CEPHALOMETRIC EVALUATION OF SOFT TISSUE PROFILE CHANGES FOLLOWING DOUBLE JAW SURGERY

(Le Fort I and Vertical Subsigmoid Osteotomy)

by

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SUMMARY

A retrospective cephalometric study was undertaken to evaluate the soft tissue changes following orthodontic decompensation, Le Fort I osteotomy and surgical setback of the mandible using the technique of intraoral vertical subsigmoid osteotomy. No genioplasty was performed.

The investigation involved a detailed analysis of 23 sets of serial cephalometric records consisting of 10 males and 13 females, in the Oral and Maxillofacial Surgery Unit of the University of Adelaide. The female sample ages ranged from 16 years, 2 months to 35 years, 5 months with a mean age of 20 years. The male sample ages ranged from 16 years, 5 months to 59 years, 5 months with a mean age of 20 years.

Of the 23 sets of patient records, 23 had cephalograms available within three months prior to surgery and within six months after surgery. 20 subjects (87%) also had cephalograms taken within one year following surgery. 10 subjects (43%) had cephalograms taken within two years after surgery. 9 subjects (21%) had cephalograms taken within three years after surgery. This series was studied for short and long term soft tissue changes.

START	23 sets
WITHIN three months PRIOR TO SURGERY	23 sets
WITHIN six months POST SURGERY	23 sets
WITHIN one year POST SURGERY	20 sets
WITHIN two years POST SURGERY	10 sets
WITHIN three years POST SURGERY	9 sets

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 standardised method of landmark location, an electronic digitiser 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, superimposition and digitisation was low. For some variables, the differences between the two sets of determinations were found to be significant at the 5% level. In these instances, they were found to require careful interpretation. The error of digitisation alone was not significant.

The superimposition method of Björk (1968) and Björk and Skieller (1983) was used in this study. This method, which utilised stable structures of the anterior cranial base, had a sound biological rationale and was of acceptable accuracy.

The sample size was small but generally larger than those of previously reported soft tissue studies of a similar nature. Therefore, the results need to be interpreted with some degree of caution. The data was normally distributed allowing the application of routine statistical procedures.

Some statistically significant differences were found between the mean value of the male and female groups calculated from the presurgical data. The changes following surgery were generally not statistically significant between males and females.

The present study is unique in that it is the first known cephalometric evaluation of soft tissue profile changes following Le Fort I advancement and vertical subsigmoid setback. However, the soft and hard tissue changes appear comparable with other studies using different techniques.

Horizontal soft tissue changes of the upper lip were positively correlated to horizontal hard tissue changes of the maxilla: A:SUN 1:0.81 ($r=0.80$, $p<0.05$); A:SLS 1:0.74 ($r=0.59$, $p<0.01$); A:LS 1:0.53 ($r=0.68$, $p<0.01$). Soft tissues generally lagged behind the hard tissues.
Vertical soft tissue changes of the upper lip were positively correlated to vertical hard tissue changes of the maxilla: A:SUN 1:0.79 ($r=0.43$, $p<0.05$); A:SLS 1:0.64 ($r=0.18$); A:LS 1:0.66 ($r=0.33$).
Horizontal and vertical soft tissue changes of the lower lip were positively correlated with horizontal and vertical changes at B-point: Horizontal: B:LI 1:0.50 ($r=0.69$,$p<0.01$); B:ILS 1:0.69 ($r=0.93$, $p<0.01$). Vertical: B:ILS 1:0.80 ($r=0.56$, $p<0.01$).
Changes of the soft tissue chin were positively correlated with changes at pogonion: 1:0.94 ($r=0.94$, $p<0.01$). These correlations need to be interpreted cautiously as the sample size is small.

The upper lip thinned following maxillary advancement. For every 1 mm of maxillary advancement (at A-point), the upper lip thickness reduces by 0.61 mm ($r=0.71$, $p<0.01$). The upper lip lengthened following surgery but this was not statistically significant.

The lower lip length reduced following surgery by a minimal amount but this was not statistically significant. This may be due to the lower lip coming under the influence of the upper lip following surgery. Lip competency is established following surgery.

During the period six months to twelve months postsurgery, the maxilla moved 43% superiorly and 28% backwards. The mandible moved 11% forwards and 34% superiorly. Upper incisors proclined during this period. The upper incisor proclination may be due to forward movement of the mandibular arch and postero-superior movement of the maxilla. The lower incisors also proclined during this period but the change was minimal. This may be due to alteration in the position of gonion at surgery since this point was often close to the site of surgery and could have influenced the lower incisor to mandibular plane angle. Ching (1995) reported proclination of lower incisors during this period.

The nasolabial angle increased in the presurgery to postsurgery six months period. Labiomental fold deepened in the presurgery to postsurgery six months period. Lip form established at surgery appears to be maintained in the longer term.

Thick and thin upper lips responded similarly to surgery. Thick and thin lower lips also responded similarly to surgery. Lip thickness did not seem to influence the surgical response.

The magnitude of surgical advancement of the maxilla did not affect the upper lip response. The magnitude of surgical setback did not affect the lower lip response. The soft tissue response is consistent and proportional to the skeletal change.

Age and sex do not appear to have a bearing on the soft tissue response of lips following surgery.

Minimal skeletal, dental and soft tissue changes were noted 12 months postsurgically indicating stability of the Le Fort I and vertical subsigmoid osteotomy procedure. Most of the correction was maintained at 12 months postsurgery. However, some degree of caution is required when interpreting the data at 24 months and 36 months postsurgery as sample size becomes extremely small.

STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university or tertiary institution and, to the the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give my consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

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CHAPTER ONE

INTRODUCTION

The first surgical soft tissue studies were associated primarily with mandibular reduction procedures. As the mandible was set back there were notable soft tissue changes in the upper lip length, lower lip fullness and inferior labial sulcus depth (Knowles 1965; Aaronson 1967; Fromm and Lundberg 1970; Hamula 1970). Björk, Eliasson and Wictorin (1971) observed that the chin moved posteriorly more than the lower lip, as the mandible was rotated back. It was reported that for 1 mm of posterior movement in hard tissue pogonion the soft tissue lip fell back 0.6 to 0.75 mm and the soft tissue chin moved posteriorly 0.9 to 1.0 mm (Hershey and Smith 1974; Lines and Steinhauser 1974). Willmot (1981) reported soft tissue profile changes following correction of Class III malocclusion by mandibular surgery and illustrated that when planning the soft tissue profile response to mandiublar setback surgery, one cannot rely on the soft tissues of the lips and chin following the mandible posteriorly in a uniform one to one relationship. He reported that the soft tissues tend to lag, to a small extent, behind any movement made by the hard tissues. Moss and Willmot (1984) reported on factors associated with relapse of Class III cases treated by mandibular surgery. They noted that the relapse was related to the occlusion and alteration in muscle patterns and a lack of change in the position of the centroid of tongue as the jaw was moved back with surgery. Lew et al. (1990) evaluated soft tissue profile changes following intraoral ramus osteotomy in Chinese adults. They reported soft tissue to hard tissue ratio of 0.95:1 for the chin. They concluded that for accurate soft tissue prediction ratios from one racial type should not be applied to other racial types. Ching (1995) reported on the stability of vertical subsigmoid osteotomies and concluded that the vertical subsigmoid osteotomy is a stable procedure.

Early studies of maxillary advancements found that the upper lip responded variably with ratios ranging from 0.4:1 to 0.82:1 (Lines and Steinhauser 1974; Dann, Fonseca and Bell 1976; Freihofer 1976; Araujo et al. 1978; Mansour, Burstone and Legan 1983; Rosen 1988). A smaller group of studies analysed cases in which the soft tissue was surgically manipulated using an Alar Base Suture and V-Y closure. They found that soft to hard tissue ratios in maxillary surgical advancements were approximately 0.9:1 (Schendel and Williamson 1983; Wolford, Hilliard and Dugan 1985; Carlotti, Aschaffenburg and Schendel 1986).

Epker, Turvey and Fish (1982) were among the first to discuss simultaneous two jaw surgery. They found that the autorotation of the mandible is seldom adequate to correct a Class II relationship in those patients with both vertical maxillary excess and mandibular deficiency. Therefore, not only would the maxilla have to be impacted, it would also have to be posteriorly repositioned to achieve a Class I occlusion. In patients with an obtuse nasolabial angle the posterior movement of the maxilla would allow the lip to fall back and accentuate an already unaesthetic situation. However, if the maxilla and mandible could both simultaneously be advanced, the nasolabial angle would decrease, improving the overall facial aesthetics. Some of the previous studies of stability with two jaw surgery have focussed on patients with skeletal openbite problems (Moser and Freihofer 1980; LaBanc et al. 1982; Hennes et al. 1988: Satrom et al. 1991; Turvey et al. 1988).

Proffit et al. (1991b) reported on stability after surgical-orthodontic correction of skeletal Class III malocclusion by combined maxillary and mandibular procedures. When the maxilla was moved forward and the mandible set back with minimal vertical change, moderate relapse tendencies were observed in both jaws, but most of the correction was maintained at 1 year. When the maxilla was moved down and forward while the mandible was set back, moderate vertical relapse of the maxilla and anteroposterior relapse of the mandible followed. Stability of the downward movement of the maxilla was, on average, better than that resulting from maxillary surgery alone. McCance et al. (1992a and 1992c) reported on maxillary advancements (Le Fort I and Kufner osteotomy) and mandibular setback (bilateral sagittal split osteotomy and vertical subsigmoid ostetomy) using CT and laser scanning.

As a surgical technique, intraoral vertical subsigmoid osteotomy has the following advantages; no damage to the inferior dental neurovascular bundle that is associated with bilateral sagittal split osteotomy (Trauner and Obwegeser, 1957), no resulting facial palsy of the facial nerve (Loh et al., 1989) and no unsightly scarring (Egyedi et al., 1981) which may be associated with the extraoral approach. Intraoral subsigmoid osteotomy was the preferred technique to set the mandible back at the Adelaide Dental Hospital for a number of years.

Simultaneous two jaw surgery has become a common and necessary form of treatment in severe dentofacial deformities. It is extremely important that the orthodontist and oral surgeon understand the short and longer term soft tissue changes which can be expected from a given amount of surgical dento-osseous movement.

1.1 SPECIFIC AIMS

The specific aims of this investigation are:

1. To develop forecasts of the profile response of the soft tissues of the lower lip and chin to mandibular setback by vertical subsigmoid osteotomies.

2. To develop forecasts of the profile response of soft tissues of the upper lip and nose to Le Fort I maxillary advancement osteotomy.

3. To examine the effects of the presurgical distance (horizontal or vertical) between soft tissue landmarks and the underlying hard tissue contours, upon the response displayed by these tissues to combined Le Fort I and vertical subsigmoid osteotomies and to determine if thin lips would behave differently to thick lips following orthognathic surgery.

4. To examine the effects upon soft tissues of the lips (comparing large surgical movements with smaller surgical movements).

5. To determine if any change occurs in the soft tissue profile between the time periods of six months after surgery and at least one year after surgery.

6 To determine whether there were significant differences in hard and soft tissues preoperatively and postoperatively when the sample is divided according to age and sex.

CHAPTER TWO

REVIEW OF THE LITERATURE

FACIAL SOFT TISSUE CHANGES ASSOCIATED WITH ORTHODONTIC TREATMENT AND ORTHOGNATHIC SURGERY

2.1 ANALYSIS OF FACIAL PROFILES

One of the first analyses of the facial profile was done by the Dutch anatomist, Camper (1794). He developed Camper's Angle to demonstrate variations in different racial groups and analyse evolutionary changes in the human face. In the early 1900's, Angle (1907) was very aware of the facial form and noted that subtle changes in the profile could markedly improve the facial appearance. However, no quantitative methods were used to describe the face. Angle wrote: "We know that while all human faces are greatly alike, yet they all differ. Lines and rules for their measurements have never been sought for determining some basic line or principle from which to detect variations from the normal, but no line, no measurement admits of anything nearly like universal applications."

