects) made for the major study, the radiographs of 20 subjects (40 tracings) selected at random were retraced and superimposed in order to study the error of the method.

2.5 DIGITIZING

The tracings were digitized on a Hewlett Packard 9874A digitizer using a Hewlett Packard 9815A controller, the data being stored on Hewlett Packard data tapes. Programs for the acquisition, plotting and transmission of digitized data were coded by Professor T. Brown for use on Hewlett Packard 9800 series equipment. Digitizing allowed the coordinates of all landmarks in relation to the x- and y- axes to be recorded on the negative track of the data tapes in sequential files.

The procedure used for digitizing was as follows:

1. Digitizer screen cleaned using ethyl alcohol.
2. Data tape initialised and files constructed; one file per tracing.

3. Digitizing program loaded into controller.
4. Tracing mounted on screen using tape.
5. Program run:
    a. Subject's identity number and file number recorded.
    b. Axis alignment using two points on the sella-nasion line (sella and x-align).
    c. Landmarks were digitized in a specific order (appendix 4, figure a) by aligning the cursor over the landmark and pressing the button on the cursor to record the coordinates of the landmark.
    d. The controller recorded the information on the data tape and the run stopped.
6. The procedure was started again for a new tracing. (Steps 1 through 5).

Three data tapes were required (including one for the study of digitizer error).

2.6 PLOTTING

Identification information and coordinate data stored on the negative track of the data tapes were plotted on A4 size paper using a Hewlett Packard 9872A plotter and the 9815A controller. Plots were made for all tracings. The tracings were then superimposed upon the plots in order to visually check the accuracy of digitizing. This ensured that the information such as the subjects identity number, age and landmarks were recorded correctly. Plots containing "wild" landmarks were later redigitized on the same file and re-plotted until all plots accurately corresponded to their respective tracings.

2.7 TRANSMISSION OF DATA

The coordinates of the landmarks and identification information were transferred from the negative track of the data tapes using the Hewlett Packard 9815A controller fitted with a serial I/O interface to the Cyber 173 mainframe computer. A Teleray terminal "echoed" the data as they were transmitted.

The coordinates of all subjects were stored on permanent disc files and subsequently they were were listed via the Teleray terminal.

2.8 VARIABLES

The 66 linear and angular variables selected are shown in appendix 8. The 48 linear measurements were horizontal and vertical. All of the 25 horizontal measurements were perpendiculars to the y-axis (nasion-sella perpendicular, NSP) and all 23 vertical measurements were perpendiculars to the x-axis (nasion-sella, NS). The linear values were selected to show the movement of the various hard and soft tissue profile points over the period of growth and treatment after suitable statistical analyses.

The 18 angular variables based on the work of other authors were selected for completeness and for the purpose of comparison. The angular variables were subdivided into 3 groups according to the information they would provide. These groups were as follows: 9 standard angles defining the dento-skeletal pattern, 3 angles defining the soft tissue inclinations and 5 angles defining the shape or contours of the soft tissue profile.

2.9 COMPUTATION OF VARIABLES

The Fortran XYDATA program (author, Prof. T. Brown) was used to calculate the variables. Input data in the form of x and y coordinates of all points were used by the program to compute the specified variables by trigonometric functions. The enlargement 8.8% (which was constant for all films) at the midsagittal plane was compensated automatically during computation of the linear variables to produce a result in millimetres. The value of angular variables did not change with enlargement (Hixon, 1960). The program allowed for the angular variables to be displayed in the appropriate way (for example, an acute angle could be described in terms of the value n or 180^{o}–n). The print out was checked for accuracy by hand measuring from the plots and/or tracings. All angular variables were checked to ensure that they had been calculated in the appropriate way.

A program was written (author, W. Schwerdt) to calculate 180^{o}–n value of the angles for variable numbers 51, 52 and 53 since the existing program did not allow for this calculation if the angles were specified using 4 points. The occasional angles which fell out of the usual range and had values around 90^{o} were edited (180^{o}–n) using the on-line facilities of the Cyber.

2.10 STATISTICAL EVALUATION

To enable a comprehensive evaluation of the data descriptive statistics were computed for all 67 variables (including age) according to the usual procedures (Croxton, 1953):

$\bar{x}$ Mean $\frac{\Sigma x}{N}$

V Variance $\frac{\Sigma(x - \bar{x})^2}{N - 1}$

S Standard deviation $\sqrt{\frac{\Sigma(x - \bar{x})^2}{N - 1}}$

E(M) Standard error of the mean $\frac{S}{\sqrt{N}}$

$\sqrt{b_1}$ Skewness

Calculated from the second and third moments of the deviations from the mean according to:

$$\sqrt{b_1} = \sqrt{\frac{N.[\Sigma(x - \bar{x})^3]^2}{[\Sigma(x - \bar{x})^2]^3}}$$

(Pearson and Hartley, 1954)

b_2 Kurtosis

Calculated from the second and fourth moments of the deviations from the mean according to:

$$b_2 = \frac{N.\Sigma(x - \bar{x})^4}{[\Sigma(x - \bar{x})^2]^2}$$

(Pearson and Hartley, 1954)

where: x = observed score
N = the number of determinations

These statistics were calculated for the male sample (N = 30) and the female sample (N = 30) separately. Calculations were made for all variables before treatment, after treatment, and for the differences between the before and after treatment values.

To determine sex differences for all variables, tests of significance were made between the male and female samples for values before treatment and for the differences before and after treatment. The tests were computed in the following way:

E(M diff)	Standard error of the mean difference	$\sqrt{\frac{\text{diff}^2 - (\text{mean diff})}{n - 1}}$
t	Student's paired t-test	$\frac{\text{mean diff}}{\text{E(M diff)}}$
F	Snedecor's F-ratio test	$\frac{V_1}{V_2}$

where: diff = the difference between the two determinations.

N = the number of determinations.

V_1 = the larger of the two V values.

V_2 = the smaller of the two V values.

To assess the strength of relations between the 67 variables, correlation coefficients were calculated in the following way:

r Correlation coefficient $$\frac{\Sigma(x - \bar{x})\,(y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2\Sigma(y - \bar{y})^2}}$$

where: x and y are the observed scores.

Coefficients were calculated for the following groups of data; before treatment, after treatment, and differences before and after treatment. Values of r were calculated for males and females separately. Therefore, 6 matrices each with 67^2 r values were obtained.

Z-scores or standard scores were calculated for all variables for each of the 60 subjects as a measure of an individual's position as the number of positive or negative standard deviations from the mean.

Z Z-score $\frac{x - \bar{x}}{S}$ (Garn, 1958)

2.11 ERROR STUDY

A group of 20 subjects were selected at random from the total sample (9 females and 11 males). The methodology used was that of sections 2.4 through 2.10. The purpose was to study the error of the method of tracing and superimposition.

The 20 subjects selected to study the error of tracing and superimposition were compared to the same subjects of the main study after basic descriptive statistics were calculated for each group. This enabled tests of error of the two determinations to be performed.

From the 20 subjects which were retraced for the second determination, 10 were redigitized (Chapter 2.5) and steps 2.6 through 2.10 were followed in order to study the error of digitizing.

The tests used to analyse the error of the method of tracing and superimposition (including digitizing), and the error of digitizing only, were as follows:

M diff	Mean difference between two determinations.	$\frac{\Sigma diff}{n}$
S(error)	Standard deviation of a single determination (Dahlberg, 1940).	$\sqrt{\frac{diff^2}{2n}}$
E(var)%	Error variance per cent	$\frac{S(error)^2 \times 100}{S^2}$
t	Student's t-test	
E(M diff)	Standard error of the mean difference.	

The formulae for the standard deviation S, t and E(M diff), and abbreviations were presented in 2.10 above.

CHAPTER 3

RESULTS

3.1 INTRODUCTION

The detailed statistical tables providing results corresponding to this chapter have been placed in Section 2 of the second volume (appendicies 9 to 15). Appendicies 10 and 11, 12, and 13 corresponding to sections 3.3, 3.4, and 3.5 respectively, have been divided into several smaller tables depending on the type of variable. Linear (horizontal and vertical) location of hard and soft tissue landmarks in relation to the reference planes NSP (nasion-sella perpendicular) and NS (nasion-sella) are provided in the first four tables in each of these appendices. Angular variables are provided in the fifth (dentoskeletal) and sixth (soft tissue inclinations and contours) tables of each appendix. The terminology for the soft tissue angles was derived from Burstone (1958) and refers to angles of soft tissue points to the underlying skeleton (inclinations) and angles involving soft tissue points only (contours).

An extensive table of correlation coefficients has been included to allow detailed observations of sex differences and trends within the data.

3.2 AGES OF SUBJECTS

(Text accompanies Appendix 9)

Appendix 9 summarizes the ages at which radiographs were obtained before and after treatment. Statistics for the precise ages at the bands-on and bands-off stages of treatment were not calculated because a complete set of hospital case-notes could not be obtained. On average, the ages of males and females before and after treatment were similar. However, because of the different maturational experiences of males and females at this age, different growth responses would be anticipated.

3.3 ERROR OF THE METHOD

A. Tracing and Superimposition.

(Text accompanies Appendix 10)

"Whenever measurements are used in scientific research, limitations in techniques give rise to errors of estimation which are included in the observed variability", (Brown, 1965).

In order to justify the use of the technique the error of the method was studied. The source of errors and how these effect the true values will allow for a more complete and accurate evaluation of the results of orthodontic treatment on the profile structures of the face. The statistics used to evaluate error were presented in Chapter 2.11.

These results include all sources of error. That is, the location of landmarks, superimposition (for tracings where this was done), projection and digitizing errors were all reflected in the results. The double determinations allowed for the reliability of all parameters to be assessed.

The first and second determinations were compared using a student's "t-test" with 39 degrees of freedom. This enabled the hypothesis that the mean difference did not alter significantly from zero to be tested. The five and one percent levels of probability were used to assess the significance.

Variables 2, 28, 45 and 60 all differed significantly from zero at the 5% level of probability. Variables 17, 26, 47, 54 and 59 all differed significantly from zero at the 1% level. This finding indicates that the horizontal location of lower incisor incisal edge (17), the vertical location of soft tissue nasion (26), the vertical location of upper molar mesial contact (47), the occlusal plane to sella-nasion angle (54) and the sella-soft tissue nasion-superior labial sulcus angle (59) were subject to a significant component of error and therefore were all found to be unreliable variables. However, all cases except the vertical location of the upper molar mesial contact (47), the mean difference was less than 0.5 mm for linear variables and less than 1^o for angular variables. A consideration of the other linear variables indicated that the vertical location of A point (37) had the next greatest mean difference (0.5 mm) for the linear variables. No angular variables had mean differences exceeding 1^o. Those for occlusal plane to sella-nasion (54), nasolabial angle (64), concavity of the upper lip (65) and concavity of the lower lip (66), however, exceeded 0.5^o.

An examination of the E(var)% indicated a generally low effect of error on the sample means. The majority of variables were lower than 5%. Those exceeding 5% were the vertical location of nasion (37), the palatal plane to sella-nasion angle (50), the occlusal plane to sella-nasion angle (54), A point-nasion-B point (57), soft tissue convexity

(58) and concavity of the upper lip (65). This indicated that these variables were relatively more difficult to determine. This was also indicated by the general trend of these variables to have relatively greater standard deviations.

B. Digitizing.

(Text accompanies Appendix 11)

Digitizing error was due to the uncertainty of the operator in placing the cursor of the digitizer over the point representing the landmark on the tracing, and the accuracy of the machine in recording the coordinates of the point. The accuracy of the machine was expected to be high.

According to the Hewlett Packard 9874A digitizer handbook the accuracy of the cursor is ±0.00492" and of the stylus 0.01969" at temperatures of 10 to 40^{o} C. The repeatability of the cursor is 0.00984" and of the stylus 0.01181".

Chapter 2.11 displays the statistics used to assess the significance and extent of digitizing error. This was calculated by comparing the same tracings of 10 subjects (20 tracings). The statistics used were identical to those used to assess the error of tracing and superimposition.

The two determinations for variables 17, 32, 43, and 45 differed significantly from zero at the 5% level. Only for one variable (2) did the two determinations differ significantly from zero at the 1% level.

Since approximately this number of mean differences could be expected to differ significantly from zero by chance alone, digitizer error did not bias the technique to any noticeable extent and where present it would probably be due to uncertainty of the operator rather than a machine inaccuracy.

The effect of digitizing error on the results was negligible. No M diff exceeded ±0.05 mm for linear measurements and 0.32^{o} for angular measurements. Indeed, for most measures the M diff was usually in the range of 0.00 to ±0.03.

The E(var)% also indicated a negligible effect of digitizing error on the sample variances. For most variables the E(var)% was about 0.00 to 0.03%. However, two variables, the horizontal position of nasion (37) and occlusal plane - SN (54), had E(var)% values exceeding 1%. The digitizing error was non-significant in each instance, however.

3.4 SIGNIFICANCE TESTS OF MALES vs. FEMALES

A. Pre-treatment

All variables calculated from the pre-treatment records were compared between males and females using t and F-ratio tests. Tables showing sex differences have not been included. In general, there were no significant differences between the male and female mean values before treatment. Only two linear variables, the horizontal location of subnasale (3) and the vertical location of labrale superius (30) differed significantly between the sexes at $p < 0.05$. The mean values in the males were larger by 1.7 mm for both variables. Only one angular variable SLS-NAS-ILS (61) showed a significant sex difference ($p < 0.05$). The means of both samples can be compared by studying tables A and B of Appendix 13.

Several values of F showed significant differences, indicating some sex differences in variances before treatment (variables 1, 2, 12, 23, 50, 51, 53, 58, and 59 at the 5% level and variables 29, 52, 55, 57, and 60 at the 1% level). In all but two variables (upper incisor to S-N, 51, and S-NAS-ILS, 60) was the variance greater in males.

B. Pre- and Post-treatment differences

(Text accompanies Appendix 12)

The t and F-ratio tests were used to assess the significance of differences between males and females of the data calculated from the post-treatment minus pre-treatment records. (Chapter 2.10). In contrast to the pre-treatment comparisons, many more variables displayed significant differences after growth and treatment.

An examination of Tables C and D reveals that most of the vertical locations of the soft and hard tissue landmarks differed significantly between the sexes at the 1% level (except variables 27, 39, and 41 which were significant at the 5% level and variables 26, and 37 which were not significant); all the mean values were greater in males. Fewer horizontal differences displayed significant sex differences (Tables A and B). Soft tissue nasion (1), pronasale (2) and nasion (12) showed significantly more change in males at the 1% level, while upper incisor apex (14) and lower incisor apex (19) showed greater horizontal change or displacement in males at the 5% level of significance. No angular variables showed significant sex differences. All variables with significant difference demonstrated larger mean values in males.

The F-ratios disclosed some significant sex differences in variances, mainly at the 1% level. The horizontal change of pronasale (2), subnasale (3), superior labial sulcus (4), labrale superius (5), inferior aspect of upper lip (6), and labrale inferius (8), were significantly more variable in males at the 1% level. This was also present for the vertical changes of subnasale (28) and superior labial sulcus (28) at the 1% level and labrale superius (30), at the 5% level. Trends were not as obvious for other variables. The horizontal and vertical changes of the upper incisor edge (16 and 41 respectively), for example, showed greater variance in the females for vertical change and greater variance in males for horizontal change at the 1% level. Other variables having unequal variances were the horizontal changes of A point (13) and prosthion (15), the vertical change of anterior nasal spine (38), palatal plane to S-N (50), SNA (55), convexity excluding nose (62) and nasolabial angle (64), all at the 1% level. The variances of horizontal changes of lower incisor incisal edge (17) and gonion (25), and vertical change of upper molar (47), all differed significantly between the sexes at the 5% level. All of these variables displayed greater variance in males except convexity excluding nose (62). Vertical change of upper incisor incisal edge (41) had only a slightly greater variance in males than females. This can be observed by comparing the E(M) values in Appendix 12 and the standard deviation values in Tables E and F of Appendix 13.

There was a general trend for the changes to be greater in males than females, and in many instances the sex difference in response was significant. This trend was most obvious for the vertical location of hard and soft tissue profile landmarks. The males also tended to show more variablility in the changes that occurred, especially in the horizontal change of soft tissue profile variables. Only two variables with a significant sex difference in variance demonstrated greater variance in the female sample.

3.5 DESCRIPTIVE STATISTICS

(Text accompanies Appendix 13)

Appendix 13 is divided into Tables A and B for the pre-treatment values for males and females respectively, Tables C and D for the post-treatment values for males and females respectively, and Tables E and F for the statistical analysis of post-treatment minus pre-treatment values in males and females respectively.

Values for skewness and kurtosis were calculated for each variable, but values have not been provided in the tables. The statistical significance of kurtosis values could not be assessed since the sample size was too small (Pearson and Hartley, 1954 provided tests for sample sizes of 200 and more). However, observation of the values for kurtosis indicated that the sample generally conformed to a normal kurtotic relationship. Although values for skewness have not been included, the sample size of 30 each for males and females allowed statistical tests of skewness, and where skewness (either + or -) was present at the 5% or 1% levels this has been indicated in the tables. In Table A only 4 variables showed significant skewness (3 at 5% and 1 at 1% levels); in

Table B there were 4 (all at 5% level), in Table C there were 3 (2 at 5% and 1 at 1% levels), in Table D there were 10 (9 at 5% and 1 at 1% levels), in Table E there were 10 (5 at 5% and 5 at 1% levels), and in Table F there were 8 (6 at 5% and 2 at 1% levels) variables displaying significant skewness. A proportion of these could be expected to occur by chance alone, and considered as a whole the amount of skewness was low. Skewness increased somewhat for the variables included in Tables E and F; however, no specific trends could be determined for this observation. The analysis of skewness and kurtosis indicated no marked trends of departure from a normal distribution so that the usual statistical procedures could be applied.

Some trends could be observed for the pre-treatment statistics in Tables A and B and the post-treatment statistics in Tables C and D. All linear variables had E(M) values of < 2 mm. All angular variables had E(M) values < 2^{o} except variables 64 (nasolabial angle), 65 (concavity of upper lip), and 66 (concavity of lower lip) which tended to be near or exceed 2^{o} in these tables. The values for variable 53 also tended to be increased somewhat. Throughout these tables variables 26 (V ST nasion), 37 (V HT nasion), 50 (palatal plane to S-N), 57 (ANB) and 58 (convexity) all tended to have large standard deviations compared to their small mean values. Variable 1 (H ST nasion) tended to have a small standard deviation in Tables A(i) and B(i). All variables tended to have ranges not exceeding of 4 to 6 standard deviations from the mean.

With respect to the data shown in Tables E and F representing the morphological changes between pre- and post-treatment records, the trends appeared to differ from those shown in previous tables. The standard deviations for all variables tended to be large in comparison with the small $\bar{x}$ values. In all cases the E(M) was < 1 mm for linear values and in the majority of cases was < 0.5 mm. In the case of the angular variables, all were < 2^{o} except that variables 53, 64, 65, 66 (also indicated in previous paragraph) which tended to exceed or be near 2^{o}. All variables had a range which was in the order of 4 to 6 standard deviations from the mean.

In discussing specific variables, Tables E and F provide the information which is of the most interest.

(Text accompanies Appendix 13, Tables E and F)

Figure 11 shows a diagramatic representation of the mean pre- and post-treatment location of several of the hard and soft tissue landmarks. This diagram allows a comparison of the pre- and post-treatment situations and the changes that have occurred due to growth and treatment. In both males and females a generally downward and forward growth pattern (with a larger downward component) can be observed with relation to the cranial base. The extent of this change was greater in males and is particularly obvious in the amount of spacing between the pre- and post-treatment soft tissue profiles and the lower border of the mandible. Superimposed upon the growth changes were the treatment changes centred around the incisor region. A downward and backward movement of the upper incisors especially, and the lower incisors has resulted. In the region of the lips the generally downward and forward growth pattern has been redirected downwards and backwards as the lips have tended to follow the incisor retraction somewhat.