What constitutes a good profile? Angle believed that balance and harmony of the face were achieved if there was a full complement of teeth in good occlusion and normal position. In contrast to Angle, Hellman (1939) found that a normal occlusion does not necessarily bring about an aesthetic face and emphasised the need for standardisation of facial measurements and the variations that exist. Case (1921) encouraged his colleagues to become aware of facial aesthetics in establishing their treatment goals. Herzberg (1952) believed that harmonious faces did not possess flared incisors and high mandibular plane angles. Tweed (1954) believed that the angulation of the lower incisors was the key to stability and facial aesthetics. Riedel (1957) and Peck and Peck (1970) analysed aesthetically pleasing faces and found that in most cases, a straight or slightly protrusive profile was preferred in Caucasians.

The challenges that confront the clinician in achieving optimal facial aesthetics may only be dealt with by addressing the following questions:

1. What constitutes optimal facial aesthetics?
2. How may facial form be quantified?
3. How do the soft tissues of the face respond to therapeutic intervention aimed at their supporting dentoskeletal framework?

Many workers have focused on the first of these three questions. Tweed (1946) and Stoner (1955) studied a panel of orthodontists' choices of desirable facial aesthetics. Burstone (1958) and Goldman (1959) chose to use artists as judges of which faces were most pleasing. Riedel (1957) and Peck and Peck (1970) have used the opinions of members of the general public in their analyses of the aesthetic face.

Hambleton (1964) reviews facial aesthetics using ancient and modern artworks to demonstrate prevailing concepts of beauty. Lines et al. (1978) used a selection of judges with varying degrees of training in assessment of profiles. They found that the "ideal' male profile differed from the "ideal" female profile and recommended that clinicians be aware of these differences in establishing treatment goals.

A new era of orthodontic analysis began with the introduction of radiographic techniques by Broadbent (1931) in his paper on cephalometric radiography. Riedel (1950,1957) analysed facial profiles and found that the soft tissue covering was closely related to the skeletal and dental framework. In 1959, Neger stressed the need for a separate orthodontic soft tissue evaluation in addition to the dentoskeletal analysis. They also noticed that a good occlusion does not always accompany a normal facial profile. Many orthodontic soft tissue analyses ensued. Ricketts (1957) developed the aesthetic plane. Burstone (1958) suggested a comprehensive soft tissue analysis and provided angular and linear norms for the variables described. This analysis was further refined and condensed in 1980 by Legan and Burstone for specific use in treatment planning for orthognathic surgery. Steiner (1959) analysed the angular and linear relationships between the teeth and skeletal components. Merrifield (1966) introduced the "Z-line". More recently, Spradley, Jacobs and Crowe (1981) developed the true vertical "Sprad" line. The "H-line" and corresponding angle was proposed by Holdaway (1983), while Burstone (1967) described the 2 mm interlabial gap, 2 mm upper incisor exposure, and the optimum vertical proportions of the upper lip to lower lip and chin. Aesthetically pleasing smiles were analysed by Hulsey (1970). He found that on smiling, the upper lip height was even with the gingival margin, the corners of the smile were above stomion, and overall, symmetry was present.

Powell and Humphreys (1984) in their book "Proportions of the Aesthetic Face", have listed many angular, linear and proportional dimensions that may be used for assessing the face from both frontal and profile views and provide suggested norms for these parameters.

Moss et al. (1992) described a method for producing an objective way of identifying landmarks on the facial profile leading to a useful segmentation and quantitative description of the contours and features of the face. The method used scale space filtering techniques and curvature analysis, first employed in pattern recognition. The method of analysis of the curves of the face described enabled the operator to avoid the use of points and yet still analyse the changes that have occurred in a meaningful way.

In summary, the literature supports the view that there is no one way to assess ideal facial proportions.

2.2 SOFT TISSUE RESPONSE TO ORTHODONTIC TREATMENT

As orthognathic surgery is a relatively recent addition to the clinical armamentarium, most of the early work on treatment response of the soft tissue profile was conducted on patients undergoing orthodontic or orthopaedic rather than orthognathic treatment. A brief review of this work is appropriate, to allow a comparison of the soft tissue response to surgical treatment with that of other treatment modalities.

Ricketts (1960) suggested that a good "rule of thumb" when predicting the response of the upper lip to incisor retraction is that for every three millimetres of incisor retraction, the upper lip can be expected to thicken by one millimetre (and thus, presumably be retracted by two millimetres). Changes in the vermilion border region of the lower lip were considered to be less dramatic than those of the upper lip, being primarily a postural response to the upper incisor position. Bloom (1961) examined a group of 60 patients, before and after fixed orthodontic therapy, and found high (0.73

to 0.93) coefficients of correlation between movement of dentoskeletal structures and their overlying integumental contours. The lower lip was found to follow the movement of the lower incisor more closely than the upper lip followed movement of the upper incisor. It was suggested that regression equations could be established to allow prediction of soft tissue response to anticipated hard tissue movements.

Hershey (1972) studied the profile changes associated with upper incisor retraction on a sample of 36 postadolescent females, to eliminate any growth changes from his data. Calculation of multiple correlation coefficients, using observed treatment response of several hard tissue points as the independent variable, yielded the data shown in Table 2.1. The hard tissue landmarks were: point A, point B, the most anterior point on the crown of the upper incisor and the most anterior point on the crown of the lower incisor.

TABLE 2.1

SOFT TISSUE LANDMARK	MULTIPLE CORRELATION COEFFICIENTS WITH HARD TISSUE LANDMARK CHANGES
SUPERIOR LABIAL SULCUS	0.71
LABRALE SUPERIUS	0.82
LABRALE INFERIUS	0.58
INFERIOR LABIAL SULCUS	0.78

The author concluded that these correlations were too small to allow for accurate clinical application in predictions, especially in cases where marked incisor retraction was planned, as the strength of the correlation between hard and soft tissue responses decreased as the magnitude of incisor retraction increased. A surprising finding was that dividing the sample into two subsamples, based on pretreatment lip morphology (incompetent versus redundant lips) did not yield significantly different correlations between hard and soft tissue response for each group. On this basis, the hypothesis that incompetent lips would follow the hard tissues more closely than redundant lips was rejected. Hershey (1972) found that as maxillary incisors were progressively retracted, the upper lip response would gradually decrease, which may suggest that perioral soft tissues may be self-supporting to a certain extent.

Roos (1977) examined post-treatment changes on 30 children treated for Class II Division I malocclusions with premolar extractions and edgewise mechanics. Subjects ranged in age from 8 years 8 months to 16 years 7 months before treatment, the mean age being 12 years 3 months. When the recordings were made after treatment, the patients were aged from 10 years 9 months to 18 years 8 months, the mean age being 14 years 5 months. Table 2.2 provides a synopsis of his findings.

TABLE 2.2

HARD TISSUE LANDMARK	SOFT TISSUE LANDMARK	RATIO HARD TO SOFT	CORRELATION COEFFICIENT
UPPER INCISOR	LABRALE SUP.	2.5:1	0.42
LOWER INCISOR	LABRALE INF.	1:0.9	0.82
SUBSPINALE	SULCUS SUP.	1:1.4	0.58
SUPRAMENTALE	SULCUS INF.	1.2: 1	0.69

When examining mean figures, most soft tissue landmarks, with the exception of the upper lip, were seen to follow their corresponding hard tissue landmarks quite closely. However, the degree of individual variation was high, and correlation coefficients variable.

Rains and Nanda (1982) took a different approach to the search for a way of predicting soft tissue responses to orthodontics. They felt that the nature of the perioral soft tissue was too complex to allow its behaviour to be predicted by the use of one independent variable. This led to an attempt to develop predictive equations using stepwise multiple regression analyses, with dental, alveolar, and mandibular base landmark behaviour as the predictors.

The sample consisted of thirty females, over the age of fifteen years, to minimise the effect of growth and any sex differences that may occur. Pogonion and menton were included as predictors in an attempt to allow for any mandibular rotation that may occur during treatment. These two landmarks were found to be statistically significant contributors to the prediction equations of both upper and lower lip behaviour. The behaviour of the lower incisor, on the other hand, was found to be a rather poor predictor of lip response, having a statistically significant role in only one of the six prediction equations derived from the data. This is at odds with Roos (1977).

Oliver (1982) investigated the effect of lip thickness on response of soft tissues to orthodontic treatment using a sample of 40 patients undergoing routine edgewise orthodontic therapy. The average correlation of osseous to soft tissue changes was 0.84 for the entire sample. When subsamples of the highest and lowest quartiles based on lip thickness before treatment were examined, the group with thin lips showed a soft tissue to hard tissue correlation of 0.95, while the group with thick lips failed to show any significant correlation. This suggested that pretreatment lip thickness could be an important predictive variable. This is at variance with Hershey (1972).

Farrer (1984) studied 60 patients, over a two year treatment period, for information about the effects of growth, and especially Begg orthodontic treatment, on the soft tissue profile of the lower face. The sample consisted of 30 males and 30 females of adolescent age, all of whom had a Class II, Division I pattern of malocclusion. It was found that, on average, the males grew significantly more in the vertical direction than the females. The tip of the nose grew forwards significantly more in males than females. The soft tissue chin closely followed the underlying hard tissue chin and was largely unaffected directly by growth or treatment. The upper lip retracted but did not follow the incisors in a 1:1 relationship. A ratio of 3.8:1 in females and 3:1 in males for upper incisor to upper lip retraction was reported. The lower lip had less tendency to follow incisor retraction than the upper lip.

Lew (1990) found that as a result of camouflage treatment of Class III malocclusions on a sample of 38 Chinese adults, the upper incisors were advanced by an average of 1.7 mm while the lower incisors were retracted by 6.4 mm. The corresponding upper and lower lip movements were 1.2 mm and 4.4 mm respectively.

Yogosawa (1990) suggests that two further criteria must be considered when predicting soft tissue response to treatment:

1. The posture of the lips on the pretreatment cephalogram. This study shows that in patients with malocclusions, considerable lip deformation

occurs in attaining lip closure. The author points out that the most accurate predictions of post-treatment lip form can be made if the pretreatment cephalogram depicts the unstrained pretreatment lip morphology.

2. The nature of the pretreatment malocclusion. In comparing results of ten cases of maxillary protrusion with ten cases of bimaxillary protrusion, the author notes that in the bimaxillary protrusions, the retraction of the lower lip was about 70% that of the upper incisor, whereas in cases of maxillary protrusion, the behaviour of the lower lip and upper incisor did not correlate well. In both cases, the upper lip was retracted 30%-40% as far as the upper incisors.

In summary, the literature supports the view that the soft tissue response to orthodontic treatment is by no means a simple or highly predictable phenomenon. In addition to the anticipated changes in dental and skeletal structures, factors such as soft tissue morphology, posture and functional activity need to be considered when attempting to anticipate the reaction of the soft tissues to modification of their underlying dentoskeletal framework. Growth and ageing changes also tend to influence the overall soft tissue response along with treatment effects of adolescents (and perhaps even young adults).

2.3 SOFT TISSUE RESPONSE TO ORTHOGNATHIC SURGERY

2.3.1 Response to Maxillary Surgery

A considerable number of investigations have been conducted into the soft tissue response to maxillary surgery. There is a wide range of surgical manipulations to which the maxilla may be subjected, ranging from subapical alveolar surgery to Le Fort III osteotomies. The Le Fort I osteotomy is the most commonly employed maxillary procedure in modern orthognathic surgical practice. This surgery came into popular use after the work of Bell (1969,1973), relating to the vascularity of the downfractured maxilla and the clinical reports of Bell (1975) and Epker and Wolford (1975).

Lines and Steinhauser (1974) report a hard to soft tissue ratio of 3:2 for maxillary advancement but caution against interpreting this result for clinical purposes as the data were derived from a sample of only three patients, all of whom had clefts of the lip and palate. Several surgical procedures were evaluated by Lines and Steinhauser (1974). A small sample consisting of three cases with maxillary advancements had an 0.66:1 soft to hard tissue ratio. They reasoned that soft tissue in the maxilla was prevented from following the hard tissue in a 1:1 manner because it was firmly connected to the base of the nose.

Dann et al. (1976) analysed the soft tissue response to total maxillary osteotomy advancement. Lateral cephalograms of eight patients (two had cleft lips) which had LeFort I advancements presented post-surgically with a horizontal 0.5:1 labrale superius to upper incisor ratio. There was a decrease in the nasolabial angle which correlated closely with the horizontal incisor measurement with 1.2 degree to 1 mm ratio. Lip thickness decreased by almost 2 mm due to stretching and was not stable until six months postsurgery and patients were not followed up beyond six months. The vertical position of labrale superius was not predictable.

Freihofer (1976) compared the response of the lip to maxillary advancement in cleft lip and palate patients to that in non cleft patients with retrognathic maxilla. The maxilla was advanced by Le Fort I osteotomy in 25 patients in each group and cephalometric records at least six months after surgery were analysed. The ratio of hard tissue to soft tissue movement did not appear to be significantly different between the two groups and was reported for the entire sample as shown in Table 2.3.

TABLE 2.3

HARD TISSUE LANDMARK	SOFT TISSUE LANDMARK	RATIO HARD TO SOFT
A POINT	SUBNASALE	7:4
UPPER INCISOR	LABRALE SUPERIUS	9:5

The author cautions against applying these mean values to individual cases, due to the large variation present in the data. By comparing data from the eight largest maxillary advancements with that from the eight smallest advancements, it was shown that the magnitude of the advancement had no effect on the above ratios. Two variables, however, were found to have significant effects on the soft tissue response:

1. Preoperative lip thickness - subjects with thin lips showed a greater soft tissue response than subjects with thick lips.

2. Surgical manipulation of anterior nasal spine. About half the sample had the nasal spine removed at the time of surgery, while the other half did not. The subjects with intact ANS showed a greater soft tissue response to maxillary advancement, especially at subnasale. Freihofer (1976) examined the soft tissue response six months after maxillary advancement. The horizontal upper lip to upper incisor ratio was 0.55:1 in patients with normal lips and 0.78:1 in patients with thin lips. The nasal tip went forward in a

0.29:1 ratio, while the nasal dorsum was unaffected. The upper lip thinned and increased in length while the lower lip changed just slightly. Araujo et al. (1978) agreed with these findings.

Freihofer (1977) reports on the changes in nasal profile after maxillary advancement, using the same sample. The ratio between advancement of A point and that of pronasale was reported as 7:2. The author explains the clinical impression of flattening of the nose after maxillary advancement by the fact that the nasal tip is advanced less than the nasal base, thus reducing the anteroposterior dimension of the nose. The columella tangent was noted to be angled upwards and forwards in response to the surgery. This movement was more pronounced in the cleft lip and palate subsample and in subjects who did not have surgical recontouring of the anterior nasal spine.

Radney and Jacobs (1981) examined ten cases which had a Le Fort I maxillary intrusion and retraction. Prediction tables based on single and multiple regressions of the following points were discussed: (1) the nasolabial angle increased slightly with maxillary impaction and retraction; (2) the upper lip soft tissue points labrale superius, superior labial sulcus, and subnasale moved posteriorly in a 0.67, 0.33 and 0.33 ratio, respectively, with upper incisor retraction; (3) upper lip stomion moved superiorly with intrusion of the upper incisor in a 0.4:1 ratio. This is important in predicting the correct upper incisor exposure; (4) the ratio of superior movement of nasal tip, subnasale, superior labial sulcus, labrale superius and stomion to the superior movement of the upper incisor were 0.20 , 0.25, 0.25 ,0.30, 0.40 respectively; (5) a multiple correlation existed between the vermilion thinning (stomion to labrale superius) and vertical intrusion of the anterior maxilla as well as intrusion of the posterior nasal spine; (6) the lower lip change was unpredictable while the soft chin had a 1:1 ratio and was dependent on posterior maxillary intrusion and subsequent autorotation of the mandible. They also found, like Schendel et al. (1976), that the lip fell behind the arc of mandibular rotation; (7) the nasal tip advanced forward slightly and moved superiorly 0.17 mm for every 1 mm of upper incisor impaction; (8) multiple regression equations were found to be better predictors of soft tissue changes.

Mansour et al. (1983) analysed 21 cases which included 14 impactions and 7 advancements. Their results for the vertical impaction group indicated that: (1) subnasale and pronasale exhibited substantial horizontal movement but was unpredictable; (2) horizontal movement of superior labial sulcus and labrale superius were highly correlated to horizontal changes in the upper incisor with soft to hard tissue ratios of 0.76:1 and 0.89:1; (3) the mandibular soft tissues autorotated the same as that described in previous studies (Radney and Jacobs 1981; Schendel et al. 1976); (4) the soft to hard tissue horizontal ratios for both inferior labial sulcus and pogonion were approximately 0.9:1; (5) labrale inferius did not have significant correlations to any hard tissue points; (6) there was reduction in the width of the vermilion border and the upper lip shortened 40%. These findings were similar to those reported by Radney and Jacobs (1981); (7) the nasolabial angle was unpredictable.

In this same study by Mansour et al. (1983) the maxillary advancement group showed that: (1) the upper lip moved horizontally in 0.6:1 ratio which closely agreed with the results reported by Lines and Steinhauser (1974) and Dann et al. (1976); (2) the mandibular soft tissue changes were unpredictable; (3) nasolabial angle was unpredictable but in general decreased with maxillary advancements.

Wolford et al. (1985) discussed the maxillary surgical soft tissue changes reported in previous studies and compared these ratios to their own post-surgical observations. They utilised a specific surgical soft tissue technique. This technique incorporates an Alar base cinch suture and V-Y closure in maxillary procedures. This soft tissue reconstruction involved one or two sutures placed in the alar base area through the intraoral incision. The tension can be adjusted to achieve the desired soft tissue response. Thus, the alar base suture, prevents flaring of the alar base and, along with the V-Y closure, prevents shortening of the upper lip and helps in maintaining lip thickness. In maxillary advancements, Wolford et al. (1985) claims to get 70-90% upper lip change and 35% pronasale change in the horizontal direction.

Stella et al. (1989) examined a group of 21 adult patients who underwent maxillary advancements by Le Fort I osteotomies. By dividing the sample on the basis of preoperative lip thickness, the predictability could be greatly improved for patients with thin lips, while the subsample with thicker lips still showed highly variable soft tissue behaviour. All subjects exhibited a thinning of the lips in response to maxillary advancement.

Rosen (1988) analysed 41 cases that underwent various maxillary surgical movements with no surgical soft tissue manipulation. He found that from a frontal view the interalar rim widened (mean of 3.4mm), and nasal tip upturn (mean of 1.8mm) occurred only when the maxilla was advanced. However, this was not significantly correlated. Thirty cases with anterior maxillary movements had the following soft to hard tissue horizontal ratios; 0.82:1 for upper vermilion border to upper incisor, 0.51:1 for subnasale to A-point. There was a tendency for thinner lips to have larger soft tissue ratios although it was not proven statistically. Twelve patients with vertical and anterior maxillary impaction showed a tendency toward upper lip shortening, however it was not statistically significant. The unpredictability of the upper lip length was discussed and a range of 20% to 50% lip shortening was recommended.

None of the above studies take into account the size differences, facial type differences and the dimension of facial width effect. These are only two-dimensional studies of a three-dimensional object. Therefore, we should not expect consistency or accuracy. There is always the problem of surgical technique variation, magnitude of the surgical change and observation period.

Betts et al. (1993) reported on 32 patients who underwent Le Fort I osteotomies, some with concomitant mandibular procedures. Preoperative, postoperative and 1-year postsurgical data derived from cephalometric and nasolabial cast analysis were compared to assess skeletodental changes, soft tissue changes and stability. It was reported that the base of the nose widened in all patients regardless of the vector of surgical maxillary movement. An associated shortening of the nose was found. The nasolabial angle decreased or remained constant in most patients. The upper lip widened and lengthened at the philtral columns.

McCance et al. (1992a) investigated three-dimensional changes in the bone and the ratio of soft tissue to bone movement in a group 16 skeletal III patients following orthognathic surgery. CT scans were performed for each patient preoperatively and one year postoperatively. The scans were superimposed, radial movements calculated and the changes illustrated by two separate colour scales. In 13 cases, the maxilla was moved using a Le Fort I downfracture procedure, in the remaining cases a Kufner osteotomy was used. The mandible was set back with either a sagittal split or a vertical subsigmoid osteotomy. There was no constant pattern of movement in the maxilla or mandible in these patients. However, following Le Fort I osteotomy there was commonly a 1:1 ratio in the midline which increased to 1.25:1 at the alar bases and over the canine regions bilaterally. There was also a 1.25:1 ratio or greater over the chin and mentalis regions following mandibular setback.

In a separate report, McCance (1992c) reported on a three-dimensional soft tissue study of the results of surgery in 16 skeletal III adult patients following orthognathic surgery using laser scans. This technique has proved to be a simple non-invasive method of measuring three-dimensionally. It has proven a very useful tool in auditing surgical outcome and measuring surgical relapse. The patient group was compared to a control group of the same population. The maxillae were moved using a Le Fort I downfracture procedure. The mandible was set back with either a sagittal split or a vertical subsigmoid osteotomy. Le Fort I advancements resulted in broadening of the lateral aspects of the nose, advancement of the dorsum and overcorrection of the alar bases. There was a marked degree of relapse in the mandible from 3 months to one year postoperatively, with a resultant anterior movement of the maxillary arch.

Although the above studies are not readily comparable, due to differences in sample, methodology and surgical technique most authors conclude that accurate prediction of the soft tissue response to maxillary surgery is not something that the clinician can take for granted. More sophisticated analyses, using multiple independent variables, appear to be enhancing accuracy, but a degree of subjectiveness still remains in predicting treatment outcomes at this point in time.

2.3.2. Response to Mandibular Setback

As mandibular setbacks were the first orthognathic surgical procedures carried out, it is not surprising to find that the earliest works on soft tissue responses to orthognathic surgery relate to these procedures.

Fromm and Lundberg (1970) studied a group of 52 patients, before and two years after mandibular setbacks. Regarding soft tissue changes, the authors conclude that the height of the upper lip is increased after surgery and, in males, the thickness of the upper lip is also increased. The length and thickness of the lower lip were not found to differ between the presurgical and postsurgical observations, although the depth of the mental sulcus was found to increase after surgery. As the lip thickness was measured by the distance between labrale inferius and the lower incisor, a failure of lip thickness to change with surgery implies that the lower lip followed the movement of the lower incisors in a one to one ratio.

Björk et al. (1971) examined two samples of patients who underwent mandibular setbacks. The first group, consisting of 22 patients was recalled one year after surgery. From the values reported, it appears that the lower lip and the soft tissue chin follow the movement of the lower incisor and pogonion respectively in a one to one ratio. The upper lip is reported to move slightly posteriorly and to elongate, even though there is virtually no change at the upper incisor.

Robinson et al. (1972), on a sample of ten patients, found that following mandibular setbacks, there was a high correlation between the movement of B point and pogonion with their respective soft tissue counterparts, in an almost one to one ratio. The relationship of the lower lip to the lower incisor position was far more variable and the overall correlation quite weak. For all landmarks evaluated, correlations for movement in the horizontal direction were always stronger than those for movement in the vertical axis. This is partly due to the nature of the landmarks - e.g. "most concave, most prominent point" and, partly due to the fact that the surgery produced far greater horizontal movement of the bony landmarks than it did with vertical movement.

Hershey and Smith (1974) using a sample of 24 patients who underwent mandibular setbacks, found that the ratio governing hard tissue movement to overlying soft tissue response was approximately 1:0.9. As a result of the surgery, pogonion was found to move further posteriorly than B point, which moved further posteriorly than the lower incisor. Thus if the surgical movement of pogonion was used as the predictive variable, the ratios were: 1:0.8 for soft tissue B point; 1:0.6 for labrale inferius; 1:0.2 for labrale superius. By examining various subsamples of the original group of patients, the authors reported that the way in which the soft tissues responded to the treatment was not affected by variables such as: the magnitude of the surgical setback, the magnitude of change in anterior facial height incurred during surgery and the presurgical mandibular plane angle.