The tables show that the upper incisors were retracted (variable 16) with a $\bar{x}$ of -6.1 mm in males and -5.8 mm in females. On average the incisal edge did not move forwards in females (range -10.4 to -2.3 mm) while in males some net forward movement occurred in some subjects, (range -13.0 to 0.9 mm) probably due to the downward and forward growth pattern. Similar changes occurred in the retraction of the lower incisors (variable 17) except that the $\bar{x}$ was lower (-1.6 mm in males, -0.9 mm in females, with no statistically significant sex difference (appendix 12B), and there was more tendency for forward movement (range -6.7 to 3.8 mm in males and -5.4 to 1.9 mm in females).

The apices of the upper incisors (variable 14) tended to retract ($\bar{x}$ -2.6 mm in males and -1.5 mm in females) with a range from retraction to forward movement. The mean retraction of the upper incisor apex was less than that of the incisal edge and the upper incisors therefore were more retroclined after treatment (Figure 11). This was confirmed by the reduction of the angle of the upper incisor to S-N (51) ($\bar{x}$, -8.1° in males and -10.0° in females). The lower incisors had a tendency to become more protrusive after treatment since the root apex (variable 19) tended to retract more than the incisal edge. This was confirmed by the increase of the angle of the lower incisors to the mandibular plane ($\bar{x}$, 5.0° in males and 5.3° in females). The interincisal angle (53) increased slightly therefore, due to upper incisor uprighting ($\bar{x}$, 1.8° in males and 4.1° in females) and lower incisor proclination.

The upper lip had a tendency for retraction (variables 4, 5 and 6) which tended to be greater as the distance from the nose increased. For example, superior labial sulcus (4) retracted with a $\bar{x}$ of -1.1 mm in males and -1.5 mm in females while inferior aspect of upper lip (6)

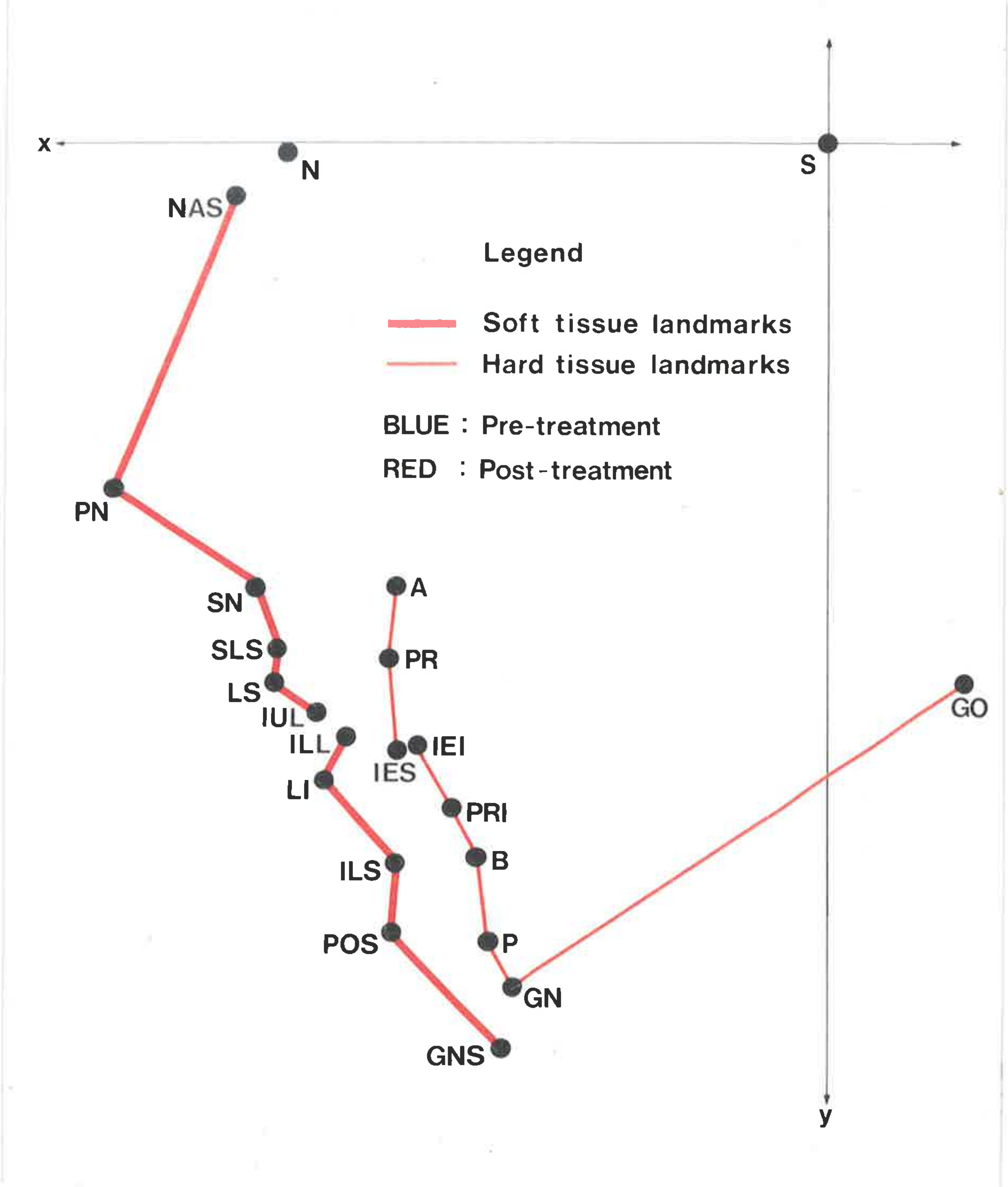


FIGURE 11A. Legend for figures 11B and 11C which depict the mean locations of selected hard and soft tissue profile landmarks calculated before and after treatment. Landmark abbreviations are listed in appendix 4.

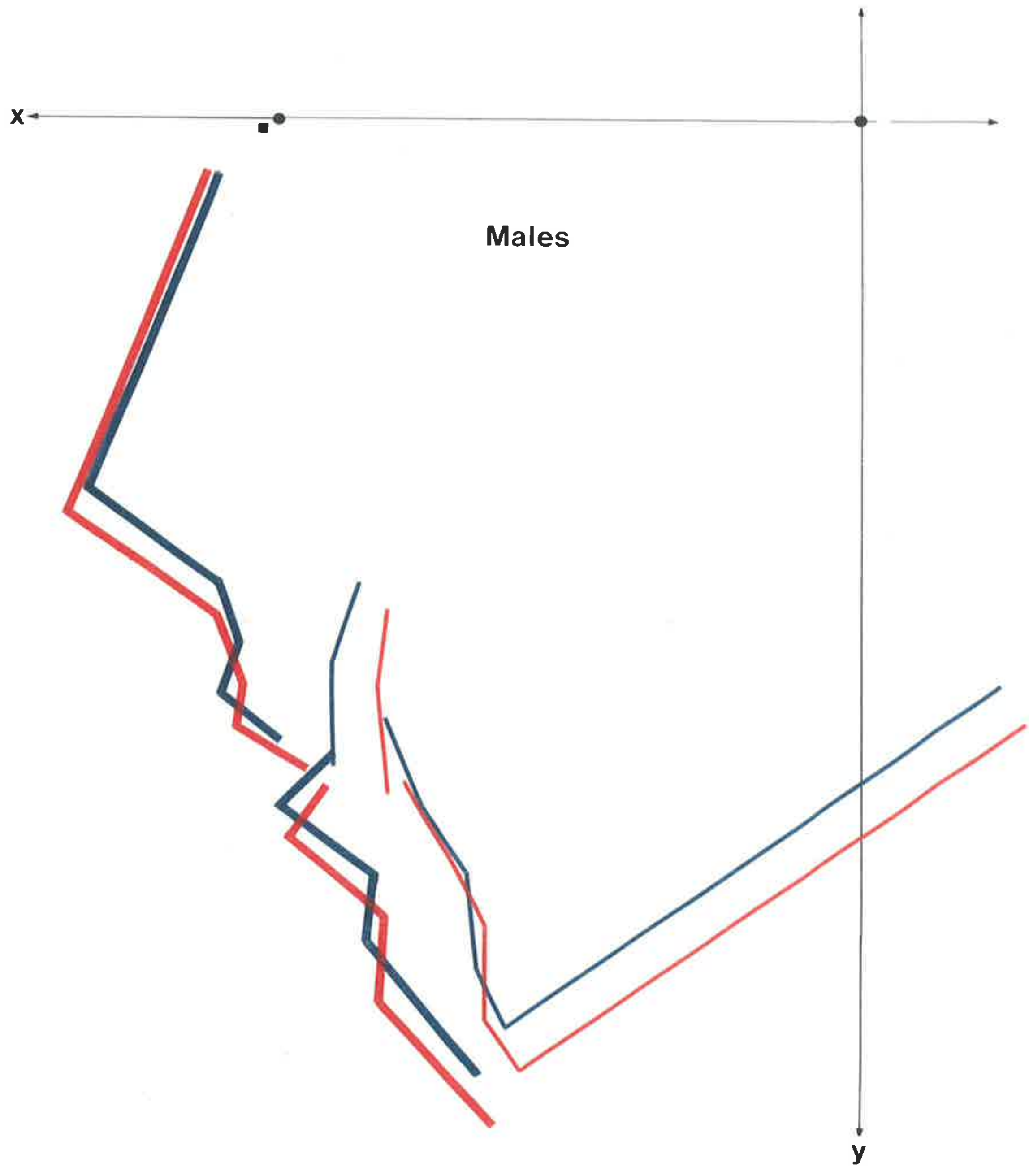


FIGURE 11B. Diagram depicting mean locations of hard and soft tissue profile landmarks calculated before and after treatment in males.

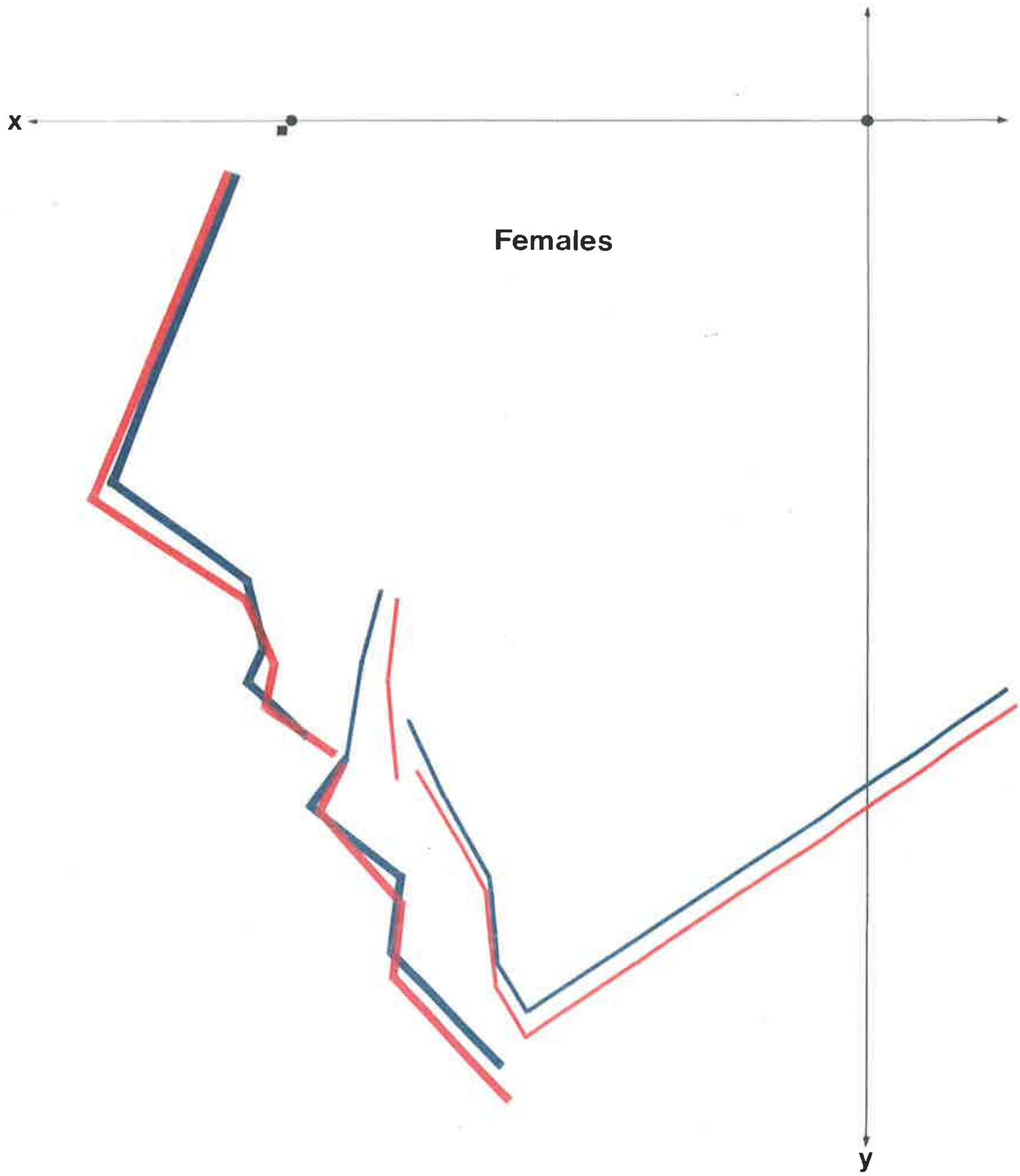


FIGURE 11C. Diagram depicting mean locations of selected hard and soft tissue profile landmarks calculated before and after treatment in females.

retracted with a $\bar{x}$ of -2.7 mm in males and -3.3 mm in females. The ranges of these variables indicated that a larger retrusive or smaller protrusive movement could occur (indicated by the sign, + or -). The lower lip had less tendency for retraction (variables 7, 8 and 9). In males the superior aspect of the lower lip (7) showed a tendency for some forward movement ($\bar{x}$, 0.5 mm). The range of upper and lower lip movement tended to be greater in males.

The soft tissue points above the upper lip displayed a tendency for a small amount of forward movement (variables 1, 2 and 3). The range was from slight retraction to forwards movement and tended to be larger overall for males. Subnasale (3) however tended to show more tendency to retract. The soft tissue chin points (variables 10 and 11) showed a small negative movement on average. This tended to be similar in magnitude to the small amount of negative movement of the corresponding hard tissue chin points (variables 21 and 22).

The convexities of the lips changed after treatment (variables 65 and 66). The upper lip tended to increase in concavity ($\bar{x}$, -5.3^{o} in males and -2.0^{o} in females) while the lower lip showed a tendency to flatten ($\bar{x}$, 7.8^{o} in males and 7.3^{o} in females). However, both the standard deviation and range was high.

The nasolabial angle (64) tended to increase ($\bar{x}$, 6.7^{o} in males and 5.2^{o} in females), as the nose moved forwards, the upper lip back, and subnasale changed little in relation to the cranial base.

The skeletal convexity (58) flattened after treatment. The ANB angle (57) was also reduced ($\bar{x}$, -2.5^{o} in males and -2.1^{o} in females) which was largely due to a reduction of SNA compared to little change of

SNB (variables 55 and 56). This was due to a greater retraction of A point than B point (compare 13 and 20). The soft tissue convexity excluding the nose (62) flattened slightly ($\bar{x}$, 1.2^{o} in males and 1.7^{o} in females) while the convexity including the nose (63) tended to become slightly more convex, especially in males ($\bar{x}$, -1.0^{o} in males and -0.1^{o} in females, no statistically significant sex difference; appendix 12F). The soft tissue angles S-NAS-SLS, S-NAS-ILS and SLS-NAS-ILS (variables 59, 60 and 61) tended to show a similar pattern of change to their corresponding skeletal SNA, SNB and ANB (55, 56, 57) variables.

The mandibular plane to S-N (49) showed only a small tendency to open ($\bar{x}$, 1.2^{o} in males and 0.4^{o} in females). Although the occlusal plane (54) increased, it should be noted that the occlusal plane was measured using the incisal edge of the upper incisor and the mesial contact of the upper molar and the increase in angle was largely due to the downward and backward movement of the incisal edge of the upper incisor (16, 41) combined with a downwards and forwards movement of the upper molar (23, 47). The palatal plane (50), showed minimal change ($\bar{x}$, 0.6^{o} in males and 0.2^{o} in females).

As reported earlier (Chapter 3.4B) the extent of change in the vertical linear dimensions were generally greater in males than females. In both males and females the lower incisor edge (42) moved downwards further than any of the lower lip points. This can be seen diagramatically in Figure 11. The upper incisor and upper lip points however showed similar vertical changes (variables 39, 40, 41 and 28, 29, 30, 31). The vertical movement of the hard and soft tissue chin points were similar. No points on the soft tissue of the upper face would be expected to move upwards in relation to the reference system as a result of growth or treatment. However, some small negative values for the differences between pre- and post-treatment records were recorded for individual subjects, most likely due to difficulties in landmark locations and the change in contours of curved surfaces of large radius with growth and treatment. This will be discussed more fully in Chapter 4.4A.

The ratios of incisor to lip retraction based on the horizontal change of landmarks representing the upper and lower lips and incisors are presented in appendix 14.

3.6 CORRELATION COEFFICIENTS

A. Introduction

(Text accompanies appendix 15)

Coefficients of linear correlation were computed to assess the strength of relations between the variables. The tables of correlation coefficients between the variables representing the change from pre-treatment to post-treatment records have been placed into four groups. The number of tables in each group diminishes as coefficients were included in previous tables. Those coefficients relating to linear soft tissue variables have been considered to be the most important group. For this reason coefficients involving horizontal soft tissue variables have been listed first, and then those involving vertical soft tissue variables, angular soft tissue variables, and then linear hard tissue variables.

In the tables, coefficients differing significantly from zero at the 5% and the 1% levels have been indicated * and ** respectively. In a consideration of the value of coefficients, coefficients differing from zero at the 5% and the 1% levels were arbitrarily classified as follows: "high" correlation, $r > 0.80$; "moderate" correlation, $0.80 > r > 0.40$; "low" correlation, $r < 0.40$, disregarding sign and according to Garn (1958) and Grave (1971).

Correlations commonly reported in the literature have been indicated by outlining the relevent values in appendix 15 for comparison with the previous literature, listed in appendix 2.

A full discussion of the interpretation and importance of correlation coefficients will be found in Chapter 4.7A. The numerical values of correlation coefficients were interpreted cautiously, particularly where the sharing of common landmarks or reference structures was likely to result in speciously inflated values (Solow, 1966).

Tables have not been provided for correlations within and between the variables calculated pre-treatment or post-treatment.

B. <u>Correlations involving horizontal soft tissue variables</u>

(Text accompanies appendix 15A)

Table (i) contains coefficients for horizontal soft tissue differences before and after treatment. Many of the coefficients were moderate to high and significant at the 1% level since "specious" correlations were often involved (Chapter 4.7A) (for example those involving 9, 10 and 11 with each other). Coefficients involving the lips (4, 5, 6, 7, 8, 9) and chin (10,11) tended to be moderate, but only in males. Coefficients involving the nose (1, 2, 3) and lips (4, 5, 6, 7, 8, 9) tended to be low to moderate, were higher for those involving subnasale (1), and some sex differences were present. Coefficients involving nose (1, 2, 3) and chin (10, 11) were significant and moderate in value with some sex differences.

Table (ii) lists the coefficients between horizontal and vertical soft tissues. Most of the values were low and non-significant. Some moderate correlations were present between variables 1 and 2 (nose) and the vertical variables.

Table (iii) includes coefficients between horizontal soft tissue and horizontal hard tissue variables. Some high correlations were found, especially in the region of the chin for both the males and females.

The coefficients involving superior labial sulcus (4) tended to be moderate for many upper and lower incisor variables with some sex differences. The correlations with A point (13) and root apex of upper incisor (14) were moderate in males but low in females. Correlations with prosthion (15) and upper incisor incisal edge (16) were moderate in both sexes.