Lines and Steinhauser (1974) on a sample of 8 patients concluded that the soft tissue chin follows the bony chin in an almost one to one ratio, while the lower lip was only retracted by 75% of the amount of lower incisor movement. The upper lip was found to move posteriorly by about 20% of the mandibular movement.

Suckiel and Kohn (1978), on a sample of 50 patients, arrived at the data summarised in Table 2.4. The upper lip was found to retract after surgery, but the response was poorly correlated to skeletal changes.

TABLE 2.4

HARD TISSUE LANDMARK	SOFT TISSUE LANDMARK	RATIO HARD TO SOFT	CORRELATION COEFFICIENT
POGONION	POGONION	1:O.96	0.99
B POINT	INF. LAB. SULCUS	1:0.95	0.95
LOWER INCISOR	LAB. INFERIUS	1:0.83	0.89
POGONION	LAB. INFERIUS	1:0.67	0.89

Kajikawa (1979) contrasted the behaviour of soft tissues in a group of patients who underwent oblique osteotomies of the ramus to that in a group where either body osteotomy or sliding osteotomy of the mandibular body was the procedure of choice. The results showed that movement of soft tissue B point, pogonion and menton, in the horizontal plane, correlated better to hard tissue movement for the group that had ramus surgery than for the group that had surgery to the body of the mandible. On the other hand, the upper and lower lips moved further posteriorly, with higher correlations to lower incisor and pogonion movements in the body procedure group than in the ramus procedure group. Changes in the vertical direction were also examined in the same study. Generally, variability was much greater in this dimension. The only significant correlations between vertical movement of hard and soft tissue landmarks were:

Hard tissue: soft tissue menton	1:0.8
Hard tissue: soft tissue B point	1:0.66

Weinstein et al. (1982) using a sample of twenty adult patients, examined the changes in distribution of the soft tissues following surgery. The premise of their investigation was that the perioral soft tissues are relatively incompressible, so a reduction in one dimension must lead to an increase in another dimension. Lip changes were measured by using the cross-sectional areas of the images of upper and lower lips on lateral cephalograms and the positional changes of the centroids of these irregular areas after surgery. The amount of horizontal repositioning of the symphysis at surgery was found to correlate well with the amount of lengthening of the upper lip, while the amount of vertical repositioning of the symphysis correlated best with the change in height and cross-sectional data of the lower lip. The need for multivariate analysis, to account for the numerous factors that affect the soft tissue response was stressed.

Willmot (1981) reported on changes after mandibular setback (including patients who had vertical subsigmoid osteotomy). There was slightly less change in the soft tissue than in the hard tissue. The ratio of soft tissue to hard tissue movement was 0.92:1. Changes at inferior labial sulcus when compared with those at B point showed a uniform change, with a ratio of soft to hard tissue of 0.87:1. Changes at labrale inferius compared with lower incisor point showed a similar relationship with a ratio of 0.80:1. Their results indicated changes in the upper lip and their magnitude increased with the increasing movement of the mandible. Soft tissues followed hard tissues in the vertical direction the same way as with horizontal changes. They showed that soft tissues moved less than the movement of the hard tissues during relapse. However, the tissues of the lip and inferior labial sulcus did relapse in a one to one (1:1) ratio and so their immediate postoperative form tended to remain. When cases which had been moved a large distance posteriorly were compared with those which had been moved little, no significant differences in the soft tissue response was seen. Similarly, no differences in the soft tissue response were seen in high angle cases when compared with low angle cases or between the different surgical procedures used. Their results illustrated that when planning the soft tissue profile response to mandibular setback surgery, one cannot rely on the soft tissues of the lips and chin following the mandible posteriorly in a uniform one-to-one relationship as has been assumed by some workers. The soft tissues tend to lag behind to a small extent behind any movement made by the hard tissues. Different soft tissue points were seen to move in proportionately different amounts resulting in changes in the form of the lips. Deepening of the labiomental groove seemed to be the most consistent. Only small changes occurred in the vertical dimensions and they were difficult to measure accurately and unpredictable. A deepening of inferior labial sulcus due principally to an eversion of the lower lip and flattening of the upper lip was reported in many cases.

Moss and Willmot (1984) reported on changes after mandibular setback (including patients who had vertical subsigmoid osteotomy). They indicated that horizontal changes in the soft tissue outline of the face measured from the vertical reference line during the postoperative period showed that there was a progressive reduction from labrale inferius 6.3 mm to soft tissue menton 10.7 mm at the lower incisor tip to 9.8 mm at menton. They reported little change in the soft and hard tissue points in the vertical direction and greatest change was noted in the position of the upper lip and labrale inferius, which decreased. The general trend of the changes indicated that during the osteotomy the mandible was moved in a backwards direction with slight rotation. No significant correlations were found although a trend indicating that more relapse occurred in those cases where the setback was greatest. Pepersach and Chausse (1978) showed similar values for patients who had a sliding osteotomy to correct mandibular prognathism.

Lew et al. (1990) studied the soft tissue response to mandibular setbacks in a group of 25 Chinese adults. They found that the soft tissue moved posteriorly with its underlying hard tissue by: 95% at pogonion (r=0.96); 89% at soft tissue B point (r=0.83); 67% at labrale inferius (r=0.81). The authors point out that these ratios differ from those reported for Caucasian samples and emphasise the need for predictive ratios to be developed for the particular populations to which they will be applied. Response of the upper lip to the mandibular surgery, although much less pronounced than that of the lower lip.

Gjørup and Athanasiou (1991) examined presurgical and postsurgical records of 50 patients who underwent bilateral vertical ramus osteotomies via an extraoral approach for treatment of mandibular prognathism. The mean soft tissue responses, expressed as percentages of the movement of the hard tissue landmarks B point or pogonion are shown in Table 2.5.

TABLE 2.5

SOFT TISSUE LANDMARK	% OF SURGICAL CHANGE AT B POINT	% OF SURGICAL CHANGE AT POGONION
LABRALE SUP.	16%	15%
LABRALE INF.	91%	82%
INF.LAB.SULCUS	103%	93%
POGONION	101%	91%

McCance et al. (1992b) also investigated the stability of surgical correction of patients with Skeletal III and Skeletal II anterior open bite, with increased maxillary mandibular planes angle. The surgical correction of 11 Class III patients and 10 Class II patients with a long face, increased maxillary mandibular planes angle and anterior open bite was undertaken using bimaxillary surgical procedure. Lateral skull radiographs were examined preoperatively, 48 hours and 1 year postoperatively, to quantify the amount and direction of surgical change achieved and the subsequent stability. There was no consistent pattern observed in the actual movements achieved in either group of patients in the maxillae or the mandibles. Some of the cases being impacted and continuing to impact, others impacting then relapsing. In the Class III patients some of the mandibular setbacks remained stable others relapsing and some continuing to move posteriorly. However, despite these inconsistent patterns, there was a 7 degree reduction in the maxillary-mandibular planes angle which relapsed by 1.7 degrees over the first year. The overbite was increased from -6 mm to a +3.1 mm post-operatively and this relapsed at the one year stage to a +2.4 mm. The overjet reduced from -4 mm to 1.7 mm and continued to improve to -0.9 mm at the one year stage.

In summary, most of the studies agree that the soft tissues overlying B point and the chin follow the movement of the underlying skeletal structures in a one to one ratio. The behaviour of the lower lip is somewhat more controversial, with ratios of between 1:1 and 1:0.75 being reported. In particular, the movement of landmarks in the vertical axis often exhibited poor correlations between behaviour of hard and soft tissues. This may partly be due to greater measurement errors reported for vertical movements. Variables that may affect the behaviour of the soft tissues have been discussed by several workers.

In summarising the maxillary and mandibular surgical soft tissue studies, the following mean soft tissue changes are expressed as a percentage of hard tissue movement:

A. Mandibular setback

1. 90% to 100% soft tissue chin response to pogonion
2. Labiomental fold becomes more concave
3. 60% to 70% lower lip response
4. 20% posterior movement of the upper lip
5. Upper lip lengthened?

B. Mandibular advancement

1. 38% to 66% lower lip response
2. 100% response at labiomental sulcus and chin

C. Maxillary advancement (No Alar Cinch or V-Y Closure)

1. 40% to 82% upper lip response
2. 1.2 degree reduction of nasolabial angle per one millimetre upper incisor advancement.
3. 30% nasal tip advancement
4. Upper lip thins slightly
5. Larger percent soft tissue advancement in thin lips

D. Maxillary advancement (With Alar Cinch and/or V-Y Closure)

1. 70% to 90% upper lip response
2. 35% nasal tip advancement

E. Maxillary impaction (No Alar Cinch or V-Y Closure)

1. 20% superior movement of the nasal tip
2. 25% superior movement of subnasale
3. 40% superior movement of stomion
4. Upper lip shortens 40%
5. 67% to 76% posterior movement of the upper lip as the upper incisors are retracted and impacted

F. Maxillary impaction (With Alar Cinch and V-Y Closure)

1. No decrease in lip length
2. Only slight vermilion thinning
3. 35% nasal tip upturn

G. Mandibular autorotation

1. 100% soft tissue response at the chin and labiomental fold
2. Lower lip falls back posteriorly inside the arc of mandibular rotation
3. Labiomental fold becomes less concave

CHAPTER THREE

REVIEW OF THE LITERATURE

LE FORT I OSTEOTOMY AND VERTICAL SUB-SIGMOID OSTEOTOMY

3. 1 LE FORT I OSTEOTOMY

In 1927 Wassmund introduced a surgical procedure for moving the entire maxilla. Called Le Fort I osteotomy, or total maxillary osteotomy, it was first used to correct an anterior open bite. The maxilla was not sectioned from its bony attachments and no attempt was made to mobilise the maxilla at the time of surgery. Postoperatively, intermaxillary elastic traction was used to close the open bite and stabilise the maxilla. Wassmund's direct approach to the maxillary deformity was clearly years ahead of its time.

The design of the bony and soft tissue incisions have been continually modified to facilitate movement of the maxilla and to maintain circulation to the maxillary bone and teeth. Schuchardt (1942) and Kole (1965) devised a two-stage procedure to prevent impairment of the vascular supply to the maxilla. Postoperatively, Schuchardt used weights from an overhead traction device to reposition the maxilla forward. The second stage of his technique involved separation of the pterygoid process from the maxillary tuberosities. Despite such measures, he became disenchanted with the procedure and concluded that the operation should not be used to treat patients with clefts. Axhausen (1934) used elastic traction after surgery to facilitate anterior movement and retention of a traumatically retrodisplaced maxilla. Gillies (1955) and, Converse and Shapiro (1952) advocated advancing the maxilla by means of a transverse palatal cut at the junction of the palatine and maxillary bone in an attempt to circumvent these shortcomings. The success of this approach was not commented on. Bone grafting has been advocated to promote bony regeneration between the buccal bone cuts in the lateral portions of the maxilla (Gillies, 1955). Obwegeser (1969) maintained that grafting the space between the posterior maxilla and the pterygoid plates was essential for stability.

Inability to move the maxilla the desired distance and relapse were common for the innovators of this operation. The surgeon's fear that mobilisation of the maxilla would devascularise and devitalise the bone and teeth was the main reason for such problems. The fear of traumatising vascular structures, such as the greater palatine and internal maxillary arteries, was also a major objection to the technique (Bell 1975).

As clinical experience increased, surgeons gradually became more aggressive and complete mobilisation and adequate fixation of the maxilla were accomplished. Surgeons began to report good results with total maxillary advancement (Hogeman and Wilmar 1967; Perko 1972; Obwegeser 1969).

The biologic basis and surgical principles for maxillary osteotomies remained obscure and obviously contributed to postoperative devitalisation and loss of bone and teeth. Micro-angiographic and histologic studies of total maxillary osteotomy performed in adult rhesus monkeys showed only transient vascular ischaemia, minimal osteonecrosis and early osseous union when the maxilla was pedicled essentially only to the palatal mucosa. Preservation of the integrity of the greater palatine arteries was not essential to maintain circulation to the maxilla. The collateral circulation within the maxilla and its enveloping soft tissue and the numerous vascular anastomoses in the anterior and posterior parts of the maxilla permit many variations of the total maxillary osteotomy technique. Intraosseous and intrapulpal circulation was not significantly altered by the buccal subapical osteotomies when bone cuts were made away from the apices of teeth and maximal attachment of the mucoperiosteum on the palatal and buccolabial gingiva of the mobilised maxilla was preserved (Bell 1969; 1975). These results generated clinical confidence in performing total maxillary osteotomies. The current surgical technique was modified after these analogous investigations in animals and previously reported clinical techniques (Wassmund 1935; Dingman and Harding 1951; Hogeman and Willmar 1967; Obwegeser 1969).

3.2 VERTICAL SUBSIGMOID OSTEOTOMY

The term "vertical subsigmoid osteotomy" is widely used in Australia to describe a procedure for mandibular setback. This term, however, is not commonly used in the literature. Consequently, surgery of the ramus of the mandible in the vertical plane has resulted in a number of synonyms, derived either from anatomical landmarks or from the direction of the osteotomy or a combination of the two. Table 3.1 summarises the terms used to describe the vertical subsigmoid osteotomy. There are only minor variations in all of these procedures covered by this list. In this thesis, the term "vertical subsigmoid osteotomy" will be used exclusively.

TABLE 3.1

AUTHOR	YEAR	SYNONYM
Limberg	1925	Oblique osteotomy
Caldwell & Letterman	1954	Vertical ramus osteotomy
Hinds	1958	Subcondylar osteotomy
Robinson	1958	Vertical subcondylotomy
Robinson	1959	Overlapping vertical osteotomy
Thoma	1961	Oblique osteotomy
Shira	1961	Oblique sliding osteotomy
Nordenham & Waller	1968	Vertical oblique osteotomy
Robinson	1970	Oblique sliding osteotomy
Hebert et al.	1970	Vertical subcondylar osteotomy
Egyedi et al.	1981	Oblique subcondylar osteotomy
Phillips et al.	1986	Transoral vertical ramus osteotomy
Quinn & Wedell	1988	Vertical subsigmoid osteotomy

(derived from Ching, 1995)

3.2.1 Surgery for the treatment of mandibular prognathism

The first deliberate surgical intervention for the correction of an acquired jaw defect was performed by Hullihen in 1849 to rectify an anterior open bite which resulted from a burn contracture of the neck. Half a century passed before Berger pioneered the surgical correction of prognathism in 1897. Berger (1897) and Jaboulay and Berard (1898) first performed a bilateral condylectomy via a preauricular approach to push the mandible back. The subcondylar osteotomy was first described by Kostecka in 1928 in which the condylar neck was divided with a Gigli saw by a blind external approach.

This technique fell into disrepute because of complications encountered. Intraoperatively, damage to the maxillary artery was a serious problem with this technique because of its position just medial to the condylar neck. Postoperatively, the occurrence of salivary fistulae and facial paralysis was noted and anterior open bites often resulted following release of maxillomandibular fixation. Smith and Johnson (1940) described a minor modification of this operation which involved removal of a section of bone from the region of the sigmoid notch to allow posterior repositioning of the mandible. The horizontal ramus osteotomy above the level of the inferior dental foramen via an external approach was described by Blair (1907) and Babcock (1909) early this century. Later, this osteotomy was performed intraorally by Aleman (1921) and is sometimes known as the Swedish approach. Obwegeser (1957) described the original sagittal split procedure in which greater bone to bone contact is achieved and various modifications of this operation are popular today. The vertical subsigmoid operation was first described by Caldwell and Letterman in 1954. Here the ascending ramus is divided vertically from the sigmoid notch to a point just anterior to the angle of the mandible. This may or may not be combined with coronoidotomy and was approached as an extraoral procedure. Trauner and Obwegeser (1957) reported the logical extension of this procedure.

With the introduction of the intraoral approach, extraoral scars could be avoided. Winstanley in 1968 and Wilbanks in 1971 termed this technique the double oblique osteotomy. The name of the technique is derived from the fact that the bone cut is oblique in two directions, that is, from the anterior region of the sigmoid notch down to the gonial angle (a superior - inferior obliquity) and simultaneously a biased cut from the lateral cortex to medial cortex (a lateral - medial obliquity). In 1970, Hebert and associates reported the correction of mandibular prognathism in seven patients via an intraoral approach using a Stryker oscillating saw which allowed a cut to be made similar to the extraoral technique. However, the method had disadvantages of poor visualisation and difficulty in access. Massey et al. (1974) and others refined the case selection by excluding patients whose mandibular morphology presented an access problem. Their basis for selection of cases was to exclude mandibles that presented with mandibular divergence angles less than 130° as these were deemed to introduce a high degree of difficulty (Akin and Walters, 1975).

CHAPTER FOUR

REVIEW OF THE LITERATURE

ERRORS IN CEPHALOMETRICS

4.1 CEPHALOMETRIC ERROR

Ever since its introduction by Broadbent (1931), cephalometric radiology has been a popular tool for both clinical diagnosis and research into growth and treatment changes. Hixon (1960) notes that random cephalometric errors can probably be ignored in the case of cephalograms taken for clinical diagnosis as the errors are small in comparison to the measurements being taken.

The intelligent interpretation of data obtained from cephalometric research requires an understanding of the sources and magnitude of errors associated with the technique. In the absence of such information, the observed changes cannot be validly attributed to growth or treatment, as they may be due solely or partly to sampling errors.
Potential sources of error in cephalometric research are:

1. Distortion at the time of exposing the cephalogram
2. Landmark identification, tracing error
3. Digitising and computer mensuration, or manual mensuration
4. Superimposition of serial cephalograms.

According to Houston (1983) the error inherent in cephalometric analysis involves the two elements of validity and reproducibility.

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 (minimal) and treatment. The validity was also enhanced by using a biologically sound method of superimposition as a basis for the reference system (Björk 1968, Björk and Skieller 1983, refer to chapter six).

Houston (1983) discussed cephalometric reproducibility under the headings of systematic error and random error. Systematic errors are those which are systematically introduced into the data due to details of the experimental methodology, for example, subconscious weighting of data due to failure to use a blind sampling technique.

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 two 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 are those which are injected into the data in a random fashion, for example, inaccurate landmark determinations. 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.

4.2 DISTORTIONS ASSOCIATED WITH CEPHALOGRAM EXPOSURE

An inherent shortcoming of the cephalometric projection is that it is a two dimensional representation of a complex three-dimensional structure. The X-ray source emits a beam of rays that diverge as they approach the object to be radiographed and then project the image of this object onto the film. Due to this divergence, structures on the side closest to the X-ray source will be magnified more than structures on the side closest to the film. In order to overcome these differential magnifications, wherever possible, structures that lie close to the mid-sagittal plane, where magnification will be standardised, are chosen for analysis.

Because of the effect of divergence of the X-ray beams, the geometric relationship between the X-ray source, the film and the subject's head must be standardised and reproducible. The X-ray source and cassette holder can be fixed so that their relationship is consistent, both with each other and, with the cephalostat. The position of the subject's head in the cephalostat, however, is not so easily determined. As Eliasson et al. (1982) state "the positioning of the patient in a cephalostat cannot be exact and never exactly the same from one examination to another".

Ideally, the patient's midsagittal plane should be parallel to, and at a constant distance from, the film and perpendicular to the central beam of the X-ray source. In addition, a chosen horizontal reference line (e.g. Frankfort Horizontal) should be parallel to the floor.

Björk (1947), Solow (1966), Midtgård et al. (1974) and Houston et al. (1986) have been able to study samples where two cephalometric radiographs had been exposed for each subject on the same occasion. These studies all agree that the errors associated with retaking a cephalometric X-ray film were small in comparison to those associated with tracing and identifying landmarks on any one film.

Considerable controversy exists over the rotational positioning of the head in the cephalostat with respect to the transmeatal axis. Many clinicians choose to orient the Frankfort Horizontal parallel to the floor when exposing cephalometric radiographs. This plane was originally defined and adopted by anthropologists in the late nineteenth century as a reference for measurements on dried skulls. Ease of identification on the living subject has led to its acceptance for orienting patients in the cephalostat.

Moorrees and Kean (1958) challenged the use of Frankfort Horizontal as a reference plane, on the grounds that individual variations in the locations of porion and orbitale preclude them from consistently defining a line which related to the subject's natural head posture. As an alternative, they advocate exposing lateral cephalograms in "natural head position", with the subject determining the transmeatal rotational status of the head by staring into his own eyes in a distant mirror. They found this to be more reproducible for each individual and less variable between different individuals than using lines connecting intracranial reference points.

In longitudinal research that involves superimposition of serial cephalograms on stable cranial reference structure, any variation in rotation of the head around the transmeatal axis between films in a series is overcome by the superimposition process. The challenge is then to establish a reference plane from which measurements can be made.

4.3 ERRORS IN LANDMARK IDENTIFICATION

Errors in landmark identification have been cited by many workers as the greatest single source of error in cephalometric research. Failure to achieve consensus on precise definitions of landmarks has made comparisons between different cephalometric studies impossible.

Björk (1947) studied errors involved in landmark identification by a series of double determinations on twenty twelve-year-old children. The methodology used was to compare various angular and linear measurements taken from two consecutive cephalograms of each subject using two observers. This actually gives an estimation of the total method error, as errors of projection and mensuration are also incorporated into the data. The author expressed the opinion that the errors involved in measurement between the marked landmarks could be considered negligible in comparison to the errors involved in locating the landmarks. Errors in linear measurements ranged from 0.3 to 1.4 mm while errors in angular measurements ranged from 0.3 to 1.6 degrees.

Hixon (1960) suggests that using a tracing introduces the inaccuracy of both the tracing process and the thickness of the pencil line in identifying landmarks. As an alternative, he suggests punching small holes in the film at each landmark and measuring from the film. Björk and Solow (1962) found that marking planes and landmarks on cephalometric films introduced systematic errors and the effect on the data was to increase correlation coefficients. They recommended making direct measurements from films with no markings.

Richardson (1966) was one of the earliest workers to study errors of landmark identification by reproducing X and Y coordinates of the landmarks studied. Depending on whether mean differences or standard deviations were used to assess reliability, a slightly different pattern emerged, although the most reliable points were the same as assessed by either method. It was noted that some of the landmarks were more reproducible in the vertical plane than the horizontal and vice versa, a factor which must be considered when determining the suitability of a point for a particular study.

Baumrind and Frantz (1971a) investigated the reproducibility of various landmarks by having five investigators trace and identify points on a series of twenty randomly selected cephalograms. They found that each landmark has a characteristic "envelope of error", which was usually non circular (figs. 4.1, 4.2, 4.3).