Correlations involving labrale superius (5) tended to be moderate with upper and lower incisor variables in both sexes. Moderate correlations were noted between labrale superius and A point (13) and the upper incisor root apex (14) in males only while moderate correlations were present in both sexes between variable 5 and prosthion

(15) and incisal edge of the upper incisor (16) in both sexes. The pattern therefore was similar to that of superior labial sulcus (4). The inferior aspect of the upper lip (6) had a similar pattern of correlations to those involving variables 4 and 5 as reported above.

The superior aspect of the lower lip (7) had a sparser distribution of significant correlations compared to the other lip variables. Moderate correlations were found with incisal edge of the lower incisor (16) and inferior prosthion (17) in females only, and with root apex of the lower incisor (19) and B point (20) in males only.

Labrale inferius (7) had moderate correlations with incisal edge of the upper incisor (16), incisal edge of the lower incisor (17), infradentale (18) and root apex of the lower incisor (19) in both sexes. Several other moderate correlations were found with other upper and lower incisor related points but in males only.

The inferior labial sulcus (9) demonstrated moderate correlations with the following variables in both sexes: infradentale (18), root apex of lower incisor (19), and B point (20).

High correlations in males (moderate in females) were found between the hard and soft tissue chin points.

Table (iv) contains coefficients between horizontal soft tissue and vertical hard tissue variables. Overall, there was a low pattern of correlation. Some moderate correlations were concentrated in relation to soft tissue nasion (1) and pronasale (2).

Since the same landmark could be involved for correlations between horizontal soft tissue and angular soft tissue variables (Table v), some reservations should be expressed regarding the interpretation of the coefficients (Chapter 4.7A). For example, a moderate correlation was found between superior labial sulcus (4) and S-NAS-SLS (59) largely because the superior labial sulcus landmark was common to each measurement. For a similar reason moderate to high correlations existed between the upper lip variables 4, 5, and 6 and nasolabial angle (64).

Table (vi) contains coefficients calculated between horizontal soft tissue points and dentoskeletal angular variables. In general there was a large distribution of low correlations. Negative and moderate correlations between variables 9, 10 and 11 (lower lip sulcus and soft tissue chin) with mandibular plane to S-N (49) occurred largely because the soft and hard tissue chin points have been shown to maintain a relatively constant relationship. However, some negative and moderate correlations were found between the mandibular plane to S-N (49) and several soft tissue profile variables in males only. A similar pattern of positive correlation was observed between the angle SNB (56) and the soft tissue variables.

C. <u>Correlations involving vertical soft tissue variables</u>

(Text accompanies appendix 15B)

Many moderate and several high correlations were calculated between vertical soft tissue variables (Table (i)). Many of these occurred because similar amounts of vertical growth of proximate soft tissue points could be expected. Moderate to high correlations were found for example, between variables involving the nose and upper lip and lower lip and chin. Some moderate correlations were also present between more distant areas such as chin and nose. Sex differences were apparent, and the overall trend was for a moderate correlation of vertical growth between the soft tissues of the facial profile. A notable exception however was soft tissue nasion (26) which displayed mainly small negative correlations with other variables.

In the main, correlations between the vertical soft tissue and horizontal hard tissue differences were low (Table (ii)). Some moderate correlations were found between variables 12, 13, 14, 15, 16, 17 and 18 (nasion and upper and lower dentoalveolar points) and variables 27, 28, 29 and 30 (nose and upper lip). However a sex difference was generally apparent, with a trend for coefficients to be low for females. Some moderate correlations were also present between gonion (25) and several soft tissue varibles, with less sex difference. These results may suggest some correlation between vertical upper soft tissue face change and horizontal changes of the dentoskeletal areas of the face, especially in males.

Table (iii) contains coefficients between vertical hard and soft tissue variables. By far the majority of coefficients were moderate. The notable exceptions were those involving nasion (37) and soft tissue nasion (26). Some lower values were also found involving superior labial sulcus (29) in the area of the lower incisor and chin, especially in females (this has also been found in many of the previous tables). In summary therefore, there was a definite overall trend for the vertical hard and soft changes in the face to be moderately correlated in males and females.

Many low negative correlations were observed between vertical soft tissue and soft tissue angular variables (Table iv). Comments made earlier regarding the higher expected correlation between a vertical and angular change involving the same landmark apply. For example the nasolabial angle (64) had moderate correlations with subnasale (28) and labrale superius (30) in males.

Table (v) contains coefficients between vertical soft tissue variables and dentoskeletal angles. Some moderate correlations were found between superior labial sulcus (29) and lower incisor to the mandibular plane (52), interincisal angle (53), occlusal plane (54), SNA (55), ANB (57) and NAP (58), in males only. The same was true of labrale superius (30) and interincisal angle (53), occlusal plane (54), ANB (57) and NAP (58). A correlation was suggested between vertical upper lip change and dentoskeletal profile changes.

D. Correlations involving soft tissue angular variables

(Text accompanies appendix 15C)

Table (i) contains correlations between soft tissue angular variables. Many of the higher correlations occurred because common landmarks were involved.

Table (ii) shows correlations between soft tissue angular and horizontal hard tissue variables. Incisal edge of the upper incisor (16) had a moderate correlation with S-NAS-SLS (59) and a negative moderate correlation with nasolabial angle (64) in both males and females. The nasolabial angle (64) also correlated moderately with prosthion (15). Profile convexity including the nose (63) correlated moderately with B point (20), pogonion (21) and gnathion (22) in males and females. Convexity excluding the nose (62) had moderate correlations with these variables in females only. Many other coefficients, as in the other tables, had large sex differences.

A lesser number of significant and moderate correlations was found between soft tissue angular and vertical hard tissue variables (Table (iii). The only moderate correlation for both males and females was between S-NAS-ILS (60) and gnathion (46).

Table (iv) displays coefficients between soft tissue angular and dentoskeletal angular variables. Several moderate correlations occurred, but once again there was a large sex difference in the value and significance of the coefficients between many of the variables. Significant negative correlations occurred between the occlusal plane (54) and convexity including the nose (63) and nasolabial angle (64) (positive in males), but the coefficients were low in males. Moderate correlations were present in males and females between SNB (56) and convexity including the nose (63).

E. Correlations involving hard tissue variables

(Text accompanies appendix 15D)

Table (i) displays coefficients between horizontal hard tissue variables. A large number of high correlations occurred between proximate (overlapping) areas, for example between variables involving the upper dentoskeletal area, the lower dentoskeletal area, and the chin. A large number of moderate, and some high correlations, were also present between vertical hard tissue variables (Table (ii)).

Table (iii) contains coefficients between the vertical and horizontal hard tissue variables. Many non-significant coefficients were found. For some variables there were several moderate correlations, such as those involving horizontal nasion (12) and gonion (25), and vertical gonion (48). The vertical variables prosthion (40), incisal edge of upper incisor (41), incisal edge of lower incisor (42) and infradentale (43) had several significant coefficients, many of them moderate in value, but mainly for the male sample.

CHAPTER 4

DISCUSSION

4.1 CEPHALOMETRIC ERROR

According to Houston (1983) the error inherent in cephalometric analysis involves the two elements of validity and reproducibility. Although conventional cephalometric measurements have been critisized by authors such as Moyers and Bookstein (1979) and Moss (1983), an attempt was made to make the study as biologically valid as possible without losing the simplicity of understanding inherent in an "conventional" cephalometric approach. Although the above authors have had valid arguments concerning cephalometric measurement, criticism of their claims was made by Zwemer (1984) and Gawley (1984) who believed that Moss's (1983) concepts were poorly communicated. Conventional cephalometric procedures were supported for ease of understanding and wide acceptance.

In the present study validity was enhanced by including a relatively large number of landmarks, and a large number of linear and angular measures (compared to other such studies) such that the results could be compared and evaluated against each other to explore the changes occurring due to growth and treatment. The validity was also enchanced by using a biologically sound method of superimposition as a basis for the reference system (Björk 1968, Björk and Skieller 1983 ; refer to Chapter 4.3B).

Houston (1983) discussed cephalometric reproducibility under the headings of systematic error and random error. Systematic errors were unique to each study and varied between different persons recording landmarks, and if the same measurements were made at different times and on different samples. For this reason, the recording of the three determinations in the error study were made several weeks apart. However, systematic error would still be present because only one person was involved in landmark recording, and the result would also have some degree of sample dependence. Systematic error therefore should be considered when comparisons are made with other studies.

Random errors were due to problems of patient positioning, soft tissue posture, variations in film density and sharpness, and errors in landmark location (Houston 1983). Random errors tended to add to the natural variability of measurements and also tended to reduce the correlation between variables.

An attempt was made to reduce random error to a low level in the present study by taking heed of the following factors (Houston, 1983). Standardized films with a constant magnification factor were used ; only films of good quality for the purpose of inspecting landmarks (especially of the soft tissues) were used ; an attempt was made to exclude cases with extreme strain of the soft tissues of the lips and chin (to eliminate some of the errors caused by variation in soft tissue posture) ; standard landmark definitions were used ; a standardized method of landmark location was devised and utilized ; plots of all landmarks were made to locate and exclude "wild" values.

4.2 SELECTION OF SUBJECTS

Several problems were encountered in selecting the sample. These were largely unforseen since this was the first study utilizing this material. The only way of identifying cases that may have been suitable for study was to refer to the post-graduate students' treatment folders. No list of patients treated in the post-graduate orthodontic programme was kept. Unfortunately the treatment folders and other patient records were found to be scattered widely in the Dental hospital, and beyond. All reasonable efforts were made to locate as many records as possible. From the available records approximately 230 patients with a Class II, division I pattern of malocclusion were identified (Chapter 2.1). The number of possible subjects was reduced to 80 on the primary basis of a complete set of radiographic records (Chapter 2.1). A complete set of hospital case-notes could not be obtained. For this reason, the ages of bands-on and bands-off were not calculated.

Appendix 3 shows that previous studies have used samples of various sizes and compositions in terms of the types of malocclusions treated. In an effort to provide some uniformity in the pattern of treatment changes that would occur in the main area of interest (lips and incisors) the sample was selected on the basis of each case having a Class II, Division I pattern of malocclusion. All cases had some degree of increased overjet.

Of necessity, the patients were aged between early and mid adolescence (Appendix 9), such that some growth potential could be expected. Thus changes occurring could be due to growth and/or treatment. The only way to remove the effect of growth would have been to use a sample of post-adolescents, such as Hershey (1972) and Rains and Nanda (1982) which was not possible in this study, or to compare values with an untreated control sample of similar ages. Some patients in the sample would be expected to have little growth potential on the basis of their age. Such a subject was included in the case analyses in Appendix 16. In particular, the female group was noted to show less overall change, especially in the vertical dimension. This difference in growth potential between the sexes in this sample will be discussed in more detail in Chapter 4.6B.

An even number of males and females was included. The patients selected could also be divided into extraction and non-extraction groups (Table 2B). Originally only non-extraction and extraction cases where four first premolars were removed were selected. Other extraction patterns were later included to provide an adequate sample size. Furthermore, it was believed that it was the actual amount of incisor retraction and not the extraction pattern which was important. Extraction space was also taken up by aligning crowded teeth and not just by incisor retraction. To measure the amount of crowding and the effect this would have on the amount of space left for retraction De Laat (1974) used an arch length deficiency measurement for the lower arch. Arch length deficiency was found to have only an indirect effect on the relationships between hard and soft tissue changes.

Further selection of cases based on the quality of the radiographs required some compromise. In general all radiographs were of good quality, with good contrast, soft tissue imaging and completeness of the profile. The selection on the basis of lip posture was of necessity largely subjective, cases being excluded on the basis of their having "obvious or excessive" lip strain. The twenty "worst" cases were excluded, leaving a final sample size of 60.

The problem of lip posture in cephalometry has been discussed by Burstone (1967), Hershey (1972), Wisth and Böe (1975), Hillesund et al. (1978), Broch et al. (1981), Oliver (1982) and Houston (1983). Although there was some concensus regarding the charateristics of lip posture there was considerable disagreement as to which lip position best allowed evaluation of growth and/or treatment changes. This topic was discussed in detail in Chapter 1.4C(i). A consideration of Appendix 3 shows that of the 23 studies of soft tissue changes due to orthodontic treatment found in the literature, only in 7 was a "standard" lip position specified as a selection criterion (these were "relaxed" lip position in 5 and "closed without strain" in 2 cases). Of the total, lip posture was not mentioned in 14 studies and in 2 studies the sample consisted of subjects with "various" lip postures. The problem of lip posture, therefore, seemed to be universal, especially where retrospective records had been used over which one had no quality control.

The sample of 60 subjects was analysed in groups of 30 males and 30 females. The sample sizes of other studies is presented in Appendix 3. The mean sample size was approximately 52 with a range of 16 (Garner, 1974) to 150 (De Laat, 1974). The sample studied by De Laat (1974) however, consisted of three groups of 50, each treated with different techniques.

The patients comprising the sample were treated by a wide variety of inexperienced operators. Stoner et al. (1956), Rudee (1964) and

Garner (1974) included only patients treated by one experienced operator. Stoner et al. (1956) further reduced operator variability by including only consecutively treated cases. However, selecting a sample on the basis of one operator may be expected to increase the operator dependence of the results, whereas a sample treated by a variety of operators may show the "more general" changes which may be attributed to the orthodontic mechanics used. The results would also be of particular interest to those involved with the Adelaide training programme, and to Begg operators in general (the sparcity of Begg studies has been noted, Chapter 1.6A). In most previous studies the patients were treated by a variety of operators, and in most instances the operators were not specified.

4.3 TRACING AND SUPERIMPOSITION

A. Error of landmark determination

The tracings for the pilot study were made on 0.003" matte acetate paper. However, because the use of this paper introduced sigificant random recording errors on the digitizer, transparent drafting paper was used with the further advantage of allowing the two tracings of one patient to be made on the same paper.

Moyers and Bookstein (1979) divided cephalometric landmarks into two types. Anatomic landmarks were described as true biologic loci identified by some feature of the local morphology and included such points as cusp tips of teeth, nasion and sella. Extremal landmarks were defined by the maximum or minimum of some geometric property and were therefore not differentiated by local properties. For example, pogonion was described as being the most anterior point on the chin. As the structure of interest rotated the extremal landmarks would be expected to move. This showed that points should be defined according to certain reference structures. Because the landmark definitions (Appendix 5) often only loosely defined the exact location of landmarks, (Moyers and Bookstein, 1979) Appendix 6 was included to show how each of the landmarks was identified. None of the studies of soft tissue changes due to orthodontic treatment cited in Appendix 3 detailed their method of landmark location.

Baumrind and Frantz (1971a), Miller and Baumrind (1973) and Houston (1983) considered that more rigorous landmark definitions were important to reduce error. No standard method of landmark location has been accepted, and although a number of attempts have been made to improve the precision of definitions, the problem has remained and must be recognised (Houston, 1983).

The Cartesian coordinate system was selected with its origin at sella point and the x- axis coincident with the nasion-sella line. With this system the x- and y- axes, namely the nasion-sella line and a perpendicular to it, became reference lines from which to locate and measure the positions of the extremal reference points. One disadvantage of this system was that the slope of the sella-nasion line in relation to other cranial structures and the natural head posture would be expected to show considerable variation (Moorrees and Kean, 1958; Marcotte, 1981). However, the use of the nasion-sella line would be expected to be more reproducible and accurate than, for example Frankfort horizontal according to such studies as Salzmann (1960), Brown (1965), and Baumrind and Frantz (1971a and b). However, Ricketts et al.

(1976), reported that Frankfort horizontal was as reproducible as nasion-sella. The advantage of using a plane such as Frankfort horizontal would be that it approximated the true horizontal position of the head (Ricketts et al., 1976) and extremal landmarks would be located according to an orientation in which the profile would best be viewed (Moorrees and Kean, 1958). Unfortunately, the retrospective records used in this study had no record of the patient's natural head posture which was reported to be accurately reproducible by Moorrees and Kean (1958) and Siersbaek-Nielsen and Solow (1982). Showfety et al. (1983) described a simple method of recording natural head position.

The landmark definitions provided in Appendix 5 were derived from the standard references of Krogman and Sassouni (1957), Björk (1960), Graber (1972) and Riolo et al. (1974), in order to provide accurate definitions and clarification of any inconsistencies.

The landmarks selected are listed in Appendix 4. All points were located in on the mid-sagittal plane so that the magnification factor was constant, except for gonion and the two molar points, which were located as the mid-point of right and left structures. All landmarks were selected after a consideration of both the necessity for describing a region of interest and the accuracy of the landmark. Landmarks which were expected to be less accurate (such as lower incisor root apex, gonion, anterior and posterior nasal spines) were chosen because they were necessary to define parameters of interest. A study of the influence of error of landmark location was allowed for in the methodology (Chapter 2.11).

Salzmann (1960) noted that all landmarks were variable in their accuracy of location. Hixon (1960) believed that all films for the same patient should be viewed at the same time in order to compare landmark location. This was necessarily done in this study since only two films were used for each subject and these were superimposed. Sekiguchi and Savara (1972) believed that the problem of landmark variation involved 1. radiographic technique (standardization had reduced the effect of this factor), 2. anatomic complexities, and 3. location of landmarks during tracing.

The studies of Richardson (1966), Baumrind and Frantz (1971a and b), Sekiguchi and Savara (1972), Mitgard et al. (1974) and Broch et al. (1981) indicated that not all cephalometric landmarks had the same degree of reproducibility. These studies indicated that such points as Bolton point, basion, porion (ear-rod), orbitale, gonion, anterior nasal spine, posterior nasal spine, A point, spheno-occipital synchondrosis and pterygomaxillary fissure would be the most variable landmarks.

Baumrind and Frantz (1971a and b) undertook a comprehensive study of cephalometric error in which they discussed error under the headings of 1. projection 2. landmark location and 3. measurement. They quantified the precision to which various landmarks could be located and found that gonion and the lower incisor root apex were the least reliable landmarks. It was discovered that the distribution of errors for each point was not random, but was directional. For example A point was shown to vary more in a vertical direction since it lay on a vertical curve of large radius. Points on a curve of large radius showed larger error. Similar observations were made by Richardson (1966).

Baumrind and Frantz (1971a) found that the sharpness of the edge of a structure in relation to surrounding structures was an important factor in landmark location. For example, superimposition made the location of the lower incisor root apex an "educated guess". Problems of landmark definitions were also considered to be important. Sella and nasion, for example, showed low error. Other points found to have low error were the incisal edges of the incisors. Mitgård et al. (1974) indicated that uncertainty on the part of the observer in placing the landmark was the greatest source of error.

Special problems have been noted in relation to A point. In 1971 Van der Linden studied the anatomy of dry skulls, compared it with the radiographic anatomy, and discusssed the differences for various landmarks. It was believed that A point was unsuitable as a representation of the anterior maxilla. Salzmann (1960) also considered the anatomy in relation to A point, and also believed that measurements involving this point could be inaccurate and misleading. Baber and Meredith (1965) noted that no explicit procedure could be found for the location of A point in the literature and that its location would vary according to the method used to locate it.

The degree of accuracy that could be expected from soft tissue landmarks was discussed in Chapter 1.4C(i). Posture produced special problems in a consideration of the accuracy of soft tissue landmarks. (Burstone, 1967; Wisth and Boe, 1975; Hillesund et al., 1978 ; Broch et al., 1981 and Oliver, 1982).

The least reliable landmarks have been listed in chapter 3.3A as a result of double determinations to determine the total errors involved.

These were: errors of tracing, superimposition, digitizing and projection. The influence of digitizer error was found to be negligible. The influence of projection error could not be studied since retrospective records have been used. Brown (1965) determined that projection error (due to subject positioning) exceeded the measurement errors for most linear and angular variables. This factor was often overlooked in previous cephalometric studies.