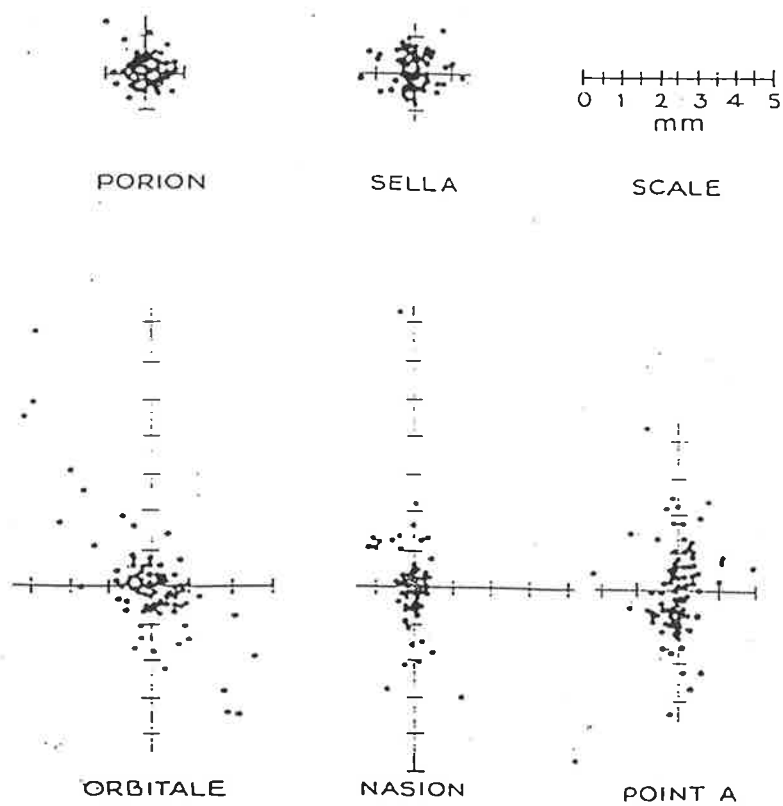


Fig. 4.1 Distribution of estimating errors, maxillary skeletal landmarks

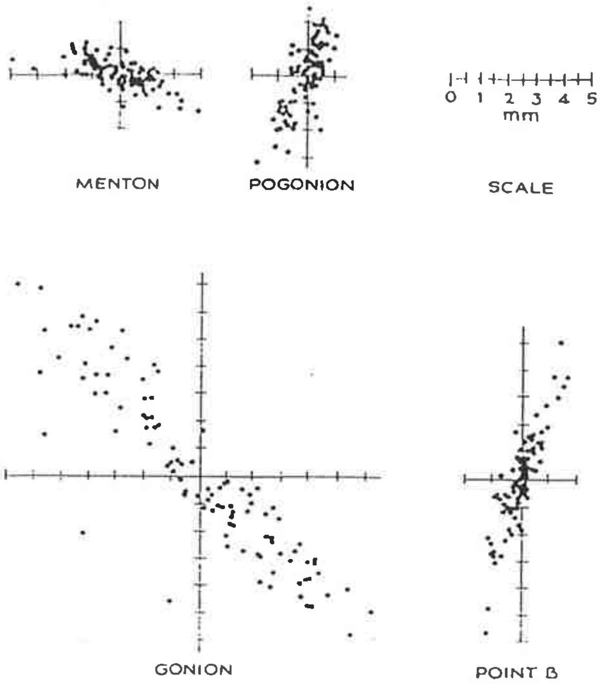


Fig. 4.2 Distribution of estimating errors, mandibular skeletal landmarks

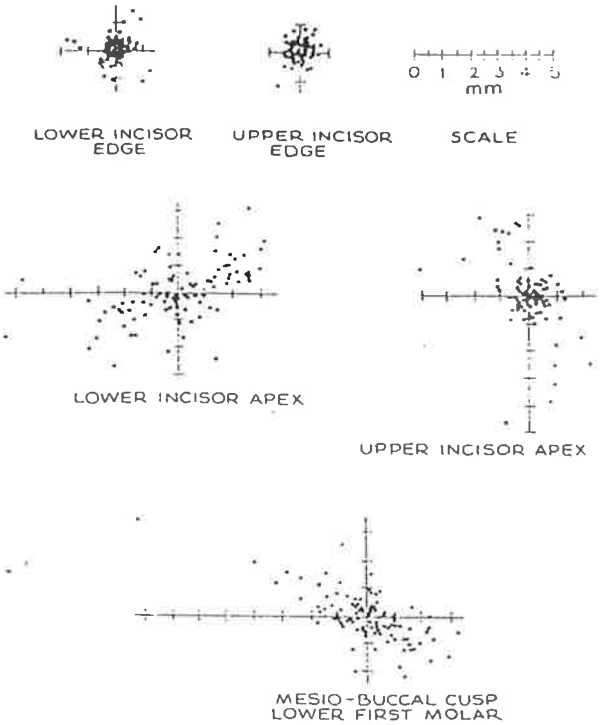


Fig. 4.3 Distribution of estimating errors, dental landmarks

Table 4.1 shows the mean estimating errors (sample mean ±2 standard deviations) for the ten skeletal and dental points studied (Baumrind and Frantz, 1971a).

TABLE 4.1

SKELETAL LANDMARKS

	MEASURES OF DISPERSION			MEAN ESTIMATING ERROR[d]
	SD[a]	SD_x[b]	SD_y[c]	
1. PORION	.53	.36	.38	.39 ± .13
2. SELLA	.64	.44	.46	.48±.14
3. NASION	1.46	.60	1.33	.73 ± .52
4. MENTON	1.38	1.25	.59	1.00 ± .36
5. POINT A	1.41	.55	1.29	1.00 ± .37
6. POGONION	1.44	.59	1.32	1.06 ± .36
7. ORBITALE	1.91	1.03	1.61	1.09 ± .65
8. POINT B	1.97	.64	1.86	1.27 ± .60
9. GONION (U)	4.71	3.33	3.34	3.48 ± 1.12
10. GONION (L)	5.21	3.71	3.53	3.75 ± 1.10

DENTAL LANDMARKS

1. UPPER 1 EDGE	.50	.34	.36	.37 ± .11
2. LOWER 1 EDGE	.64	.45	.44	.44 ± .19
3. UPPER 1 APEX	1.58	.89	1.31	.98 ± .50
4. LOWER 6 CUSP (L)	1.63	1.40	.86	1.05 ± .50
5. LOWER 6 CUSP (R)	1.98	1.70	1.02	1.32 ± .59
6. LOWER 1 APEX	2.36	2.03	1.22	1.74 ± .59

a STANDARD DEVIATION FOR TOTAL ERROR

b STANDARD DEVIATION FOR ERROR IN HORIZONTAL DIRECTION

c STANDARD DEVIATION FOR ERROR IN VERTICAL DIRECTION

d SAMPLE MEAN ± 2 SEM

Points that lie on sharply curving surfaces are apparently more accurately located than those that lie on gently curving surfaces.

Midtgård et al. (1974) found very little difference in landmark locations between double determinations done consecutively and double determinations separated by one month. They concluded that this interval did not affect landmark reproducibility and were also unable to demonstrate significant differences in landmark placement by two judges using the same film, suggesting that intraobserver variation and interobserver variation are similar.

McWilliam and Welander (1978) studied the effect of different intensifying screen - X-ray film - KVp combinations (i.e. different image clarity) on the ability to locate cephalometric landmarks. They found that only landmarks with very small envelopes of error were affected by image quality and, for most clinically employed landmarks, the error of identification was not significantly altered by varying the quality of the cephalometric image.

Broch et al. (1981) studied landmark identification using a digitiser, thus eliminating the error associated with tracing and manual measurements. Errors in the X and Y axes were measured separately and were found to range from: 0.14 mm (incision inferius, X axis) to 0.88 mm (basion, Y axis). The fact that errors reported by Broch et al. appear to be lower than those reported by Baumrind and Frantz (1971a) may be partially explained by the use of the digitiser. In concurrence with previous studies, each landmark was seen to have a characteristic pattern of error distribution.

Stabrun and Danielsen (1982) also using digitised data showed similar envelopes of error to those in previous studies. They also showed that interobserver variability was greater than intraobserver variability, despite careful previous calibration of landmark definitions.

Savage et al. (1987) compared accuracy of landmark identification in relation to three variables: level of experience of the observer; quality of radiographic images; geometrically constructed vs. anatomic points.

The distributions of errors were similar to those reported in previous studies and none of the above variables was found to bear a statistically significant relationship to the coefficients of variation of each landmark. Geometrically constructed points were found to be equally reliable to directly determined points.

Vincent and West (1987) listed factors related to errors in landmark identification as:

1. The curvature of the line upon which the landmark is positioned - sharp curves of small radius make for easier landmark identification than large, gradual curves.
2. Contrast - landmarks are more easily identified in areas of high contrast.
3. "Noise" - superimposition of structures medial and lateral to the landmark reduces accuracy of identification.
4. Definitions of landmarks - any ambiguity in definitions leaves scope for larger variability.

Their findings on errors in individual landmark locations agree with those of previous studies.

Few investigations have been conducted into the reliability of identifying soft tissue landmarks on cephalometric films. Wisth and Böe (1975) hypothesised that soft tissue landmarks would be less reliably identified due to anatomical and postural considerations. They studied a series of 90 patients, each of whom had two cephalograms taken, with an interval of three weeks. The test group was equally divided into: (1) adults, (2) lip-competent children, (3) lip-incompetent children. All films were taken in habitual occlusion with the lips in repose. Errors of landmark identification were estimated by comparing various angular and linear measurements using the landmarks of interest. Although this technique also incorporated the error of measurement into the data, the assumption is made that this error is consistent throughout the study. Double determinations on the same cephalometric film produced errors that were comparable to those reported for hard tissue landmarks. When consecutive films were compared, however, the errors for soft tissue landmarks were greater than those for hard tissue landmarks, presumably because of soft-tissue postural changes between the two cephalograms. Soft tissue landmarks on children with incompetent lips were harder to reidentify than those on adults and children with competent lips.

Hillesund et al. (1978) studied reproducibility of soft tissue landmarks in both lips-closed and lips-relaxed posture, on two groups of children, one with increased overjet and incompetent lips, the other with normal overjet and competent lips. Each subject had four cephalograms taken - one in each lip posture, on two occasions, with an interval of three weeks. Average errors were 1-1.5 mm in the horizontal axis, and greater and more variable in the vertical axis. There was no statistically significant difference in interlabial gap between the first and second record in relaxed lip posture for each subject. This was true for both normal and increased overjet groups and offers support to the view of Burstone (1967) that relaxed lip posture is reproducible. Because of this reproducibility and, because of the large variations in postural changes between the relaxed and closed lip positions, the authors advocate routine use of relaxed lip position for cephalometrics.

In summary, it is fair to say that almost all of the studies carried out in the field of errors in landmark identification agree that each landmark tends to have a characteristic envelope of error. The magnitude of errors determined between the different studies varies somewhat, possibly due to different methodologies e.g. the use of a digitiser vs. manual measurement. The ranking of landmarks in order of reliability, however, is relatively consistent between studies, with landmarks such as sella and nasion consistently more reliable than landmarks such as basion and gonion. Soft tissue landmarks appear to involve greater errors in identification than hard tissue landmarks, probably due to the effects of posture and less clearly defined anatomical lines.

4.4 MEASUREMENT ERRORS

There are essentially two methods of making measurement from cephalometric radiographs - manual measurement, using calibrated protractors and callipers or computer assisted measurement, using a digitising pad. The former is commonly used in clinical practice and was also popular for research purposes, prior to the introduction of digitisation by several workers e.g. Houston (1970). The latter is the most commonly employed method of measurement in modern cephalometric research.

Baumrind and Frantz (1971b) are of the opinion that machine computation of linear and angular measurements has totally eliminated errors of mensuration and focus on the far more significant errors of landmark identification.

Bergin et al. (1978) found that errors associated with automated measurement were of little significance compared to the errors associated with landmark identification. Houston (1979) states that digitising pads should have an absolute accuracy of better than 0.15 mm and there is little to gain from improvements in accuracy beyond this, as the magnitudes of these errors are far outweighed by those of landmark identification.

Houston (1979) cites the errors associated with using a digitising system as arising: "..... from carelessness on the part of the operator, from an incorrect sequence of digitisation, from movement of the record during digitisation, from environmental variation affecting a sensitive digitiser and even from intermittent faults in the apparatus." The value of repeated determinations to identify any of these errors is noted.

Bondevik et al. (1981) describe a digitising system with resolution to 0.1 mm and 0.1 degree. With correct operation of the system, they find the only error to be that arising from landmark identification. Broch et al. (1981), in using a digitising system to quantify errors in landmark identification are of the opinion that they have been able to exclude error from all other sources.

Houston (1982) has shown that the errors associated with direct digitisation are much smaller than those that arise from tracing and manual measurement.

Savara et al. (1966) studied the reproducibility of linear distance measurements, taken manually, and found that landmark location variability was about five times that associated with the measurement process.

Midtgård et al. (1974) measured several linear distances manually on tracings of cephalograms and found that the errors associated with these measurements reflected the difficulty of reliably locating their dependent landmarks e.g. errors in linear measurements involving A and B points were much greater than those involving two more reliably located landmarks such as sella and nasion.

Bergersen (1980) discussed the issue of enlargement in both frontal and lateral cephalometric projections and suggested the use of compensation tables which, he claims, can give corrected linear measurements with errors no greater than 0.7 percent. This error, of course, is in addition to the errors outlined in preceding paragraphs.

The consensus of opinion thus appears to be that if an automated measuring system is used carefully, the errors arising from the process of measurement are minimal in comparison to those arising from landmark identification. It is reasonable to overlook them when interpreting the obtained data provided the automated system is standardised and checked regularly.

4.5 ERRORS ARISING FROM SUPERIMPOSITION OF SERIAL FILMS

Brodie (1949) attributes the earliest use of a superimpositional method of comparing serial cephalograms to Downs. Errors associated with superimposition can be divided into two broad categories: (1) those related to the ability to locate and superimpose the selected anatomical structures and, (2) those related to remodelling of superimposition landmarks as a result of growth and/or treatment.

In studies concerned with the positional changes of the maxilla and mandible in space, it is most common to use the cranial base as a reference structure. Ideally, landmarks chosen on the cranial base for superimposition purposes should be: close to the midsagittal plane to avoid projection distortions; easily identified and sharply delineated to avoid ambiguous superimposition; unaltered during normal growth (if the sample to be studied includes growing individuals).

DeCoster (1953) and Kerr (1978) advocate superimposing serial radiographs on outlines of the brain case's floor from planum sphenoidale forward into the anterior cranial fossa, as he found these not to be altered after the age of seven years, when observing numerous series of radiographs.

Richardson (1966) found that DeCoster's line was not reproducible with a high degree of accuracy. He concluded that if superimposition was to be carried out using this line, it should be justified on grounds other than reproducibility.

Björk (1955), in a longitudinal study of cranial base development on Swedish males, ages twelve to twenty years notes that although nasion moves forward due to frontal apposition, the length of the anterior cranial fossa remains essentially unchanged over this period. He observed a constant relationship between the nasion-sella line and the deepest median contour of the anterior cranial fossa and cited this as grounds for using the nasion-sella line for comparing cephalograms from subjects in this age range.

Scott (1967) and Sicher (1970) also advocate the cranial base as a suitable structure for superimposition, on the grounds that its growth may be considered to be virtually completed before adolescence.

Melsen (1974) studied cranial base development by histological examination of human autopsy material, from neonatal to twenty years. The following observations are relevant to the suitability of cranial base structures for superimposition:

- the cerebral surface of the frontal bone appears to be stable after the age of one year;
- the lamina cribosa was generally stable by age four years;
- laminar apposition occurs at jugum sphenoidale up to the prepubertal period. This apposition is not always detectable radiographically and could thus lead to errors if this structure is used for superimposition;
- the spheno-ethmoidal and frontal-ethmoidal sutures, responsible for lengthening of the cranial base, appear to be inactive after the age of seven years;
- the anterior wall of sella turcica was generally stable by age five to six years. This is in contrast to the posterior wall, tuberculum sellae and dorsum sellae, which may display remodelling into the late teens.

Björk and Skieller (1983) advocate the nasion-sella line as a reference plane, but caution against using it for superimposition. Instead, they recommend transferring this line from the original cephalogram to subsequent tracings after superimposition on structures of the anterior and middle cranial fossae.

Baumrind et al. (1976) studied the errors associated with superimposition and categorised them as: (1) primary errors - rotational or translational errors associated with overlaying the anatomic structures being used for superimposition and, (2) secondary errors - the displacement of cephalometric landmarks caused by the primary errors.

Rotational effects were found to contribute more to the overall superimposition error than translational effects. The primary errors associated with superimposition on sella-nasion were found to be slightly greater than those associated with superimposition on structures of the anterior cranial base. This was attributed, in part, to errors in locating nasion, especially in the vertical plane. Secondary errors were found to be a function of the distance of a particular landmark from the plane of superimposition. Landmarks placed further away from the plane of superimposition were far more affected by primary errors than those closer to the plane.

Houston and Lee (1985) compared superimposing on sella-nasion and anterior cranial base, using a variety of methods, including the subtraction technique. They found that all methods compared carried an appreciable degree of error and could not commend any one method as being more accurate than the others.

Buschang et al. (1986) suggest superimposing a tracing from one cephalogram directly onto the next cephalogram in the series. This represents an attempt to compromise between errors of tracing and bias from looking at structures other than those used for superimposition, when two films are superimposed directly. Using this technique, they find that a trained cephalometrist can reliably superimpose on cranial base structures.

Ghafari et al. (1987) compared four methods of cranial base superimposition:

(1) using the sella-nasion line, registered at sella

(2) using structures of the anterior cranial base, as proposed by Björk and Skieller (1983)

(3) using the Bolton-nasion plane, registered at R point, as proposed by Broadbent (1937a)

(4) using the nasion-basion line, as proposed by Ricketts (1979).

Each method differed by up to one millimetre in establishing landmark displacements between pretreatment and post-treatment films. Furthermore, the Ricketts method was seen to differ from the other techniques by more than one millimetre for several of the landmarks studied. The authors stress that any analysis of growth or treatment changes can only be interpreted in the light of the specific superimpositional technique used.

The use of computer generated analysis means that superimposition of anatomic planes must be transferred to the computer by digitisation of reference points or lines. The most commonly employed technique involves the use of two or more fiducial points, as described by Baumrind and Frantz (1971a). Sluiter et al., (1985) have suggested digitising two lines, defined by two sides of the cephalometric film as an alternative. They cite greater accuracy and the avoidance of damaging the films by punching holes as the advantages of this method.

The task of superimposing serial cephalograms is less problematic when growth is not a variable in the sample being examined. When growth must be considered, several stable structures have been reported that, at the present time, provide the best means of superimposition. In a non-growing sample, the choice of superimposition structures is more influenced by reliability of identification and in this respect, it appears that the sella-nasion line and structures of the anterior cranial base give fairly similar results.

4.6 SELECTION OF A REFERENCE LINE

There is no one cephalometric line that is able to fulfil all the requirements of an ideal reference line and thus, no one line has gained universal use (fig. 4.4).

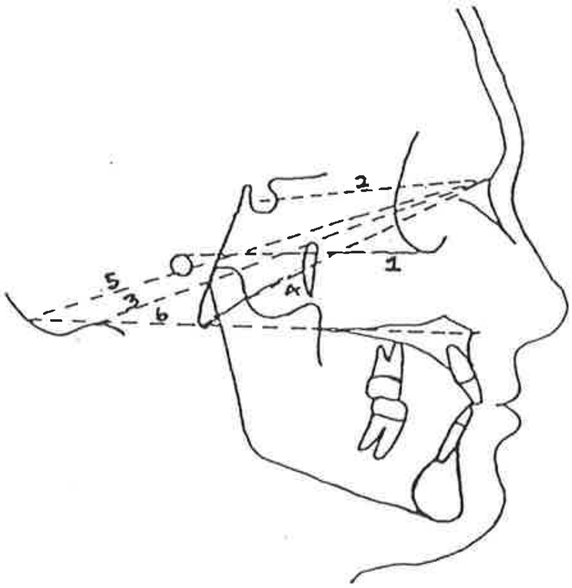


Fig. 4.4 Anatomical planes

(Derived from Stamatis, 1992)

1 FRANKFORT HORIZONTAL	- Von Ihering (1872)
2 NASION-SELLA LINE	- Brodie (1941)
3 NASION-BOLTON LINE	- Broadbent (1937b)
4 NASION-BASION LINE	- Welcker (1868)
5 NASION-OPISTHION LINE	- Beltrami et al. (1952)
6 ACANTHION-OPISTHION LINE	- His (1864)

Bjerin (1957) states "Whichever plane is chosen for mensuration its relation should be known to the true horizontal plane through the cranium, the head being in its normal position." This statement is especially true when applied to modern orthognathic practice, where aesthetics often dictate important treatment planning decisions. It is pointless to create a profile that is in perfect harmony to an intracranial reference line if it appears unharmonious when the patient assumes his or her natural head posture.

As previously stated, Moorrees and Kean (1958) advocate use of natural head position when exposing cephalograms, so they may be analysed with respect to the true vertical and the true horizontal. The use of these lines of reference is recommended on the basis of increased reproducibility and lower population variability in comparison to other reference lines. A very precise radiographic technique is required.

Wenzel et al. (1989) have shown that altered mandibular morphology, such as after orthognathic surgery, may be associated with altered postural positioning of the head. Thus, the natural head position may well be different before and after surgery.

The Frankfort horizontal plane forms the basis of many established cephalometric analyses, such as those of Downs (1956) and Tweed (1946). One of the major advantages of this line is cited as its approximation to the true horizontal. However, Bjerin (1957) has reported that it may range from 15.3 degrees to negative 13.8 degrees from the true horizontal.

The reproducibility of the Frankfort horizontal has come under question, especially in view of the reasonably large "envelope of error" described for orbitale by Baumrind and Frantz (1971a). In addition, the use of "machine porion" versus "anatomic porion" has introduced another variable into the definition. Koski and Virolainen (1956) advocate the use of anatomic porion, to avoid variation in placement of the ear-rods, but even so, they found the systematic error of measurement for the Frankfort horizontal to exceed acceptable limits.

The sella-nasion line is commended as more easily identified by Wei (1968) and he advocates its use on this basis alone. Steiner (1953), Richardson (1966) and Pancherz (1984) were of the opinion that the sella-nasion line was more reproducible. Steiner (1953) noted that its end points are both midline structures, in contrast to those of the Frankfort horizontal.

A criticism of the sella-nasion line has been its failure to approximate the true horizontal. Bjerin (1957) found similar standard deviations from the true horizontal for both sella-nasion and the Frankfort horizontal.

To obtain a closer approximation to the true horizontal, yet retain the reproducibility of the sella-nasion line, Burstone et al. (1978) advocate constructing a horizontal line, the SN-7 line, through nasion, at seven degrees to sella-nasion. Marcotte(1981) is of the opinion that the SN-7 line gives a good approximation to the angulation of Frankfort horizontal.

It may thus be concluded that interpreting the data of any cephalometric study requires knowledge of reference lines used, as the conclusions may well only be valid within the realms of this reference. On an individual basis, the importance of relating whatever reference line is chosen back to the patient's postural head position must not be overlooked. Anatomical variation is considerable and using SN-7 is just as problematical as using SN when the extremes of flat and steep cranial base occur.

CHAPTER FIVE

MATERIALS AND METHODS

5.1 SAMPLE

The soft tissue profile response to a given amount of hard tissue movement was evaluated by comparing preoperative and postoperative standard cephalometric radiographs of 23 post-adolescent (not actively growing) patients treated for maxillary deficiency and mandibular excess. The female group ranged in age from 16 years to 35 years 5 months (mean age 20 years). The male group ranged in age from 16 years to 59 years 5 months (mean age 20 years). The patient records were selected from the files of the Oral and Maxillo-Facial Surgery Unit of the Adelaide Dental Hospital and were studied to provide information about the soft and hard tissue changes after orthognathic surgery.

The following selection criteria were used:

1. The patients were non-syndromic, post-adolescent individuals (they were not actively growing) with no craniofacial anomalies.
2. Surgical treatment consisted of simultaneous double jaw surgery with a Le Fort I osteotomy to correct the maxillary deficiency and Vertical Subsigmoid Osteotomy (VSSO) to correct the mandibular excess.
3. No concurrent chin procedure, infra orbital augmentations, rhinoplasties or other soft tissue manipulation that would mask the primary soft tissue response.
4. Patient must have a natural dentition supporting the lips.
5. Postsurgical orthodontic tooth movement was kept to a minimum.