Some of the findings concerning the reliability of variables in Chapter 3.3A may be considered in light of the above discussion. The replicated measurements (second determination) were made using the accepted procedure of selecting records at random from the total sample to study error (Houston, 1983).

Since digitizing error was neglibile, the main sources of random error of variables would be likely due to problems of landmark locations, landmark definitions and superimposition error. In anticipation of this a standardized way of landmark location was devised (Appendix 6). The finding that the horizontal location of the lower incisor incisal edge (17) was an unreliable variable was surprising. The vertical position of nasion (37) affected the determination of the error inherent in its measurement. For example the error variance was 17.7% of the estimated total variance for the vertical position of the point. However, this high value is misleading because of the proximity of nasion to the X-axis and also because of positional changes of nasion with growth.

The results indicated that landmarks may vary more in one direction than another in accordance with the findings of Baumrind and

Frantz (1971a). Most of the linear variables which were or could be unreliable (with the notable exception of lower incisor incisal edge) varied more in a vertical direction.

Reference to Appendix 10 indicates that four variables varied significantly from zero at the 0.05 level. By chance alone 3.3 of the 66 variables would be expected to vary significantly from zero at this level. This error was, therefore, not much more than could be expected by chance alone. Five variables varied significantly from zero at the 0.01 level. By chance alone 0.66 of the 66 variables would be expected to vary significantly from zero at this level. Therefore, the errors involved were more than could be expected from chance alone, and superimposing and tracing had a significant effect on the means for several variables. This indicated that the horizontal location of lower incisor incisal edge (17), vertical location of soft tissue nasion (26), vertical location of upper molar mesial contact (47), occlusal plane to S-N (54) and S-NAS-SLS (59), could all be unreliable variables.

The consideration of the error of the method, especially for those variables indicated, will be important when evaluating the results of the statistical analysis.

B. Reliability of superimposition

The growth of the cranial base is important in a consideration of the mechanisms of facial growth and morphology of the face (Mills, 1983). The cranial base has long been regarded as an important reference structure in cephalometric studies of dentofacial growth and development. The basis for the superimposition method of Björk (1968) and Björk and Skieller (1983) was the stability of the bony structures of anterior cranial base in the later growth stages (from at least 10 years of age onwards). A discussion of the growth of the cranial base is considered important to provide a biological background for the superimposition method used in the study.

Scott (1953) described the cranial base as consisting of four bony elements between basion and nasion; the basioccipital, the sphenoid, the cribriform plate of the ethmoid, and the frontal. For the purpose of analysing growth, the cranial base was divided into three parts:

(1) Basion to the anterior margin of the pituitary fossa. This posterior section was noted to grow mainly by proliferation of cartilage at the spheno-occipital synchondrosis which continued until the end of the second decade.

(2) From the anterior margin of the pituitary fossa to foramen caecum. This middle part grew at the spheno-ethmoidal synchondrosis which extended laterally to the roof of the orbits as the spheno-frontal sutures. Growth at these sutures was completed after the 7th year. Scott (1967) in his text on dentofacial growth wrote that this middle section reached 62% of its adult size at birth, 94% between the ages of 4 and 7 years and 98% between the ages of 8 and 13 years.

(3) Foramen caecum to nasion. This anterior part grew by anterior surface deposition of the frontal bone and was related to the degree of development of the frontal paranasal sinuses; this also continued into adulthood.

In his 1941 study, Brodie used basion-sella-nasion to represent the cranial base and found no angular change from 4 years to 18 years of age in twelve of his thirty cases. The rest showed a change of less than 4 degrees in all but five cases. The ratio of the posterior and anterior parts was reported to be essentially unchanged throughout this period.

After using radiographic superimposition, De Coster (1953) claimed that a line drawn from the anterior lip of sella turcia, the upper line of the sphenoid masses, the spheno-ethmoidal suture, the lateral masses of the cribriform plate and encephalic surface of the frontal cells and foramen caecum, and the internal osseous line of the frontal bone, was absolutely superimposable. Growth of the cribriform plane ceased at age 7 years. This was confirmed by Ford (1958) by direct measurements on skull material and by Scott (1958) radiographically. Björk (1955) found that the extension of the anterior cranial fossa generally ceased at around 10 years of age and that continued longitudinal growth of the facial structures was compensated for mainly by the formation of bone on the outer surface of the frontal bone thus increasing the distance sella to basion (also described by Scott, 1953). Björk (1955) found that the shape of the anterior cranial fossa remained the same from 12-20 years but that this was only for the ethmoid part. Sella point was found to be comparatively stable and changes that occurred due to bony remodelling in the region of the pituitary fossa were noted.

Brodie (1941) and Ford (1958) found that the cranial base as a whole had a growth rate intermediate between the general skeletal and neural rates. Ford (1958) discussed this further and found that individual parts of the cranial base had either the general skeletal or neural growth rates. The area between nasion and foramen caecum and sella to basion had the general skeletal rate, the area from the anterior margin of foramen magnum to the posterior margin had the neural rate. It was proposed by Ford (1958) that further growth of the cranial base was necessary after the brain had ceased to grow at 7-8 years to allow for facial growth, the greatest amount of which was yet to come, and agreed with Scott (1953) and Björk (1955), that this was almost entirely by increased pneumatization of the frontal and ethmoid bones.

Ricketts (1960a) believed that there may have been as much as 2.5 mm per year of growth along the sella-nasion line due to growth at the frontonasal area in some males at puberty. Some cases showed a greater increase between basion and sella possibly due to growth of the spheno-occipital synchondrosis. However, Nanda (1955) in a study of growth rates of several linear craniofacial dimensions found circumpubertal increases in growth in all parameters except sella-nasion and cited Boyd (1955) as confirming this. Of all the dimensions sella-nasion showed the smallest percentage gain from 10-17 years.

Björk (1955) also recognized that the cranial base, being the border between the face and cranium, was forced to follow two different growth rates, one along the internal surface (neural) and one along the external surface (general skeletal). He showed that although the cranial base was constant in shape from 10-12 years of age there could be marked individual growth changes with an opening or closing of the cranial base angle occurring. Rotations of the cranial base and brain case were also described as having affected the position of the facial skeleton.

Coben (1966) and Mills (1983) also discussed the importance of the cranial base, especially the spheno-occipital synchondrosis, in relation to its influence on the jaws. Cranial base growth, as co-ordinated with that of the maxilla and mandible, could be important in the production of a malocclusion according to these authors.

Moss and Greenberg (1955) also noted that the cranial base had a characteristic flexure through the body of the sphenoid bone dividing the base into pre- and post-sella components and that the form and position of the cranial base influenced the maturation of the neural and facial skeletons. In a study of dry skull material from adolescents and adults they concluded that the medial areas of the cranial base were essentially stable while the lateral areas underwent prolonged change.

Björk (1955), Baume (1957), Ford (1958), Bergerson (1961) and Scott (1967), have all noted that both the pituitary fossa and nasion may have risen during growth. In the case of the fossa this could have been due to growth of the spheno-occipital synchondrosis, the sphenoidal air sinuses or minor remodelling of the fossa itself.

Very few studies have been made of the reliability of superimposition methods. In 1972 Steuer confirmed the accuracy of using the midline outlines of the sphenoidal portion of the cranial base for superimposition during the usual orthodontic age range. The greater the time interval, the less the congruence, since slight growth changes were noted to occur. The deepening of the pituitary fossa with age was also confirmed.

Baumrind et al. (1976) noted that superimpositional error involved the types of error discussed earlier (landmark location and projection) and the additional error of the act of superimposition itself. This latter type of error could not be studied previously, although it was widely recognized, due to a lack of suitable technology. They divided the error of superimposition into primary and secondary errors. Primary errors involved the actual process of superimposition according to certain biological concepts which depend on the judgement of the person involved. That is, it was not a mathematically defined operation but a "weighted best fit". Secondary errors arose from the displacement of landmarks resulting from the primary errors. Since they were systematically related to the primary errors they were entirely mathematically defined.

Two methods of cranial base superimposition were amongst the superimposition techniques tested by Baumrind et al. (1976). These were sella-nasion registered on sella (SN), and anterior cranial base superimposition (ACB) based on anatomic structures and similar to the technique used in the present study (Björk, 1968 and Björk and Skieller, 1983). Four trained judges were used and repeated measurements were made on 25 film pairs to produce 100 superimpositions for each method. They found that for each landmark for any given superimposition the translational component of error was constant while the rotational source of error varied with the distance from the centre of rotation. The rotational effects produced a larger proportion of the total error. The rotational error for the ACB superimposition was a bit smaller than for the SN method, and this was regarded as a surprising finding. A large number of points on the floor of the anterior cranial fossa were used in the ACB method whereas only two were used in the SN method so that a bad estimate of either landmark could tip the SN plane markedly. The weakness of the SN method lay in the occasional large errors of nasion in the vertical plane which confirmed the earlier findings of

Baumrind and Frantz (1971b). Baumrind et al. (1976) stated "... we conclude that the SN and ACB superimpositions are, overall, not markedly different in reliability. Therefore, it would appear that the choice between them should be made on the basis of which superimposition method is best for answering the particular biological question which is being asked. On the available evidence, the users of the ACB superimposition need have no fear that reliability is less for that superimposition than for SN". These authors believed that the findings were particularly applicable in a consideration of individual cases, since in studies with large samples, most measurement errors would tend to randomize out.

The radiographic anatomy of the cranial base region has been described by such authors as Yen (1960), Bowden (1970) and Rakosi (1982). These works, and a dry skull, were studied as an aid to the identification of structures of interest.

It can be noted in Appendix 3 that none of the studies of soft tissue profile changes due to orthodontic treatment have used a method of superimposition which could be considered to be acceptable, according to the pertinent literature. For example, Stoner et al. (1956), Rudee (1964), Hershey (1972) and Garner (1974) used superimposition based on sella-nasion which according to literature cited above was unacceptable, largely since both sella and nasion could move significantly due to growth in relation to other more stable structures (for example, Björk, 1955 ; Baume, 1957 ; Scott, 1957 ; Ford, 1958 ; and Bergerson, 1961). Other studies did not superimpose but used measurements in relation to the same cranial base planes (such as sella-nasion). Examples of reference planes and linear measurements are depicted in Figure 12.

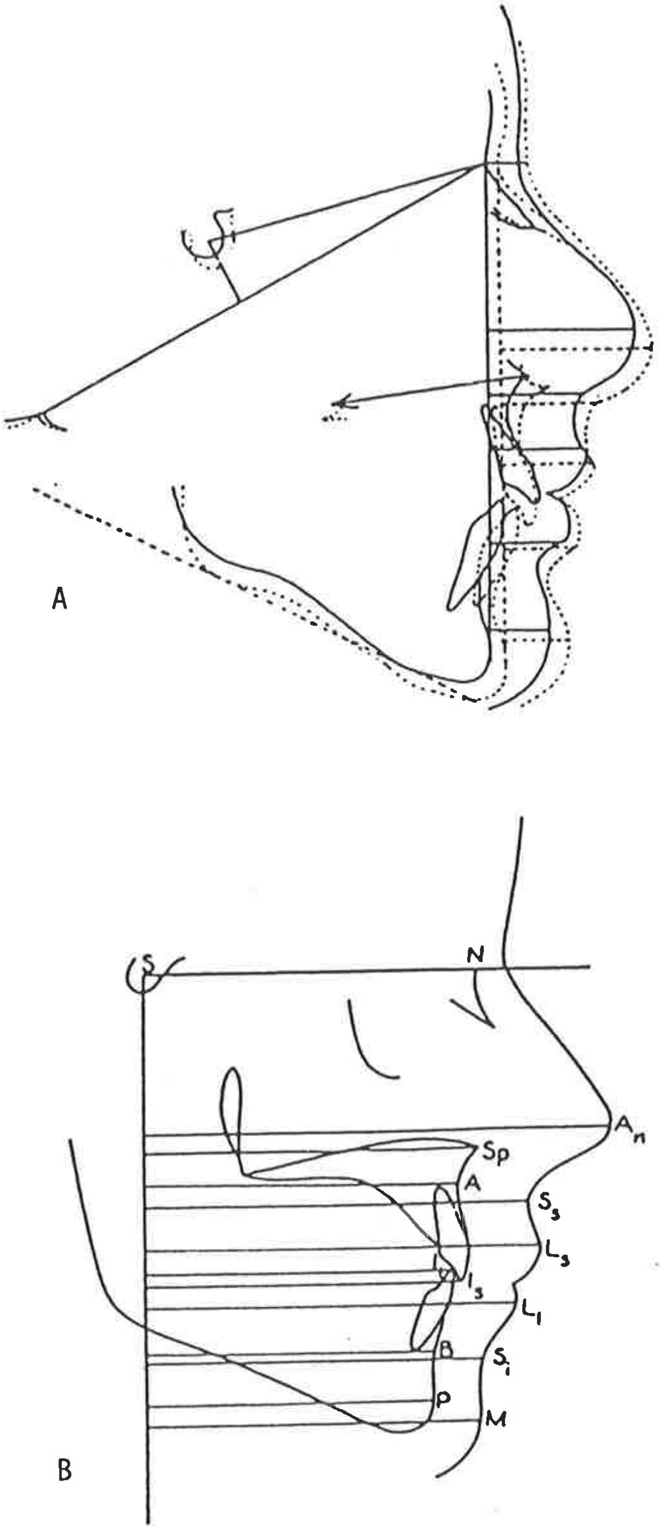


FIGURE 12. Examples of reference planes and linear measurements.

A. Reference to nasion-pogonion. (From Huggins and McBride, 1975)

B. Reference to sella-nasion perpendicular. (From Roos, 1977).

4.4 MEASUREMENT

Hixon (1960) noted that small measurement errors could be significant in studying morphological changes resulting from growth or treatment effects. The use of averages tended to reduce random error. Baumrind and Frantz (1971b) wrote that measurement error was introduced by drawing lines between points by hand and measuring with ruler and protractor. They believed that by using machine computation to compute the linear and angular relations algebraically, given the landmark coordinates, this type of error could be largely eliminated. The errors of angular and linear measures were studied and found to be significant and variable according to the landmarks involved. This was confirmed somewhat by the pattern of errors found in Chapter 3.3A. It was believed by Baumrind and Frantz (1971b) that many authors seriously under-estimated their measurement errors. It was found that with greater error, the apparent correlation between two measures could be greater, and that this spurious result would not be detectable using simple statistics. In 1981 Broch et al. stated that when using a digitizer landmark identification was the only source of error since measurement error was eliminated.

Barrett et al. (1968) discussed the advantages of a coordinate system of measurement. Coordinate values could be determined quickly and accurately and computer entry and storage of the data in coordinate form simplified subsequent processing and analysis. In spite of the known advantages of semi-automatic methods of measurement, only 2 of 23 previous studies of soft tissue changes due to orthodontic treatment used electronic digitizers to record landmark coordinates and computers to process the data. (Anderson et al., 1973 and Lo and Hunter, 1982).

The use of the Hewlett Packard 9874A digitizer and 9815A controller in the present study allowed coordinate values to be obtained instead of conventional measurements, thus reducing one significant source of error.

4.5 VARIABLES

No uniformity existed in the literature with respect to the type of variables used (Appendix 3). A combination of linear and angular variables was common. The linear variables, usually horizontal, were taken as perpendicular distances to the reference plane (Appendix 3). A large range of angular variables have been used.

Vertical and horizontal linear values of the landmarks of interest have been used as the primary source of data since this would serve to precisely locate each landmark in relation to the reference structures and show the changes occuring due to growth and treatment. This would allow values to be determined in actual millimetres (taking into account the enlargement factor).

The disadvantage of angular values according to Moyers and Bookstein (1979), was that the actual area of change could not be determined since the change oculd be due to movement of one or more of a combination of three or four points. A large range of angular variables have been used in previous studies (studies cited in Appendix 3). A selection of these were included from various sources to supplement the data derived from the linear variables, and to allow comparison with previous studies.

4.6 GROWTH AND TREATMENT EFFECTS ON THE FACIAL PROFILE

A. Introduction

Growth and treatment effects on the hard and soft tissues of the facial profile cannot be absolutely separated in this study since an untreated control sample of similar age and sex distribution to the treated sample was not studied. However, on the basis of what changes could be expected due to growth or treatment alone from previous studies, treatment effects can be discusssed with reference to the growth changes that could be expected in males and females of early to mid- adolescent age.

In 1941, Brodie stated that the morphogenetic pattern of growth of the head was established by the third month of post-natal life and once established did not change. This concept of constancy of the individual growth pattern has been challenged by many authors including, Downs (1956), Moore (1959) and Nanda (1971). In addition, Björk (1947). Neger (1959), Burstone (1958, 1959), Subtelny (1959), Salzmann (1964), Coben (1966) and Enlow (1982) have all demonstrated that variation existed in form and size, as well as growth changes in proportion within and between individuals. Authors such as Ricketts (1960b, 1972, 1975), Johnston (1975), Popovich and Thompson (1977) and Ricketts et al. (1979) have advocated methods of predicting growth in individual subjects. However, the general concensus of most authors has been that attempts to accurately predict growth, and treatment results, were quite futile. Much of this could be accounted for by the great overall variation in all aspects of growth and development, and treatment. Graber (1969) wrote that the use of mean measurements to assess the biologic continuum or even to predict future changes had led to controversy.

Serial cephalometric radiographs could be used to determine a pattern, but this pattern could change at any time either spontaneously or as a result of the influence of orthodontic treatment, according to Salzmann (1964). The factors which contributed to the expression of change and which were subject to change were regarded as being: (1) areas of growth; (2) increments of growth; (3) vectors of growth; (4) duration of growth; (5) timing of increments; and (6) treatment influence. Predictions could be confirmed in retrospect only.

The cephalometric workshop of the American Association of Orthodontists as reported by Salzmann (1960) concluded that growth involved extrinsic and intrinsic systemic, local and environmental influences, and that with the present state of knowledge only imperfect predictions could be made. In 1968 Johnston studied the accuracy of growth prediction and found that contemporary methods were generally incapable of providing an efficient estimate of individual growth changes.

In 1971(a), Baumrind and Frantz wrote that vigorous testing was not successful in demonstrating the proprietary of the use of head films to predict growth trends, and "that there are both theoretical and practical considerations which imply that head films can never be of more than adjunctive use in growth prediction". They suggested that conventionally used linear and angular measures were often highly intercorrelated, with the implication that apparently discrete measures were, in fact, markedly overlapping so that two or more measures could reflect the same underlying anatomic condition in slightly different terms. "Therefore even sophisticated statistics do not explain a sufficient proportion of the total variation in the growth system to be clinically effective". They concluded that even if all the parameters contained in head films could be assessed perfectly, the amount of information contained in head films would still be insufficient to make clinically meaningful predictions possible from this source alone. This was confirmed in a later study (Baumrind et al., 1976).

Coben (1971) believed that it was impossible that growth could ever be specifically and accurately predicted. Hirschfield and Moyers (1971) discussed the science of prediction under the headings of theoretical, regression, experimental and time series, and found that the prediction of growth was only poorly predicted in a discussion of the parameters of interest (size, relationship of parts, timing of stages, vectors, effect of treatment). They found that effects in growth prediction were crude and simplistic compared to the sophisticated mathematics used in many other fields of science. Another problem was that the right parameters had not always been measured. They suggested that the time series method based on measurements of one individual offered the best promise for growth prediction.

In 1971, Nanda concluded that mean measures were of no use in growth prediction since individual variation was not taken into account, showed that the pattern of growth changed in any case, and that the variation was great. Mauchamp and Sassouni (1973) noted that most prediction studies were based on changes in the skeleton, and in their study concluded that changes in the soft tissue profile were as predictable as changes in the skeletal profile when made over a 4-year period, which was not true when prediction was based on a 1-year span.

Chaconas and Bartroff (1975) in their study of prediction of normal soft tissue facial changes compared a method using multiple linear regression equations for the prediction of 16 year old measurements from the 10 years of age data, with a method based on the use of group averages. They found that the standard deviation of the estimate was twice as large when using group averages as it was when using the prediction equation method where they found significance to the 0.01 level comparing predicted and actual values at 16 years. They concluded that it was possible to predict soft tissue facial form for an individual given the profile configuration at an earlier age. Their results showed that in some cases a particular variable proved not to be its own best predictor as may be expected, but that an adjacent or associated area may be more important.

Wisth (1975) found that it was difficult to predict the changes of the profile from skeletal analyses and knowledge of skeletal growth alone. Greenburg and Johnston (1975) studied the accuracy of the commerical computerized prediction method of Ricketts since the method had not been adequately tested, and found that the method had only limited accuracy.

Houston (1979) in his review of the current status of facial growth prediction concluded: "In view of the variability of growth of most facial dimensions, detailed and accurate individualized growth prediction is not possible". He wrote that even minor variations in growth could assume considerable importance.

The various cephalometric analyses, for example Downs (1948), Steiner (1953) and many others, have described a range of normality about a mean, of the dentofacial pattern based on various "normal" samples. Other studies such as Riolo et al. (1974) and Garn et al. (1984) have described serial growth changes in samples of males and females.

In view of the problems of growth prediction brought about by individual variation and inadequacies of the methods (even though these would tend to "randomize" somewhat in a large sample), an attempt to predict changes in the pre-treatment samples in this study due to growth alone has not been attempted. Such an attempt, most likely by "adding means to means", would introduce its own considerble problems of inaccuracy and reliability to an analysis of the different effects of growth and treatment. For this reason comment will be made on such matters by refering to pertinent literature.

B. Overall profile dentoskeletal changes

(Text accompanies Appendix 13)

The results indicated that pre-treatment the males and females were of a similar size (Tables A and B) and age (13.7 and 13.8 years respectively, Appendix 9). However, during treatment there was a significant difference in the amount of growth that occurred between the sexes. Males showed a significantly larger amount of growth, especially vertical, in both the hard and soft tissue profiles in relation to the cranial base reference system (appendix 12). Bowker and Meredith (1959) also found significantly more vertical growth in males than females.

Oliver (1982) found that pre-treatment there was little sex difference and that after treatment there were significant sex differences in the soft tissue profile.

The literature indicated that males and females did not follow the same general growth pattern. For example, this has been recognised by authors such as Baum (1961, 1966), Graber (1969), Oliver (1982) and Enlow (1982) (refer also to Chapter 1.3 and 1.4). According to Enlow (1982) the faces of prepubsecent males and females were essentially comparable, and with puberty in the male the dimorphic features tended to develop and continue into early adolescence and early adulthood. Enlow described the sexual dimorphism in facial form in the following way: Males tended to be larger than females. The nose and forehead were noted to be the two areas that showed the greatest amount of sexual dimorphism. The male nose tended to point down, the female up. The male forehead tended to be sloping with a protruding lower part due to larger frontal sinuses, whereas the female forehead tended to have a more bulbous, juvenile form. The upper jaw of the female tended to appear more protrusive and the face flatter, the male was noted to have a coarser, more deep-set face and the cheek bones appeared less prominent.

Although the present study could not confirm, or otherwise, this descriptive account of Enlow (1982), the evidence supported the dimorphic changes that occurred in the sexes with growth and that males grew larger than females (Nanda, 1955; Downs, 1956; Baum, 1961; Horowitz and Thompson, 1964) and showed larger soft tissue changes due to growth (Oliver, 1982).

According to Graber (1969) the range of puberty in females was 10.5 to 12 years and this was the age of the greatest changes in the face with significant but reducing increments for the next 2-4 years. The most likely growth spurt in males was between 12.5 and 17 years (Figure 13). Baum (1966) also noted that faces of females tend to assume adult proportions much earlier than males and summarized the sex differences by stating that boys grew "later, longer and larger".

After treatment the males and females in this study averaged 15.6 and 15.8 years of age respectively. The time between radiographs being taken (post-treatment minus pre-treatment) was 1.9 years in males and 2.0 years in females. This would correspond to a period of much reduced adolescent growth in females, whilst the male sample would still be in a period of active growth (Grave and Brown, 1976). This would explain the pre-treatment similarities, and the post-treatment differences in the samples. The soft tissue studies of Subtelny (1959), De Kock et al. (1968), Mauchamp and Sassouni (1973) and Chaconas and Bartroff (1975) all indicated that females matured earlier than males and that this occurred in the years indicated above by Graber (1969).

The skeletal profile became straighter after treatment in both males and females (Tables E (v) and F (v)) which supported the results of studies such as Downs (1956), Subtelny (1959), Mauchamp and Sassouni (1973) and Fosberg and Odenrick (1979). However, no significant sex differences were found for the change in convexity which was contrary to the results of Mauchamp and Sassouni (1973), but agreed with Subtelny (1959). It should also be noted that changes in profile and basal relationships of the jaws (variables 55, 56, 57, 58 in Tables E (v) and F(v) occurred not only due to growth, but also treatment effects on A

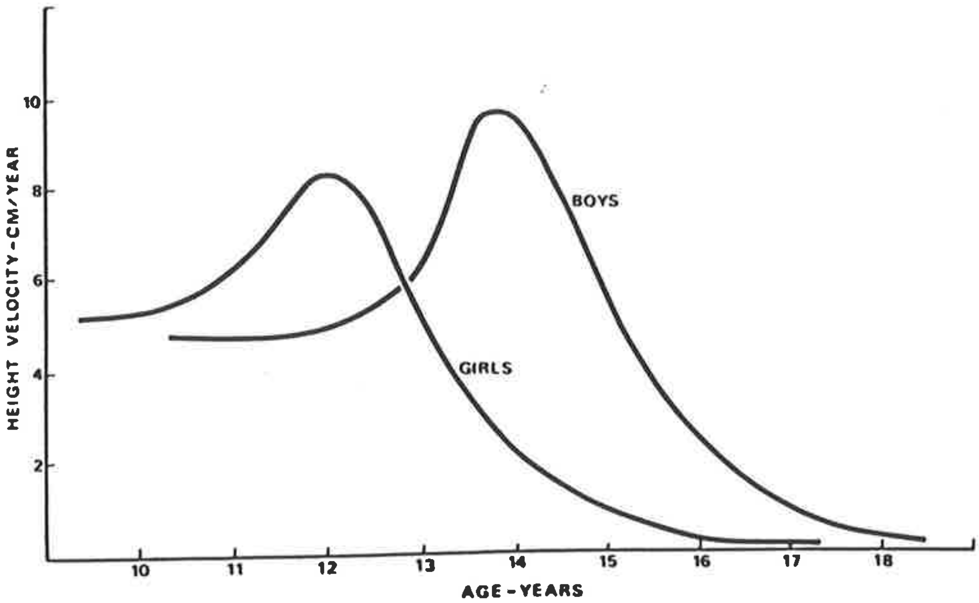


FIGURE 13. Average growth curves for males and females.

(From Grave and Brown, 1976)

point and B point (refer to variables 13 and 20 in Tables E(ii) and F(ii)). The angles SNA and SNB (variables 55 and 56) were also noted to decrease in the growth studies of Nanda (1955), Baber and Meredith (1965) and Fosberg and Odenrick (1979). Decreases of the these angles and/or linear retraction of points A and B have also been noted to occur due to treatment in the studies of Silverstein (1954), Holdaway (1956), Stoner et al. (1956), Buchin (1957), Taylor (1969), Kimmons (1969), Pridemore (1969), Checkoff et al. (1971), Kottraba (1971), Barton (1973), Venezia (1973), De Laat (1974), Williams (1977) and Cohen (1983). This study also agreed with those cited above that the retraction of A point was larger than that of B point (variables 13 and 20, Tables E (v) and F (v)). The soft tissue angles S-NAS-SLS, S-NAS-ILS and SLS-NAS-ILS (59, 60, 61) that corresponded to the angles SNA, SNB and ANB respectively showed similar changes to the corresponding dentoskeletal angle.

Björk (1947), Lande (1952), Silverstein (1954), Nanda (1955), Downs (1956), Subtelny (1959, 1961), Baum (1961), Horowitz and Thompson (1964), and Baber and Meredith (1965) all demonstrated that the mandible became more prognathic in relation to the maxilla with growth, that growth occurred in a downwards and forwards direction, and that the angle sella-nasion-pogonion (or similar) increased. Although this angle was not measured in this study, the results would indicate that the growth changes over the two year period were largely vertical in both males and females in relation to the cranial base reference system, and that the horizontal retraction of B point (representing the anterior mandible) and A point (representing the anterior maxilla) especially, occurred due to a treatment effect. The chin (as measured by variables 10 and 11, Tables E(i) and F(i)) even showed a slight tendency for posterior movement which may have been an effect of growth, or an indirect treatment effect, (such as mandibular plane opening), or both.

The "clockwise" effect of treatment opening the mandibular and occlusal planes as noted in the studies of Silverstein (1954), Wylie (1955), Stoner et al. (1956), Ricketts (1960b), James (1968), Williams (1968), Kottraba (1971), Barton (1973), De Laat (1974) and Cross (1977) was also found in the present study. However, the mandibular plane opened only a small amount compared to the occlusal plane (variables 49 and 54, Tables E(v) and F(v)). The occlusal plane (54) (an unreliable variable ; Chapter 3.3A) was measured in a different way in this study compared to other studies (as mentioned in Chapter 3). The small change in mandibular plane angle (49) may imply that relatively little molar extrusion occurred in treatment and that bite opening was largely by incisor intrusion (especially lower incisor intrusion ; refer to Chapter 3.5). Opening of the mandibular plane was due to molar elevation as discussed by the authors cited above, and tended to reduce after treatment (Williams, 1968).

None of the dentoskeletal angular means had significant sex differences (Appendix 12E).

Where significant differences occurred in the variances of males and females as determined by the F-ratio test, the variance was nearly always greater in males (Chapter 3.4B). This occurrred because of the wider variation in pubertal peak growth changes in males (different subjects would be in various stages of pre-peak and peak growth changes from the ages of 13.7 and 15.6 years) compared to females (most of whom would be in a decelerative phase of growth from the age of 13.8 to 15.8

years) (Grave and Brown, 1976). Males would be expected therefore to show more variance than females (Graber, 1969 and Brown, 1984).

The results in Chapter 3.5 indicated that only a small change occurred in total profile measurements excluding and including the nose. Overall, the profile was flatter, or less convex excluding the nose, and slightly more convex including the nose. Burstone (1959) observed a tendency of the soft tissue profile to flatten somewhat when he compared his untreated adolescent and adult samples. Subtelny (1959) using the same angles as this study (variables 62 and 63) to study growth changes, found little change in convexity excluding the nose from 6 to 18 years of age, while convexity including the nose increased. Ritchie (1962), Rudee (1964), Posen (1967), Angelle (1973) and Chaconas and Bartroff (1975) all indicated that the nose growth had the most important influence on overall soft tissue profile measurements.

Subtelny (1961) believed that all elements of the soft tissue profile could change as a result of growth during the time of orthodontic treatment (adolescent) and that treatment influenced the lips only. Branoff (1971) indicated that during treatment nose growth was the most important influence on the profile and was twice as great as forward chin growth and retraction of the lips.

C. Soft tissue profile changes

(Text accompanies Appendix 13)

(i) Lips and incisors

The results detailed in Chapter 3.5 indicated that after growth and treatment the upper incisors moved downwards and became more retruded since the upper incisor to S-N (51) angle reduced and the incisal edge (16) retracted more than the root apex (14). The lower incisors were intruded with treatment in relation to skeletal chin structures and proclined slightly since the lower incisor to mandibular plane angle (52) increased, and the root apex (19) tended to retract more than the incisal edge (17). The interincisal angle (53) had a net tendency to increase slightly. These overall dental changes are in keeping with the expected changes after Begg treatment as outlined by Kottraba (1971), Barton (1973), De Laat (1974) and Williams (1977).

The upper lip moved downwards and backwards and increased in concavity after treatment (Chapter 3.5) as it followed the incisor retraction. Lip retraction at labrale superius was greater than higher up near the nose. The ratio of upper incisor to upper lip retraction (calculated using the values in Tables E(i) and (ii), and F(i) and (ii) for horizontal change of labrale superius (5) and upper incisor edge (16) in males and females) are displayed in Appendix 14, where comparisons can be made with previous studies in Appendix 1. Similarly, the ratios of upper incisor to lower lip and lower incisor to lower lip (using labrale superius (5), labrale inferius (8) and incisal edge of the lower incisor (17)) have been calculated. These ratios should be interpreted cautiously since there was great variation between studies in superimposition technique, reference plane(s), variables used and lip posture (Appendix 3), and hence the way in which ratios were calculated.

The ratio for upper incisor : upper lip retraction, which has been the ratio most commonly reported in the literature, compared most favourably with that of Rudee (1964), Wisth (1974) in the large overjet group, and Waldman (1982), (Garner, 1974 used a Negro sample). The ratios indicated less lip movement per amount of incisor movement than other authors ; a ratio of around 2.5:1 has been commonly reported. The lip response in males was less than in females. However, Appendix 12 shows that there was no significant difference in the horizontal retraction of the incisors and lips between males and females except for the upper and lower root apices (14 and 19), where males had a little over 1 mm more retraction than females for both points (although this may not be clinically significant).

An explanation of the sex difference in lip response is difficult since there are many difficulties inherent in such a comparison arising from the amount and type of data present, and especially the problem of lip posture. The only other study which calculated separate ratios for males and females, Garner (1974), also reported less lip response in males, and attributed this result to the small sample size, problem of lip posture, and effect of growth on measurements from the reference plane.

The lower lip retracted less than the upper lip and reduced in concavity (Chapter 3.5). Ratios involving the lower lip and upper and lower incisors have not been reported very often (Appendix 1). Appendix 14 shows a large sex difference in the ratios, but generally low upper incisor : lower lip relationship. The lower incisor : lower lip ratios in females was similar to the ratios reported by Garner (1974) in Negroes, and Roos (1977) (Appendix 1).

After treatment the upper lip maintained a fairly constant vertical relationship to the upper incisor, a finding which was also reported by Subtelny (1959, 1961) in subjects studied after the completion of growth when the upper incisor had fully erupted. Unlike the studies of authors such as Subtelny (1959, 1961) and Vig and Cohen (1979), the lengths of the lips were not studied. Jacobs (1978) and Abdel Kader (1983) were the only other authors to study the vertical treatment relationshps of the incisors and lips. Jacobs (1978) was especially interested in the closure of interlabial gap with incisor retraction (Chapter 1.6B), Jacobs (1978) and Abdel Kader (1983) found that the upper lip tended to lengthen with incisor retraction, perhaps due to a reduced lip strain. This result agreed with Buchins' (1957) observations. A large range of interlabial gap closure was found by Jacobs (1978), and Abdel Kader (1983) found only a small mean upper lip height increase (detailed in Chapter 1.6B). No firm conclusions could be drawn concerning vertical lip and incisor changes in the present study since all landmarks were related to the cranial base reference system and problems of growth, treatment and postural differentiations were involved. In both sexes, especially females, the superior aspect of the lower lip (32) tended to move less in the vertical plane than the inferior aspect of the upper lip (31). This was probably due to retraction of the upper incisors from the interlabial region allowing the lower lip to assume a less curled shape. The diagrams of the mean profile changes (Figure 11) show that the landmarks representing the superior aspect of the lower lip and inferior aspect of the upper lip tended to move towards each other after treatment indicating a greater tendency towards lip closure.

Burstone (1959), Subtelny (1959, 1961), Ricketts (1960b), Ritchie (1962) and Burke (1980) found that the lips tended to flatten or retrude somewhat with growth especially in the adolescent to adult years when the incisors tended to upright somewhat. Burstone (1959) noted that this change was small. Chaconas and Bartroff (1975) and Burstone (1959) both indicated that the upper lip tended to protrude more than the lower with growth. Burke (1980) found more variation in the upper than the lower lip and some forward movement of the lower lip, although both lips tended to retrude as a whole. The changes noted in the present study were different to those expected by growth alone, considering the above remarks. The amount of lip retrusion (especially the upper) and different pattern of lip shape change would, therefore, be a treatment response to incisor retraction. These results differed from those of Hershey (1972) who found that the lower lip tended to retrude more than the upper in his Class II sample of post-adolescent females. However Hershey (1972) also found that superior labial sulcus moved lingually more than inferior labial sulcus. Angelle (1973) found that the upper lip tended to maintain its anteroposterior position and didn't follow the upper incisor. Angelle (1973) and Koch (1979) found that the lower lip tended to become more protrusive in males and retrusive in females. De Laat (1974) found that only Tweed edgewise produced a significant lower incisor retraction, and that the upper lip retraction was greater for Tweed edgewise compared to the Begg sample. The diagram depicting the results of the present study seemed to compare closely with the Begg Class II, Division I group of De Laat (1974) (Figure 8).

The results of Ricketts (1960b), Anderson et al. (1973), Angelle (1973), Wisth (1974) and Roos (1977) all indicated that the upper lip tended to thicken with treatment. Broch et al. (1981) believed that this could have been due to a camouflaging affect of the lips, as the lips tended to be thin when closed over proclined upper incisors. The diagram of mean changes (Figure 11) shows that the lower lip thickness in relation to the dentoalveolar structures changed little. This agreed with the findings of Anderson et al. (1973). The distance between the upper dentoalveolar structures and the upper lip increased considerably in both sexes, especially males. However, a more complex explanation than "upper lip thickening" is believed to be involved. The upper lip may not increase in tissue thickness, but rather may increase in antero-posterior dimension from the outer lip surface in relation to the labial aspect of the dentoalveolar structures due to the effect of relaxed strain and because the upper lip did not follow the upper incisor retraction in a 1:1 relationship. Hershey (1973) suggested that a void could have been created between the upper lip and incisors. This would be supported by the findings of Oliver (1982) and Holdaway (1983) regarding the influence of lip strain, and by Hershey (1973), Angelle (1973) and Robinson (1960) (cited by Burstone, 1967) who indicated that the lips had some postural independence to the teeth. However, Holdaway (1983) did find that the lips of adults more nearly followed the incisor retraction. Anderson et al. (1973) found that 10 years post-retention the lip thickness reduced somewhat in females. These studies suggest that independent lip posture may be reduced in adults.

The general findings regarding the change of the lips and incisors during treatment have been found to be supported by several authors, including Anderson et al. (1973), De Laat (1974) (Begg sample), Roos

(1977) and they are also in keeping with the change found by Cangialosi and Meistrell (1982) in the third stage (root torque) of Begg treatment.

(ii) Nose and chin

Changes of the nose over the two year period studied were due to growth alone. The literature supports the view that treatment was unable to affect the nose (Subtelny, 1961 ; Angelle, 1973). However, Ricketts et al. (1979) claimed that orthodontic treatment could alter the nose but provided no supporting evidence. Oliver (1982) believed that the nose influenced the drape of the lip, but apparently didn't believe that treatment influenced the subnasale region at the junction of lip and nose. Lo and Hunter (1982) found that most of the change in the nasolabial angle was due to lip retraction, and that as the lip retracted the subnasale area was pulled downwards and forwards. The results in Tables E(i) and F(i) indicated that minimal horizontal changes occurred in the region of subnasale (3). A small amount of forward movement occurred in males and a small amount of retraction occurred in females, however the difference was small and non-significant statistically (appendix 12). Below subnasale (upper lip) retraction occurred. Above subnasale (nose) there was a forward movement. From the figures in the tables the influence of treatment on subnasale cannot be deduced and correlations may help provide an answer (see below in Chapter 4.7B).

The forward growth of the tip of the nose, pronasale (2), and the bridge of the nose, soft tissue nasion (1), was significantly greater in males than females (at the 1% level). Pronasale grew forwards 1.5 mm more in males than females. Soft tissue nasion (1) grew forwards 0.9 mm more in males than females. However, the vertical growth change of soft tissue nasion (26) was the only vertical soft tissue change that did not differ significantly between the sexes. Pronasale (27) showed a 0.9 mm greater downward movement in males which was statistically significant at the 5% level. The male nose tip therefore moved downwards and forwards by equal amounts and the female nose tip moved down slightly more than forwards (only by 0.6 mm). These results differed somewhat from Subtelny (1959) who found that the male nose was longer (as measured from nasion to pronasale) at all ages and that the increase in length during adolescence (1 to 1.3 mm per year) was the same in males and females. In the present study males and females did not differ significantly in the vertical and horizontal locations of pronasale before treatment. The growth seemed to be greater in the males at the ages studied. Subtelny (1959) reported that the growth spurt in nasal dimensions occurred much more commonly in males than females. He also found that growth of the nose was greater in the vertical than horizontal direction in both sexes, and that females displayed greater horizontal growth than males. (Subtelny, 1959 and 1961). This result also differed from the present findings.

Posen (1967) found larger overall nasal dimensions in males than females but similar growth rates in males and females and confirmed Subtelny's (1959, 1961) results (Posen used Subtelny's (1959) sample). Ricketts (1960a) found more horizontal nose growth in males after orthodontic treatment.

Analyses using more measurements of the nose, for example such as those of Posen, (1967), Chaconas, (1969) and Chaconas and Bartroff, (1975), may provide more answers concerning growth of the nose and the effect of treatment on the subnasale region.

The results showed that the soft tissue chin points pogonion and gnathion (variables 10, 11, 35 and 36) followed the underlying skeletal chin (variables 21, 22, 45 and 46). There was minimal change in thickness due to growth (or treatment). For example soft tissue pogonion (10) moved backwards less than pogonion (21) but only by 0.7 mm in males and 0.3 mm in females. This may have occurred due to a minor growth response, or it may have been due to the effect of reduced lower lip and mentalis strain in at least some individuals effecting the mean for the sample (however, the amount of change was similar in size to the E(M) values for these variables). That is, reduced strain could allow some forward movement in the region of soft tissue pogonion. Similar observations were made by Ricketts (1960b). Stoner et al. (1956) believed that little change occurred with growth in soft tissue thickness over the chin during the age of orthodontic treatment. Subtelny (1959) indicated that the soft tissue overlying the chin increased in thickness from 3 months to 18 years of age. This was less than the increase over A point, but more than the increase over nasion over this age period.

The results supported the collective findings of Stoner et al. (1956), Anderson et al. (1973), Angelle (1973), De Laat (1974), Wisth (1974) and Stromboni (1979) namely, that treatment had very little effect on the soft tissue overlying the chin.

4.7 CORRELATIONS

A. Introduction

Several authors have investigated problems pertaining to the interpretation of correlation coefficients. These involve more than a consideration of biological associations, and include a consideration of methodology (Solow, 1966).

Pearson and Davin (1924) ascribed the term "spurious" to those linear measurements which "covered" the same anatomical region and shared anatomical components. Correlations between non-overlapping measurements were called "organic".

Croxton (1953) indicated that the presence of correlation between variables does not necessarily mean that causal relationship is present, even if the correlation is high. Correlation could arise as a result of the following: Fortuitous correlation ; one variable may have been the cause (not necessarily the sole cause) of the other ; the two variables could have been interdependent ; the two variables could have been affected by the same cause.

Garn and Shamir (1958) warned against attaching too great a biological relationship between age-associated events, since many such developmental events were essentially irreversible and occurred in a definite sequence. Correlations involving age have not been included in the tables in Appendix 15.

Garn (1958) explained the interpretation of values of r which ranged from +1 (perfect positive correlation) through zero (no correlation) to -1 (perfect negative correlation). For "convenience" a value of r of 0.00 to 0.39 was designated "low", 0.40 to 0.79 "moderate", and 0.80 to 1.00 was called "high". However the measuring of such a designation relied upon a reference to the coefficient of determination, r^2, which explains the percentage of shared variability accounted for by the value of r in question. For example, for an r value of 0.5, r^2 is 0.25 ; for an r of 0.7, r^2 is 0.49, and so on. Therefore an r value of 0.5 accounts for only a quarter of the variability shared in common by the two variables concerned leaving 75% unexplained.

Björk and Solow (1962) investigated the influence of measurement methodology and error on the determination of correlation. They found that correlation coefficients were biased when variables shared common reference points. The inflated values occurred because the systematic error involved with marking the landmarks was also correlated. These authors favoured a method whereby direct measurements were made without marking reference points or lines for correlation studies. They also determined that indirect measurements, calculated between other measurements, could increase, or under other conditions decrease, the correlation coefficients. An increase occurred when the indirect measurements had common dimensions and therefore common registration errors. A decrease occurred when the indirect measurements had no dimension in common since indirect measurement usually involved a greater registration error. The former error was believed to be more powerful. These authors therefore recommended the use of direct measurements, not calculated from other values.

Solow (1966) demonstrated that a correlation between two variables resulted from the use of common reference points, lines, or angles. This form of correlation was named topographical. The variability of the common points used to determine the variables was included in the variability of each variable and therefore this source of variation was common to both variables. "Non-topographical" correlations were those in which the variables had no common reference points or lines. "Non-topographical" correlation was considered to indicate the presence of biological coordination. Solow's (1966) distinction between "topographical" and "non-topographical" correlations differed from Pearson and Davin's (1924) "spurious" and "organic" correlations. The distinction involved the presence or absence of a common reference structure. Brown (1967) introduced the term "specious" to describe correlations between variables sharing common components and sharing common reference points or lines. Therefore the term "specious" included both the previous terms, "spurious" and "topographical". However the presence of specious coordination didn't preclude the possibility of additional biological coordination, but the values should be interpreted cautiously.

Correlation coefficients calculated from the pre-treatment and post-treatment variables in males and females (tables have not been included) confirmed the previous discussion since coefficients between similar variables tended to have consistently moderate to high correlations because the correlations were "specious". Examples were coefficients between horizontal (or vertical) soft tissue variables, horizontal (or vertical) hard tissue variables, and also horizontal (or vertical) soft tissues with horizontal (or vertical) hard tissue variables. Angular variables had higher correlations with other variables when landmarks were common to both variables.

An examination of the method in Chapter 2 reveals that all linear variables were calculated from a common reference system, that is the NSL and NSP lines determined from the Björk superimposition method. Angular variables also commonly involved the NS line.Therefore "topographical" correlations could be expected between most of the variables. In addition, "spurious" correlations were present between all the horizontal measures which displayed some degree of overlapping because they were measured from the same vertical reference. This was also true of the vertical measures and angular measures where one arm of the angle or a landmark was common to both angles or an angle and a line. The tables of correlations for the differences were calculated indirectly from the post-treatment minus the pre-treatment value for all variables. According to Björk and Solow (1962), and as discussed above, this would also alter the value of the correlation coefficient. Correlations between horizontal variables would be increased since there was a dimension in common to both variables. The same was true of the vertical measurements and several of the angular measurements (also for coefficients involving some angular and linear measures where a dimension or a landmark was common to both).

Peck and Peck (1980) believed that a correlation coefficient greater than or equal to 0.7 was necessary before clinical importance could be assigned to correlations.

When interpreting correlations one should be aware of the various factors, as outlined above, which would tend to increase (especially) or decrease (considering all the factors involved this was much less important) the value of the coefficient in question. Recognising the "specious" nature of the correlations, the terms "low", "moderate" and "high" have still been used. The term significance implies statistical rather than biological significance unless otherwise indicated.

The main value of the correlations lay in making comparisons between various coefficients in order to ascribe some biological importance and in confirmation or otherwise of discussion in previous sections of this chapter.

B. The pattern of correlation

(Text accompanies Appendix 15)

Overall, non-significant and low correlations were found between "dis-similar" variables, such as between horizontal soft tissues and vertical hard tissues, vertical soft tissues and soft tissue angles, and soft tissue angles and vertical hard tissues.

The correlation coefficients involving hard and soft tissue chin points were moderate to high (except between vertical soft tissue and horiziontal hard tissue and horizontal soft tissue and vertical hard tissue) which confirmed the close relationship between the soft and hard tissue chin with growth and treatment during adolescence (Chapter 6C(ii)). Less sex difference was found for these correlations than for many others.

Very little study has been made of vertical correlations involving soft tissue points. Jacobs (1978) used correlations to study vertical lip and incisor relations and found that both the vertical and horizontal relationshps of the incisors and lips were highly correlated. The tables in Appendix 15B show that moderate to high correlations were found between nose and upper lip and lower lip and chin which probably reflected the similarity in overall growth pattern in the soft tissues of the facial profile. Many moderate correlations were also found between vertical hard and soft tissue changes, again reflecting a general pattern in the downward growth of the face.

Appendix 15B (iii) contains a large overall pattern of moderate correlations between vertical hard and soft tissue changes such that a treatment effect in the region of the lips and incisors could not be isolated from this information alone. Several moderate correlations were present between vertical change of labrale superius (30) and superior labial sulcus (29) and several dentoskeletal angles (Appendix 15B(v) indicating a relationship between the upper lip and dentoskeletal change. However, in general these correlations were moderate in the male sample which may indicate that a difference in growth pattern could be important in this correlation pattern. A large sex difference was often present in the correlation matrix and often the male sample had significant coefficients where the coefficients were non-significant for females for a group of variables. (For example, between the vertical soft tissues and horizontal hard tissues in the upper face depicted in Appendix 15B(ii)).

The following discussion will mainly concern coefficients presented in Appendix 15A and C.

The strengths of the correlations reported in the literature for horizontal retraction of the incisors and lips varied widely. Previous discussion in Chapter 4.6C(i) indicated that differences between studies could be largely due to variation in samples with respect to age, malocclusion, size and treatment technique, and, to different methodology, especially choice of reference planes and variables.

The correlations presented in Appendix 15A(iii) indicated that in males superior labial sulcus (4), labrale superius (5), inferior aspect of the lower lip (6), labrale inferius (8) and inferior labial sulcus (9) were generally correlated to a moderate extent with landmarks involving the upper and lower incisors. In females non-significant correlations were more common amongst these variables. Lower lip points (7, 8 and 9) generally had low or non-significant correlations with upper incisor points (14, 15 and 16). Females also had non-significant correlations involving root apex of the upper incisor (14) and upper lip variables (4, 5 and 6). Sex differences in correlation coefficients have also been reported by Oliver (1982) who noted some significant differences in males and females which were believed to be due to differences in growth and maturation.

Appendix 2 displays correlations reported in previous studies. Cangialosi and Meistrell (1982) reported no significant correlations between the upper lip and incisor in the third stage of Begg treatment. Relatively small movements were involved and lip posture variation may have been important. Hershey (1972) and Roos (1977) claimed lower correlations between the lips and upper incisors than previous studies. Several of Hershey's (1972) values, however, would be considered moderate. Moderate correlations between upper and lower lip and upper incisor retraction were also reported by Rudee (1964), Anderson et al. (1973), De Laat (1974), Jacobs (1978), Lo and Hunter (1982), Oliver (1982) and Rains and Nanda (1982) when their values were examined. However, several authors rated their own correlations as high, for example, Rudee (1964), De Laat (1974), Jacobs (1978) and Lo and Hunter (1982). Huggins and McBride (1975) found some moderate correlations between lip and incisor retraction using angular incisor variables. Bloom (1961) found high correlation coefficients between most of the lip and incisor retractions. Most authors found lower correlations for the upper lip and lower incisor than for the upper lip and upper incisor.

Many authors (listed in Appendix 2) also calculated coefficients involving the lower incisor. These ranged from no lower lip/incisor correlation for Huggins and McBride (1975) and Rains and Nanda (1982), through to low coefficients for labrale inferius/incisal edge of lower incisor for Anderson et al. (1973), through to moderate for most authors, and high coefficients were reported by Bloom (1961) and Roos (1977). Most studies reported similar coefficients for upper lip/upper incisor and lower lip/lower incisor. Roos (1977) and Chang (1983) however reported stronger correlation, for the lower lip/lower incisor. The present study confirmed the former, but with slightly lower correlations for the lower lip.

The results of the present study confirmed the general findings of others that moderate correlations were present between upper incisor incisal edge and labrale superius, upper incisor incisal edge and labrale inferius, and lower incisor incisal edge and labrale inferius. The correlations between upper lip and upper incisor and lower lip and lower incisor were the strongest.

De Laat (1974) reported coefficients involving other incisor related points such as A point, B point and the root apices. Moderate correlations were reported by De Laat, between the following: A point and superior labial sulcus, root apex of upper incisor and superior labial sulcus, B point and inferior labial sulcus and root apex of lower incisor and inferior labial sulcus. In the present study moderate correlations were found only in males between A point (13) and root apex of upper incisor (14) with superior labial sulcus (4) (the corresponding coefficient was non-significant in females). Correlations were strongest between B point (20) and root apex of lower incisor (19) with inferior labial sulcus (9) (were moderate in males and females).

Coefficients involving angular soft tissue variables have been calculated by Wylie (1955) who found a moderate correlation between horizontal upper incisor retraction and soft tissue convexity. Appendix 15C(ii) indicated a moderate correlation of the nasolabial angle (64) S-NAS-SLS (59), convexity including the nose (62) and convexity excluding the nose (63) with several horizontal hard tissue variables. Large sex differences were once again apparent. Hard tissue variables in the lower part of the face correlated with soft tissue convexity change, while the change of the incisal edge of the upper incisor (16) correlated moderately in males and females with changes of the nasolabial angle (64) and S-NAS-SLS (59), again indicating a relationship between incisor retraction and soft tissue changes.

All the authors listed above recognized the wide variation in lip and incisor response in their samples, and for this reason the correlations and/or ratios reported should not be used for predicting lip responses to incisor retraction. Large variability has been confirmed in this study. Many suggestions, most of them untested, have been put forward to explain this observed variability. Bloom (1961) indicated that the variation in lip response arose out of broad factors of the "environment", heredity, and growth and development. He recognised that further analysis was required to isolate these factors. Burstone (1967) recognised that the lip pattern was an important factor. Redundant lips were less likely to follow incisor retraction, and therefore no simple formula relating incisor and lip retraction could be produced. Hershey's (1972) work did not fully support the importance of lip pattern since no significant difference in lip retraction was found between a group of subjects with incompetent lips and a group of subjects with redundant lips. Hambleton (1964) indicated that there were many variations of imbalance as a result of malocclusion, variation of lip tone, and length and thickness of the lips. Burstone (1967) believed that not only were structural variations of the lips important, but the postural position of the lips was also important (discussed fully in Chapter 1.4C(i)). Salzmann (1964) believed that lip response depended not only on tooth movement but also muscle size and tonicity, mimetic muscle habits, psychomotor involvements and alveolar bone changes.

As stated earlier (Chapter 4.6C(i)), several authors have indicated that the lips had some degree of postural independence (Robinson 1960, cited by Burstone, 1967 ; Hershey, 1973 ; Angelle, 1973). Studies that have investigated the pattern of lip response in groups of subjects with small and large overjets have reached some conflicting conclusions. Hershey (1973) and Wisth (1974) found increased variability of lip response to increased incisor retraction. Anderson et al. (1973), however, found more variability in the situation of less incisor retraction. The correlation between lip and incisor retraction was found to increase with more incisor retraction by Hershey (1973) and Anderson et al. (1973). Using scatter diagrams, Rains and Nanda (1982) also found that there was a more variable lip response to increased upper incisor retraction, especially of the lower lip.

The response to incisor retraction could also be dependent on the age of the patient, especially with regards to soft tissue posture and muscle tone, as indicated by the work of Oliver (1982) and the observations of Holdaway (1983). Hershey (1972) believed that the variation in lip response could have involved the original force per unit area exerted by the lips and variation in the amount of muscle and adipose tissue in the lips.

Huggins and McBride (1975) indicated that mandibular growth, especially in males, could be an important factor in lip response to incisor retraction. Rains and Nanda (1982) believed that mandibular rotation had an important influence in lower lip response since no significant correlation between lower incisor and lower lip response was found.

Waldman (1982) believed that growth, soft tissue consistency and musculature and "other factors influencing the physical form of the face" were important factors in lip response to incisor retraction. Based on mnay years of clinical observation, Holdaway (1983) indicated that lip thickness and strain were important factors in lip response. These recent observations indicated that most of the contentions regarding the factors influencing lip movement during orthodontic treatment have remained untested.

In 1978 Jacobs determined that more closure of the interlabial gap and lip lengthening occurred with intrusion as well as retraction of the upper incisor. However, the explanation given for the lip response was only conjecture ; reduced strain was suggested. Extrusion of the upper incisor was believed to place more influence on the lower lip. Although Abdel Kader (1983) didn't find a significant relationship between vertical lip height and incisor height, this author also believed that lip height increased as a result of the relaxation of stretched lips as overbite and overjet were reduced. (Some problems relating to this study have been noted in Chapter 1.6B). The present results have shown that after treatment the interlabial gap was reduced, the upper lip flattened somewhat and the lower lip increased in curve. Due to problems in the "specious" nature of the correlations, and the variations of lip posture, growth and treatment response, specific relationships could not be found. The samples were not further divided to test response to varying amounts of incisor retraction, intrusion, or other factors.

Oliver (1982) divided his sample into smaller groups on the basis of lip thickness and strain. Non-significant correlations were found between hard and soft tissue changes in the thick-lipped and low lip strain groups. Oliver (1982) therefore concluded that variation in lip response was due to factors of lip thickness, length and postural tone. This author warned against using the results for predicition due to methodological problems such as the small sample size and inability to separate growth and treatment changes, and because lip tone (strain) could be more accurately measured using strain gauges and electromyographic techniques.

The discussion indicates that the factors associated with variable lip response to incisor movement in orthodontic treatment requires further study in order to confirm, reject or modify, the views put forward in the literature, to which only scant attention has previously been directed.

4.8 FACIAL PROFILE AESTHETICS

A. Introduction

Criticism of the Begg technique for "dishing-in" facial profiles appears to be on an emotional rather than a scientific basis. The sweeping statement that an orthodontic technique produces unaesthetic facial profiles deserves a careful study of concepts of facial aesthetics and an analysis of how the profile was altered by treatment with, or without, growth. The study of individual cases is considered to be useful to highlight individual variation. In this regard, the use of Z-scores calculated for each patient will be utilized and interesting cases examined.

B. Concepts of Facial Aesthetics

Facial aesthetics has generally been dealt with in a very subjective way in the literature. Only recently have researchers tried to quantify the characteristics of an aesthetic profile. However, quantification of facial aesthetics is difficult conceptually because it could be argued that aesthetic concepts are subjective and are based on an individual's own judgement.

Several authors have recognized that a consideration of facial aesthetics was important in orthodontic treatment planning, such as Riedel (1950), Burstone (1959) and Subtelny (1961). Riedel (1950) stated that the three goals of orthodontic treatment were a functional occlusion, stability and beauty. Burstone (1959) believed that the aims of stability and aesthetics in treatment were parallel objectives as the same muscular imbalances that led to instability also led to disharmony of facial contour. Hertzberg (1952) noted that most patients sought orthodontic treatment because of the presence of facial disharmony, dental malalignment, or both.

Iliffe (1960) hypothesized that norms of human beauty were culturally determined. In a questionnaire based on examination of three-quarter profile views of women, he concluded that men and women of all ages shared a common basis of aesthetic judgement which was believed to be culturally transmitted. Furthermore, the concept that the human face had a "balance" or harmony which was shared by all beautiful things was rejected. Peck and Peck (1970) cited Udry (1965) as finding similar results in America using Iliffe's 1960 material and concluded that there was indeed a common basis for aesthetic judgement regardless of nationality, age, sex or occupation.

Reidel (1957) believed that orthodontists had derived their concepts of facial aesthetics from three main sources: aesthetic idealism from art, concepts of incisor positioning beneath the soft tissues (cited Tweed, 1944), and the many cephalometric analyses such as Downs (1948), Steiner (1953) and others. Another suggested source was the mass media, such as magazines.

Early standards of facial aesthetics were developed mainly on the basis of individual judgement, as recognized by Cox and van der Linden (1971). For example, Downs (1948) cited Angle (1907) as one of the first orthodontists to be concerned with facial aesthetics. Angle devoted a chapter in his text to "Facial Art". Angle's aesthetic ideal is often referred to in the literature as being the Greek sculpure, Apollo Belverdere. Angle did not define his aesthetic objectives except in broad terms according to Rudee (1964). Herzberg (1952) regarded the face to be in "balance" when it was pleasing in appearance, and noted that facial balance was a matter of individual opinion. He described facial features, which in his opinion characterized an aesthetic profile. Downs (1956) believed that while all individuals showed variation in facial type and pattern, those possessing optimal oral health, functional balance and aesthetics had in common certain profile characteristics. It was believed that these were reflected in his 1948 cephalometric normal sample.

More recently there have been attempts to quantify and standardise concepts of facial aesthetics. However, Peck and Peck observed in 1970 that up to that time all studies except that of Riedel (1957) used normal samples based on the orthodontist's rather than the popular opinion of facial harmony. Riedel (1957) studied a group of beauty contestants cephalometrically and found that in half the cases the upper lip, lower lip and chin fell on the same plane. The measurements fell very close to standard mean values except for the upper incisors and he concluded that the public's concepts of facial aesthetics agreed closely with the cephalometric standards established by orthodontists.

Other studies have investigated and compared the aesthetic judgements of orthodontists, other dentists and the public. For example, Riedel (1950) used profile outlines placed into "good", "fair" or "poor" groups on the basis of profile aesthetics, judged by orthodontists, and found that the underlying dentoskeletal structures, analysed by the Downs method (Downs 1948) and other measures, had a marked influence on the facial profile. Generally it was found that a more convex profile needed more upright incisors to produce good facial aesthetics, and conversely, if the skeletal profile was straighter more incisor protrusion may be allowed.

Peck and Peck (1970) studied a sample of 52 faces (with only 3 males) with "publically accepted" facial aesthetics (such as models and actors). Cephalometrically it was found that the sample favoured a fuller, more protrusive dental pattern than orthodontic standards would permit. The dentition tended to be more forward positioned and inclined. This agreed somewhat with Riedel (1950). Cox and van der Linden (1971) studied facial aesthetics on the basis of not preselecting a sample based on normal occlusion or good facial balance. From a sample of 241 young adult females and 186 young adult males a random sample of 3 groups of 29 males and 3 groups of 29 females was selected. Ten orthodontists and 10 laymen each placed the profiles into a normal distribution from best to poorest aesthetics. This method is sometimes called a Q-sort frame. The two groups were found to show remarkable agreement in their ratings. Groups of "worst" and "best" male and female profiles were analysed cephalometrically using hard and soft tissue points. This analysis showed that in both sexes persons with poor facial balance had more convex faces. In males with poor facial harmony the incisors were significantly more anteriorly positioned. The variation in the "good" aesthetics groups was noted to be large and a number of good faces were associated with malocclusions which, they believed, if treated may have improved the occlusion at the expense of the facial aesthetics. It was proposed, therefore, that cephalometric standards had been set too rigidly.

In 1973, Foster studied facial aesthetics by asking six diversified groups to judge seven silhouette facial profiles. Each silhouette was unchanged except that the lips were made progressively 2 mm fuller. Each person was asked to select the most pleasing profile for males and females at ages 8 years, 12 years and adult. It was found that the diversified groups shared a common aesthetic standard, fuller lips were preferred in children and all groups preferred fuller lips in females, but the orthodontic group preferred lesser female lip protrusion than the other groups. The results were also studied according to the "E" line of Ricketts (tip of nose to tip of chin) and "H" line of Holdaway (tip of chin to tip of upper lip) and they found that the preference for adult males was near the accepted means while females' lips approached closer to the lines. In general orthodontists were found to prefer a more protrusive lip pattern which Foster hypothesized was because orthodontists rarely saw a patient in full maturity and tended to finish to a "fuller" profile. Overall a "straighter" adult male compared to the female profile was preferred. This study centred around the importance of the lips in facial aesthetics.

Lines et al. (1978) examined the profile preferences of orthodontists, oral surgeons and laymen and found that there was a significant difference in profiles preferred for males and females. A series of sets of profile outlines were used, each set varying in a certain area of the profile. The overall findings indicated that preferences for the female profile were for a more acute nasolabial angle, and in males for a more prominent nose and chin. From their findings they produced the preferred overall male and female profiles and a composite for comparison (Figure 14).

Several authors have attempted to quantify facial aesthetics based on cephalometric analysis. Wylie (1955) found that Tweed's (1954) (cited by Wylie 1955) concept that if the lower incisors were positioned at 65^{o} to the Frankfort horizontal, good aesthetics would result in 90% of cases, was over-simplistic. Lindquist (1958) also reached the same conclusion. Holdaway (1983) believed that aesthetics concepts based upon hard tissue measurements, such as Tweed's lower incisor concept, and the lower incisor to A-pogonion (Ricketts, 1960a) often were lacking as far as the harmony of facial lines was concerned. Rudee (1964) believed that the upper incisor was more important in facial aesthetics than the lower incisor since the upper incisor imparted a greater influence on lower lip position.

Ricketts (1957) noted that a means of evaluating the nose, lips and chin was lacking in the literature. He proposed the use of the "E" line which was a line joining the tips of the nose and chin. Based largely on clinical impressions and photographic examination, he found that the upper lip was 4 mm and the lower lip 2 mm posterior to this line. He also studied the position of the incisors in a group with "good" facial aesthetics and concluded that the upper and lower incisors were important in facial aesthetics but pointed out that normal occlusion was not necessarily a criterion for facial beauty. In 1968 Ricketts proposed

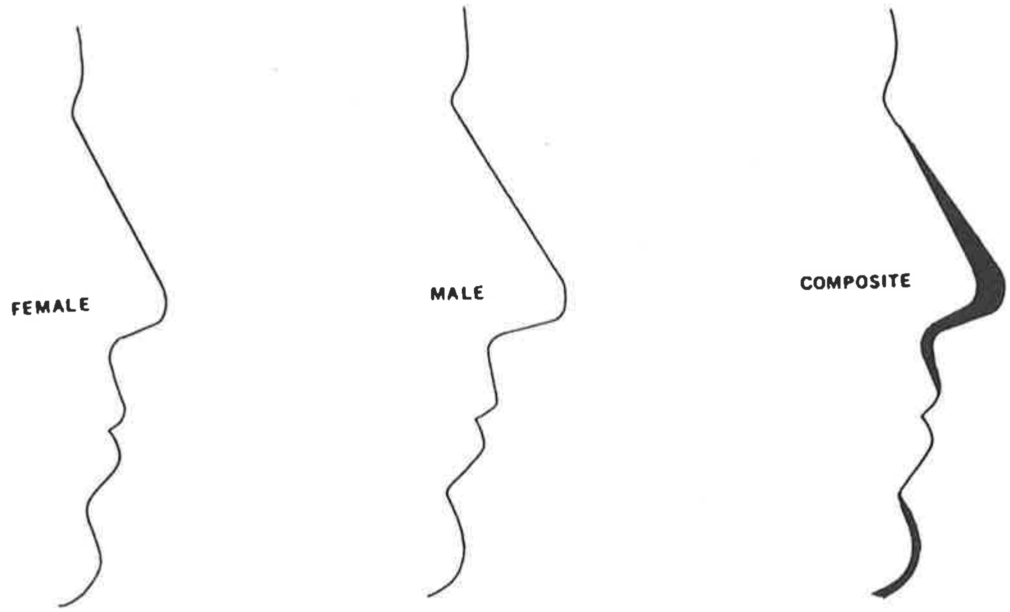


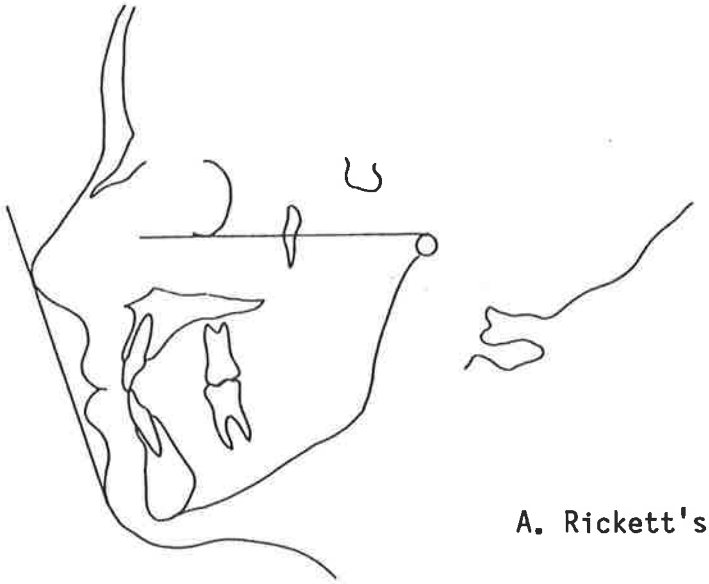
FIGURE 14. Preferred male and female profiles. Aesthetics as judged by the participants of a study and arranged in a composite manner to demonstrate the most prefered facial angles. The male and female profiles are overlaid on their common facial lines to show the sex differences preferred by the participants of the study (right).

(From Lines et al., 1978).

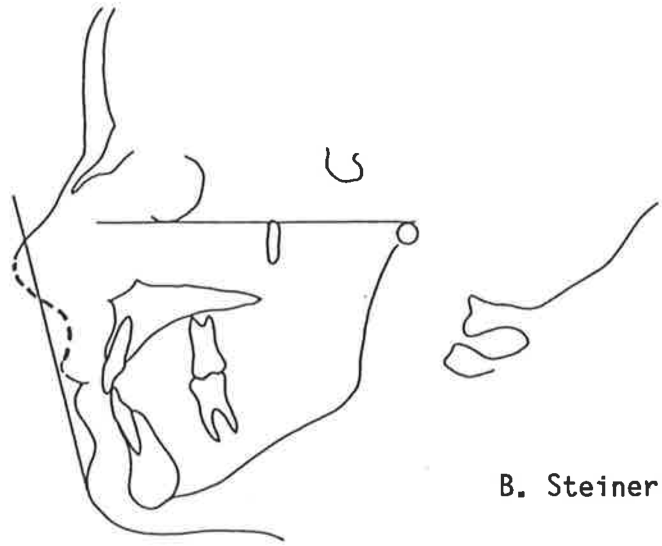
a "law of lip function" based on observations using the "E" line : "In the normal white person at maturity, the lips are contained within a line from the nose to the chin, the outlines of the lips are smooth in contour, the upper lip is slightly posterior to the lower lip when related to that line, and the mouth can be closed with no strain". Ricketts described the importance the form and function of the face in profile and frontal views, and tongue function, in facial aesthetics.

Rakosi (1982) summarized several soft tissue analyses. The three most standard methods relating the lips to the chin and nose were Ricketts' "E" line, Steiner's "S" line analysis and Holdaway's "H" line and "H" angle. The normal characteristics of these analyses were described (Figure 15). Rakosi also cited the proportional analyses: the "rule of thirds" and the 45%/55% "rule" relating the upper and lower faces. The Schwartz method of profile analysis was also described, which analysed the face in terms of Frankfort horizontal, a perpendicular through the orbit and a line from subnasale to the chin.

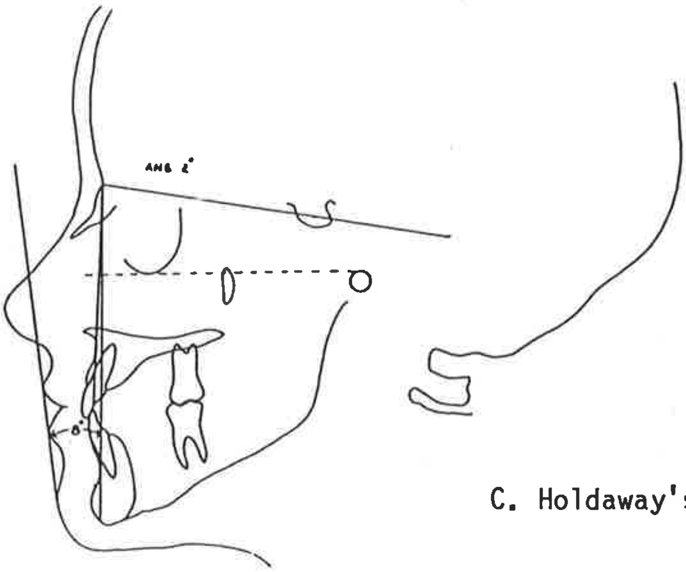
Holdaway (1983) proposed a quantitative analysis using 11 linear and angular measurements to quantify facial aesthetics as a guide to treatment planning. This represented a more sophisticated approach to aesthetic treatment planning than the use of single lines such as the "S", "H" or "E" lines. Once again standards were based on an author's personal concept of facial aesthetics, since the measurements were largely derived from a young female patient who had had a "disfiguring" malocclusion treated to "ideal facial balance". However Holdaway did pay considerable attention to the variation in profile aesthetics and treatment response (refer also to Chapter 1.6B).



A. Rickett's "E" line.



B. Steiner's line.



C. Holdaway's "H" line.

FIGURE 15. Assessment of Profile Aesthetics.
(From Hambleton, 1964).

However, Powell and Rayson (1976) believed that the cephalometric radiograph, being a two dimensional record, should not have been used as an aesthetic gauge. It was noted that such records were usually taken with the teeth in occlusion, which could change the typical appearance of the subject. Powell and Rayson studied the use of various facial views and found that the three-quarter view provided more information than the profile or full face, but noted that because it was difficult to standardize it should be used to complement rather than to replace the other views. Furthermore, Salzmann (1964) noted that when the natural head position varied from Frankfort horizontal, there was an obvious difference in the appearance of the profile. Moorrees and Kean (1958) showed that the natural head position showed less biological variation than any intracranial reference lines and believed that it was the best way to orient the profile since similar profiles, if oriented on intracranial references, could appear different (Figure 16).

Stoner (1955) and Burstone (1958) produced measurement standards derived from samples selected on the basis of "good" facial aesthetics. Stoner (1955) compared his standards to a treated group also with "excellent" aesthetics and it was found that their measurements compared favourably. Stoner believed that the chin had very little influence on facial aesthetics. He concluded that the aesthetic standards he produced were based on his own concepts of beauty and need not be accepted. Burstone (1958) produced standards of soft tissue measurements derived from a sample of young adult faces selected on the basis of good aesthetics by a panel of artists. The disadvantages of the standard were recognized as being: (1) the nose was not included; (2) means and standard deviations represented sample bias; and (3) appearance did not just depend on morphology. Burstone recognized that the amount of facial

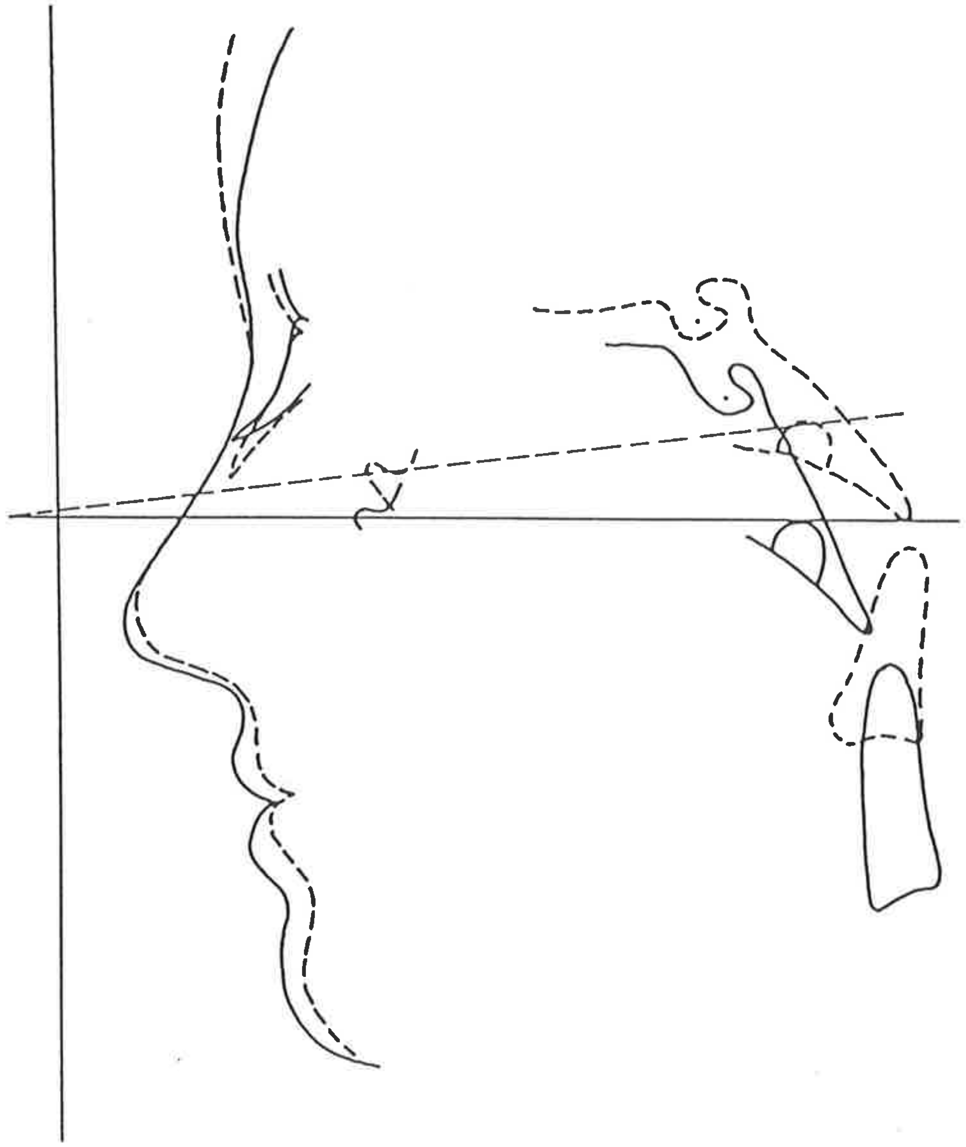


FIGURE 16. Marked differences in the inclination of the cranial base and Frankfort horizontal in two females with close similarity in facial profile. The cephalometric radiographs were taken with the head in natural position. The vertical is shown for reference purposes.

(From Moorrees and Kean, 1958).

variation possible before profile aesthetics were impaired could not be determined because this depended on the critical nature of the observer. Factors believed to influence an observer's concepts of facial aesthetics were discussed.

Although quantification of facial aesthetics is difficult, various authors have proposed definitions for important elements in aesthetic interpretation. Stoner (1955) cited Tweed's (1953) concept of "normal" as being "that balance and harmony of proportions considered by the majority of us as most pleasing in the human face". Peck and Peck (1970) defined facial harmony as "the orderly and pleasing arrangement of facial parts in the profile", proportion as "the comparative relation of facial elements in the profile" and orientation as "the relationship of facial profile parts to the head". The aesthetic profile was described in terms of a "profile flow" consisting of a series of "s" shaped curves that demonstrated regularity and evenness, with irregularities or acute curves interrupting an otherwise harmonious profile (Figure 17).

Authors such as Bloom (1961), Hambleton (1964), Peck and Peck (1970) and Powell and Rayson (1976) have all concluded that it was impossible to produce a formula or analysis for facial aesthetics that would please everyone. Powell and Rayson (1976) believed that facial beauty was virtually impossible to study scientifically, because while facial changes could be observed objectively, the aesthetic interpretation, therefore, remained subjective. They believed that the concept of schematic formulae to assess facial aesthetics could not match the intuitive judgement of an observer when applied to a range of facial types, and that such formulae could not provide for subjective variation between observers. The nose, proportions of upper and lower

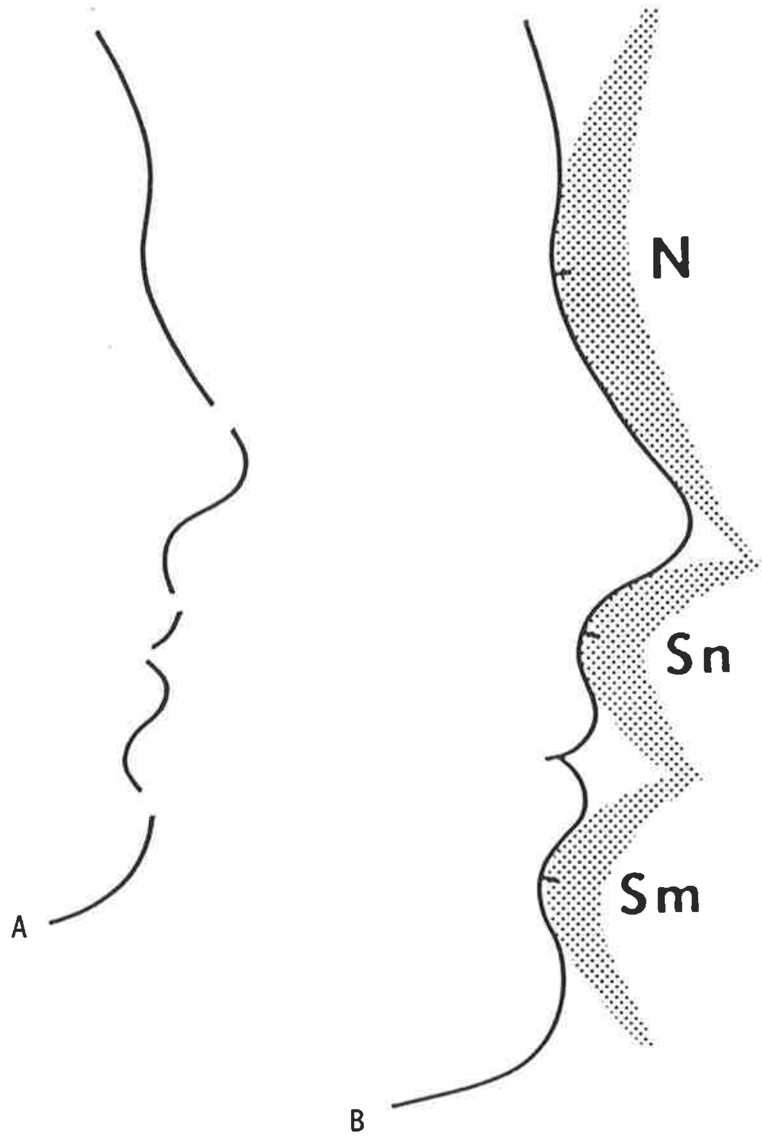


FIGURE 17. Profile harmony.

A. Harmonious profile flow. Represented by a series of smooth 'S' - shaped curves.

B. Facial harmony. The relative profile concavity observed at nasion (N), subnasale (Sn), and supramentale (Sm) affects total profile harmony.

(From Peck and Peck, 1970).

lips, and chin were all inter-related individually, and according to the face as a whole, according to these authors. Treatment planning should be evaluated against changes in the individual face. Peck and Peck (1970) concluded: "Obviously there is no such thing as an equation for facial beauty. No numbers or devices can totally express the complexities of facial aesthetics".

C. Aesthetic Assessment of Treatment Results

The majority of studies of treatment results involving the soft tissues were noted to make aesthetic judgements based on the authors own subjective impression (for example, Anderson et al., 1973). The following discussion indicates that previous studies have used various methods to analyse the aesthetic results of orthodontic treatment.

Baum (1961) related the change in position of the upper incisor to the soft tissues due to treatment and growth in young adolescents. It was found that, due to sex differences in growth, the male dentition tended to retrude relative to the profile due to growth at the chin and nose such that, in this author's opinion if the incisors were retracted too far in treatment, the result would be poor aesthetically, with the lips becoming too concave.

Merrifield (1966) proposed the use of the profile line, a modification of the Holdaway "H" line which was a tangent from the chin to the most prominent lip and its intersection with the Frankfort horizontal which was named the "Z" angle. Using this method, Merrifield believed that young females showed a better chin-lip relationship at the end of treatment than the males.

Angelle (1973) used the "H" line, "E" line and "S" line to assess the profile changes due to orthodontic treatment and reached the conclusion that orthodontic treatment markedly improved the profile; the mean values after treatment were found to be close to the ideal values proposed by Holdaway, Ricketts and Steiner.

De Laat (1974) produced silhouette profiles of his 150 patients (pre- and post-treatment) and showed each pair to each member of a group of 15 non-professional laymen who chose the most aesthetic profile of the pair and rated the difference in change between the two. A negative score was assigned if the pre-treatment record was selected as more aesthetic. The ten most appreciated post-treatment profiles from each of the three treatment groups were selected also and arranged in a Q-sort frame, the best profiles from each group were then combined and a scoring system produced to rate all the profiles in each treatment group.

De Laat found in the Class I group that all 20 Begg profiles were considered improved and in the Riedel and Tweed groups the numbers were 14 and 17 respectively. The mean positive scores (maximum, 3) were Begg 1.6, Riedel 1.4 and Tweed 0.9. The negative changes received a -1.0 score in the Riedel group and -0.7 in the Tweed group. In the Class II, division I group 28 of 30 Begg profiles were judged to have been improved and in the Riedel and Tweed groups improvements were noted in 25 and 27 cases respectively. The mean positive scores were Begg 1.0, Riedel 1.6 and Tweed 1.7. The negative changes received mean scores of Begg -1.3, Riedel -0.9 and Tweed -0.8. De Laat's conclusion was that both edgewise Class I groups showed negative and positive changes, the Begg group only positive changes. Moreover, the quality of the positive changes in the Begg group were judged to be higher than in the other two groups. De Laat believed that this may have been due to the fact that the Begg technique used only intra-oral elastics while the edgewise techniques used more retraction auxiliaries, and that this "could have prevented the developing of dished-in profiles in the Begg group, which in fact did happen in the other groups". The more "flattened" Tweed profiles received a larger negative score than the Riedel group which he believed may be explained by the increased amount of dentoalveloar retraction in the Tweed group.

The mean positive scores for changes in the Class II, Division I cases were lowest in the Begg group and again De Laat (1974) explained this as being due to a difference in treatment method, this time in favour of the Tweed method with more retraction producing more improvement in facial harmony.

Differences between the five most appreciated profiles from each group were examined, and it was found that the Begg Class I was the least appreciated of the three Class I groups, which was believed to be influenced by the poorer pre-treatment harmony of the Begg group compared to the two edgewise groups. De Laat believed that the five best of each group may have had the best pre-treatment aesthetics also.

In the Class II, division I group the five best Begg profiles were less appreciated than the five best Tweed profiles and the pre-treatment harmony in each of the five were also found to be better than the rest of the group. It seemed likely that the profiles that were best during treatment were also profiles with the best harmony after treatment according to De Laat. The possible factors involved which affected the judgement of facial harmony were found to involve: (1) lip opening, positioning; (2) production of a dished-in profile due to lip retraction and/or nose and chin growth; (3) humping of the bridge of the nose; and (4) little or no changes causing rather arbitrary preferences.

De Laat (1974) also evaluated correlations between the cephalometric changes in the area of the dentoalveolar tissues and lips and the changes in facial harmony. No differences were observed between the subgroups and it was concluded that all three methods had similar influences on facial harmony. A positive change in facial harmony correlated with increased steepness of the upper lip, retraction of its vermillion border and retraction of the crown of the upper incisor. In the mandibular area only increased steepness of the lower lip correlated with a positive change in facial harmony. Changes in upper and lower labial sulci and lip relation were found to have no influence on facial harmony. De Laat concluded that these correlations indicated general tendencies and should not be used for prediction of changes in the individual patient.

Chang (1983) found that the rating of profile attractiveness of Chinese patients by Chinese always improved after treatment regardless of extraction, non extraction or retraction or protraction of the teeth. Profile attractiveness was associated with flatter lip postures and straighter facial contours. An inconclusive relationship was determined between cephalometric measurements and profile aesthetic ratings.

No attempt has been made to "rate" the aesthetics of the subjects using techniques such as De Laat (1974) and Chang (1983). Their results provided little in the way of objective insight into the relationship between profile changes and aesthetics. The results of Chang (1983) and De Laat (1974) were sample dependent. Chang (1983) studied Chinese patients and De Laat (1974) also made comment on the possible reasons for aesthetic differences between his various groups of cases.

Discussion in previous sections of this chapter has indicated that the study found very similar results to other studies using Begg, and mainly edgewise appliances. On average, the occlusion was closer to "normal", the curl in the upper lip increased, and in the lower lip decreased, as the upper incisors were removed from the interlabial region permitting the lips to move towards a more closed position. The "profile flow" (Peck and Peck, 1970) in the region of the lips was therefore smoothed on average, and consisted more of a series of "S" shaped curves with more regularity and evenness and less irregularities or acute curves compared to the pre-treatment situation. The profile aesthetics were therefore judged to be better after growth and treatment.

To further examine the influence of growth and treatment on the facial profile five cases from the sample were selected. These are presented in Appendix 16. Cephalometric tracings (superimposed on the same marks made on the films for the main study), profile photographs, graphs of Z-scores (using selected variables) and treatment data have been included for each subject. The cases were selected primarily on the basis of lip and incisor changes after growth and treatment. These cases highlight the great range of individual responses to growth and treatment. Only subjective judgements regarding profile aesthetics can be made.

Of the total sample only one variable for one subject had a score in excess of 3 standard deviations from the mean for the pre-treatment data. For the pre-treatment/post-treatment differences, only six subjects had any scores in excess of 3 standard deviations from the mean. Three subjects had only a single variable in excess of 3 standard deviations from the mean. One subject had extreme Z-scores for the lip concavity variables which was mainly due to a difference in lip posture between the two cephalograms for this subject, when the films were re-examined.

Case 1 was a subject who had close to mean values for as many of the variables as possible before treatment, and for the before and after treatment differences. Only two variables exceeded ±2 standard deviations from the mean before treatment (V HT nasion, and convexity including the nose). No variables exceeded ±2 standard deviations from the mean for the differences. This patient was not necessarily the "most average" in all respects, but represented a case example of the mean changes.

Case 2 represented an extreme where the upper and lower incisors and upper and lower lips were retracted approximately 1 standard deviation less than the mean but the nose, and especially the chin grew forwards more than the mean with the result that this patient had a decidedly "dished in" face after treatment (unfortunately there was agenesis of several lower teeth also).

Case 3 represents less than average upper incisor retraction and the lip change was close to the mean.

Case 4 had close to mean incisor changes and yet lips (and other soft tissues) moved forwards from 1 to 2 standard deviations more than the mean.

Case 5 had a large interlabial gap and short upper lip before treatment. A large amount of horizontal and vertical soft tissue movement occurred, associated with a greater than normal incisor movement.

CHAPTER 5

CONCLUSIONS

1. Standard procedures were used to reduce the effect of random error on the results. These included selection of cases according to radiographic quality, the use of accepted landmark definitions, a standardized method of landmark location, an electronic digitizer to record landmark coordinates and computer plots to identify "wild" recordings. Replicated measurements were made in order to quantify the error component. The error of the method involved in landmark location, superimposing and digitizing was low. Of the 66 cephalometric variables, 4 were subject to a significant component of error at the $p < 0.05$ level, and at the $p < 0.01$ level of probability. The error of digitizing alone was non-significant.

2. The superimposition method of Björk (1968) and Björk and Skieller (1983) was used in a study of the soft tissue profile changes resulting from orthodontic treatment for the first time. This method, which utilised stable structures of the anterior cranial base, had a sound biological rationale, was of acceptable accuracy, and was therefore preferred to the constructed methods of superimposition and measurement used in most previous soft tissue studies.

3. The sample size was adequate. The data were normally distributed allowing the application of routine statistical procedures.

4. Very few statistically significant differences were found between the mean values of the male and female groups calculated from the pre-treatment data. However, after treatment, some statistically significant differences between males and females were observed and these were due mainly to a sex difference in growth response:
   a. The tip of the nose grew forwards significantly more in males than females by 1.5 mm ($p < 0.01$). Otherwise, very few horizontal variables displayed significant sex differences.
   b. Most vertical hard and soft tissue variables were significantly larger in males than females, indicating that the males grew more vertically than the females.
   c. No angular variables displayed significant sex differences, perhaps indicating similarities in proportion.
   d. In general, the males were more variable than the females, significantly so for several variables.
   e. These results confirmed the sexual dimorphism and sex differences in growth responses observed in previous cephalometric growth studies.

5. Treatment and growth changes in the region of the lips and incisors could not be absolutely separated in this study, mainly because of the lack of an untreated control sample, or a sample of non-growing treated cases. Therefore, the observed changes resulted from a combination of growth and treatment. However, the following mean changes were determined as being mainly as a result of treatment:
   a. The upper incisors were retracted and uprighted due to treatment, and moved downwards and backwards as a result of growth and treatment.

b. The upper lip moved downwards and backwards as a result of growth and treatment as it followed the incisor retraction. The upper lip increased in concavity after treatment; that is, it assumed a more curled profile. The upper lip retraction was greater lower down on the lip, away from the nose. The vertical relationship of the upper lip and the upper incisors changed very little after growth and treatment.

c. The lower incisors were intruded, retracted slightly and were proclined approximately 5^{o} in both sexes.

d. The lower lip retracted and reduced in concavity; that is, the extent of the labiomental fold reduced as the incisors were retracted and the upper incisors were removed from the interlabial region.

e. The interlabial gap reduced after treatment.

f. The nasolabial angle opened by 6.7^{o} in males and 5.2^{o} in females after treatment.

g. The skeletal profile became straighter after treatment. The angle ANB reduced by 2.5^{o} in males and 2.1^{o} in females after treatment, due mainly to a retraction of A point.

h. The soft tissue profile was straighter after treatment as measured by the angles S-NAS-SLS, S-NAS-ILS and SLS-NAS-ILS and showed a similar pattern of change as the corresponding skeletal SNA, SNB and ANB angles.

i. The mandibular plane opened by only 1.2^{o} in males and 0.4^{o} in females.

j. The soft tissue chin closely followed the underlying hard tissue chin and was largely unaffected by growth or treatment. However, there was a possibility that some forward soft tissue chin movement may have occurred as a result of reduced mentalis muscle strain.

6. Horizontal change of the upper lip and incisors did not occur in a 1:1 ratio. the ratio of upper lip to upper incisor retraction was 3.8:1 in males and 3.:1 in females which indicated less lip response to incisor retraction than most previous studies, most of which were of edgewise treatment. A ratio of 2.5:1 has commonly been reported. The ratio of lower lip to lower incisor retraction was 2.5:1 in males and 0.8:1 in females. The hypothesis that the lips tend to have a degree of postural independence to the teeth (Burstone, 1967) was supported.

7. A complex pattern of moderate correlations were observed between variables of horizontal lip and dentoalveolar changes. Discretion should be exercised in the interpretation of the numerical values of the correlation coefficients due to the specious nature of many of these.

8. The findings of previous studies were confirmed, that a complex relationship exists between dentoalveolar changes and soft tissue changes in the region of the lips as a result of treatment. Lip response could vary according to factors of soft tissue growth and muscular tone, lip length, thickness and strain, extent of incisor retraction, amount of vertical incisor change, amount of mandibular growth and rotation, the influence of the structure and growth of the soft tissues of the nose and chin, general qualitative and quantitative growth factors, and age of the patient. However, due to the way in which variables were measured in the present study,

no detailed conclusions in relation to these individual factors could be made.

9. On average, the soft tissue profile was not "dished-in" by Begg orthodontic treatment. The figures indicated that, for example, the nasolabial and lower lip angles were opened, and the upper lip angle increased. As a result, there was a more even, smoother flow of profile curves. Such a pattern was found to be associated with better profile aesthetics by Peck and Peck (1970). This was confirmed by a study of individual cases from the sample, for which Z-scores were calculated. This allowed an appreciation of the great extent of individual variation that occurred in growth and treatment responses which has been emphasized by most previous authors of soft tissue studies. Cases in which the soft tissue profile could be judged to be "dished-in" tended to have large noses and chins, and/or considerable growth in these regions during the time of treatment. Moreover, this was often more important in terms of the overall profile than the lip retraction, as also found by authors such as Rudee (1964) and Branoff (1971).

10. As a result of considerable individual variation in morphology and growth and treatment responses, the multifactorial relationship between lip and incisor changes is complex. In addition, because of possible sample dependance of the statistics, the findings should not be used to predict the soft tissue response due to growth and orthodontic treatment.

11. A consideration of sex differences and the possible factors influencing the morphology, growth and treatment responses of the soft tissue profile of individuals should be allowed for in orthodontic treatment planning.

12. As a result of this study, the first statistical analysis of orthodontic records from the Adelaide Dental Hospital, the following avenues for further research are proposed:

    a. A long term follow-up of patients, possibly from this sample. This could examine factors such as stability of treatment changes, late growth changes and the long-term response of the soft tissues to treatment.

    b. A study of factors influencing the lip response to incisor retraction (listed in 8 above). For example, factors such as lip length and thickness could be studied in relation to factors such as overbite and overjet reduction. Very little study of the areas outlined in a. or b. has been made, and findings would help confirm, or otherwise, contentions made in the literature regarding the relationship between lip and incisor retraction. For example, Holdaway (1983) contends that the relationship between lip and incisor retractions is not linear.

    c. Soft tissue changes in region of the face could be studied by other methods of superimposition; for example on stable structures of the maxilla and mandible, as described by Björk (1968) and Björk and Skieller (1983).

    d. A more detailed analysis of soft tissue profile could be made using computer based methods and appropriate algorithms for quantifying complex curves and shapes.

e. The relationship between various dental arch parameters and hard and soft-tissue facial form could be studied using dental models as additional material.

f. A study comparing the influence of lip posture on the relationship between hard and soft tissue changes has not been made. The contention as to which lip position (relaxed or closed; Burstone, 1967) is best for the study of the soft tissues remains.

g. Using technological advances in computer graphic techniques a comprehensive three-dimensional analysis (using for example stereophotogrammetry) could be made on a treated sample of patients.

h. The research methodology could be extended to other classes of malocclusions and could include cases treated by orthognathic surgery.

CHAPTER 6

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Am. J. Orthod. 85. 182.

ERRATA

PAGE 81: LINE 4.
'practise' should read 'practice'.

PAGE 86: LINES 13, 14.
'pattern of malocclusion' should read 'incisor relation'.

PAGE 88: LINE 6.
'beggining' should read 'beginning'.

PAGE 88: LINE 20.
'2.4C(1)' should read '1.4C(1)'.

PAGE 152: LINE 12.
'considerble' should read 'considerable'.

PAGE 157: LINE 19.
'Appendix E' should read 'Appendix 12 Table 12E'.

ADDENDA

PAGE 128: PARAGRAPH 3.

Cases were excluded on the basis of extreme strain of the soft tissues of the lips on the Baiseeee basis of the following:

1. Upper lip flattening (absence of releeee relaxed curl, or even convex form).
2. Flattening in the region of the chin (due to mentalis contraction).
3. Extreme labiomental fold.

Further clarification appears in the last paragraph of page 130.

PAGE 129: PARAGRAPH 1.

Cephalometric radiographs were taken before treatment (within 3 months of appliance insertion) and after treatment (on the day of bands off or within several days thereafter). Retention changes were therefore not examined.

PAGE 130: PARAGRAPH 2.

The amount of incisor retraction in each subject, rather than the extraction pattern per se, was considered more important due to variables of extraction space loss from aligning crowded teeth and because of the considerable variation in the use of mechanotherapy. Consequently, the direct effects of extraction pattern upon incisor retraction were not considered germaine to the study of soft tissue responses.