6. Good quality lateral cephalometric X-ray projections available for each of the following time periods:

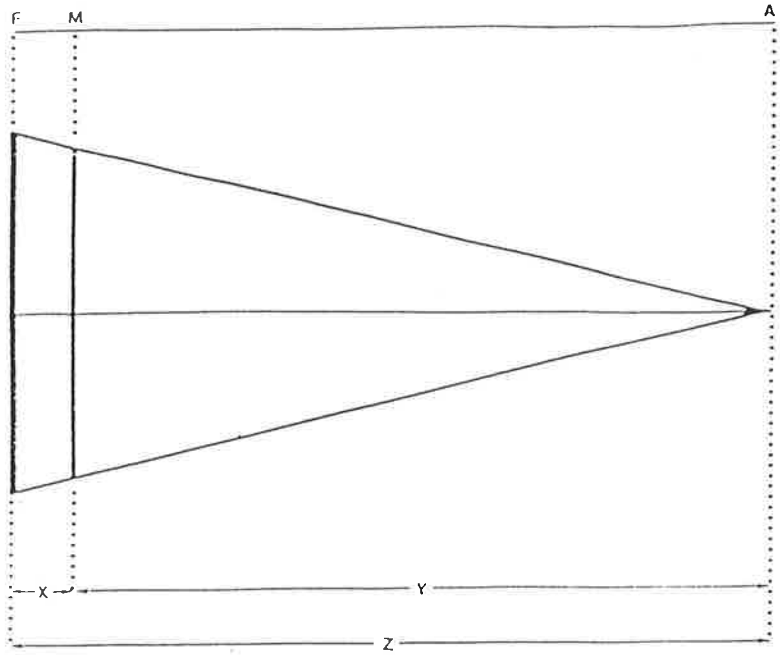
T1 (Preorthodontics)	- Starting x-ray
T2 (Presurg.)	- Less than three months before surgery
T3 (Six months)	- Within six months after surgery
T4 (One year)	- Within one year after surgery
T5 (Two years)	- Within two years after surgery
T6 (Three years)	- Within three years after surgery

5.2 CEPHALOMETRIC TECHNIQUE

All radiographs were exposed in the Adelaide Dental Hospital Radiology Unit. The radiographic procedure was standardised as much as is possible. However, the Adelaide Dental Hospital Radiology Unit has a large staff turnover for teaching purposes.

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. In order to maintain enlargement of the radiographic image in the mid-sagittal plane at a constant 8.8%, the distances from the source to the mid-sagittal plane and from the mid-sagittal to the film plane were standardised (Fig. 5.1).

In order to reduce patient dosage, intensifying screens were used 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 standardised according to the film type by using an automatic processor for all films.



F = Film plane
A = Focus
Y = 1818 mm

M= Mid-sagittal plane
X = 160 mm
Z = 1978

Fig. 5.1 Calculation of the enlargement factor for points lying on the mid-sagittal plane. (X,Y,Z drawn to scale)

E = Enlargement Factor

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

$$E = 100 \times \left[\frac{1978}{1818} - 1\right] \qquad E = 8.8\%$$

The radiographic procedure was:

1. Film loaded in holder.
2. Patient positioned in a standing position, looking straight ahead. Ear-rods placed in external auditory meatus. 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 occlusion.
7. The lip position was standardised (The patients were instructed to relax their lips).
8. Exposure made.

5.3 TRACING AND SUPERIMPOSITION

All radiographs were traced under standardised 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 pacer 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).

Superimposition allowed the transfer of the reference planes of the first (presurgical) film to the second (postsurgical) 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).
These structures are depicted diagramatically in Fig. 5.2.

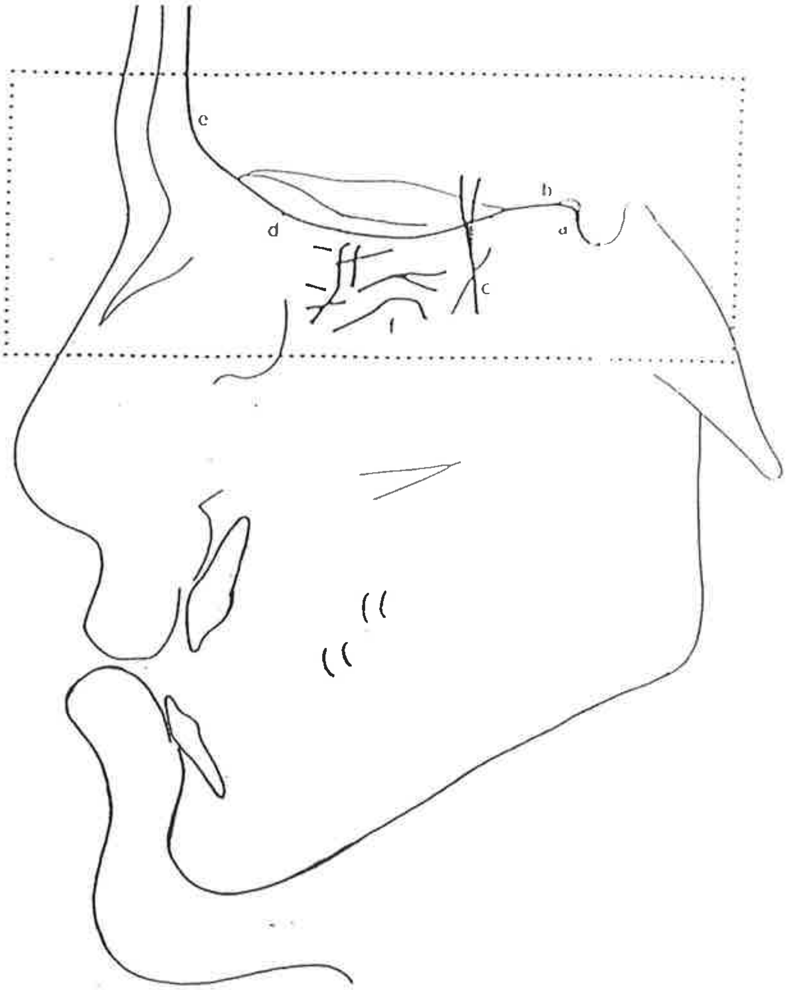


Fig.5.2 Principal structures used for cranial base superimposition

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)

This method of superimposition allowed facial soft tissue changes to be studied in relation to the cranial base. The reference planes selected were SN-7 which formed the X-axis and a perpendicular to SN-7 through sella (first film transferred to second) which formed the Y-axis of the cartesian coordinate system with sella at the origin.

5.4 LANDMARKS

(listed in order of digitising)

1. **Sella turcica(S):** the centre of the pituitary fossa of the sphenoid bone.

2. **X ALIGN(X):** Any point on the S-N 7 line except Sella.

3. **Glabella (G):** the most prominent point in the midsagittal plane of the forehead. (Legan and Burstone 1980).

4. **Soft tissue nasion(NAS):** the point of greatest concavity in the midline between forehead and nose (Krogman and Sassouni 1957).

5. **Rhinion(R):** junction of bony and cartilaginous dorsums. It approximates the maximal prominence of a bony-cartilaginous dorsal convexity (hump) when present (Powells and Humphreys 1984).

6. **Pronasale(PN):** the most prominent point on the contour of the nose (De Laat 1974).

7. **Columella point(CM):** the most anterior point on the columella of the nose (Legan and Burstone 1980).

8. **Subnasale(SUN):** the point at which the nasal septum merges with the upper cutaneous lip in the mid sagittal plane (Legan and Burstone 1980).

9. **Superior labial sulcus(SLS):** the point of greatest concavity in the midline of the upper lip beteen subnasale and labrale superius (Holdaway 1983).

10. **Labrale superius(LS):** a point indicating the mucocutaneous border of the upper lip (Legan and Burstone 1980).

11. **Stomion superius(STMS):** the lowermost point of the vermilion border of the upper lip (Legan and Burstone 1980).

12. **Stomion inferius(STMI):** the uppermost point of the vermilion of the lower lip (Legan and Burstone 1980).

13. **Labrale inferius(LI)**: a point indicating the mucocutaneous border of the lower lip (Legan and Burstone 1980).

14. **Inferior labial sulcus(ILS):** the point of greatest concavity in the midline between the lower lip and chin (Legan and Burstone 1980).

15. **Soft tissue pogonion(PGS)**: the most anterior point on the soft tissue chin (Legan and Burstone 1980).

16. **Soft tissue gnathion(GNS)**: the constructed midpoint between soft tissue pogonion and soft tissue menton; can be located at the intersection of the subnasale to soft tissue pogonion line and the line from cervical point to soft tissue menton (Legan and Burstone 1980).

17. **Soft tissue menton(MES):** the lowest point on the contour of the soft tissue chin; found by dropping a perpendicular from the horizontal reference plane through menton (Legan and Burstone 1980).

18. **Nasion(N)**: the junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose (Riolo, Moyers, McNamara and Hunter 1974).

19. **Anterior Nasal Spine(ANS)**: the tip of the median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening (Riolo, Moyers, McNamara and Hunter 1974).

20. **A point(A)**: the most posterior point on the curve of the maxilla between the anterior nasal spine and supradentale (Riolo, Moyers, McNamara and Hunter 1974).

21. **Supradentale(PR)**: the most anterior inferior point on the maxilla at its labial contact with the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

22. **Upper incisor incisal edge(IES)**: the incisal tip of the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

23. **Lower incisor incisal edge(IEI)**: the incisal tip of the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

24. **Infradentale(PRI)**: the anterior superior point on the mandible at its labial contact with the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

25. **B point(B)**: the point most posterior to a line from Infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible. B point should lie within the apical third of the incisor roots (Riolo, Moyers, McNamara and Hunter 1974).

26. **Pogonion(PG)**: the most anterior point on the contour of the bony chin. Determined by a tangent through nasion (Riolo, Moyers, McNamara and Hunter 1974).

27. **Gnathion(GN)**: the most anterior-inferior point on the contour of the bony chin symphysis. Determined by bisecting the angle formed by the mandibular plane and a line through pogonion and nasion (Riolo, Moyers, McNamara and Hunter 1974).

28. **Menton(ME)**: the most inferior point on the symphyseal outline (Riolo, Moyers, McNamara and Hunter 1974).

29. **Lower incisor apex(RI)**: the root tip of the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

30. **Upper incisor apex(RS)**: the root tip of the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

31. **Orbitale(OR)**: the lowest point on the average of the right and left borders of the bony orbit (Riolo, Moyers, McNamara and Hunter 1974).

32. **Upper molar mesial contact(MS)**: the mesial contact (height of contour) of the maxillary first molar relative to the functional occlusal plane (Riolo, Moyers, McNamara and Hunter 1974).

33. **Upper molar mesial cusp tip(MTU)**: the anterior cusp tip of the maxillary first molar (Riolo, Moyers, McNamara and Hunter 1974).

34. **Lower molar mesial cusp tip(MTL)**: the anterior cusp tip of the mandibular first molar (Riolo, Moyers, McNamara and Hunter 1974).

35. **Lower molar mesial contact(MI)**: the mesial contact (height of contour) of the mandibular first molar relative to the functional occlusal plane (Riolo, Moyers, McNamara and Hunter 1974).

36. **Posterior nasal spine(PNS)**: the most posterior point at the sagittal plane on the bony hard palate (Riolo, Moyers, McNamara and Hunter 1974).

37. **Pterygo-maxillary fissure, inferior(PTM):** the most inferior point on the average of the right and left outlines of the pterygo-maxillary fissure (Riolo, Moyers, McNamara and Hunter 1974).

38. **Gonion(GO):** the midpoint of the angle of the mandible. Found by bisecting the angle formed by the mandibular plane and a plane through

articulare posterior and along the portion of the mandibular ramus inferior to it (Riolo, Moyers, McNamara and Hunter 1974).

39. **Condylion(CO):** the most posterior superior point on the curvature of the average of the right and left outlines of the condylar head. Determined as the point of tangency to a perpendicular construction line to the anterior and posterior borders of the condylar head (Riolo, Moyers, McNamara and Hunter 1974).

40. **Basion(BA):** the most inferior, posterior point on the anterior margin of foramen magnum (Riolo, Moyers, McNamara and Hunter 1974).

41. **Articulare(AR):** the point of intersection of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles (Riolo, Moyers, McNamara and Hunter 1974).

42. **Cervical point(C):** the innermost point between the submental area and the neck located at the intersection of lines drawn tangent to the neck and submental areas (Legan and Burstone 1980).

All points were located on the mid-sagittal plane except gonion, articulare, condylion and pterygomaxillare so that the magnification factor was constant. A study of the influence of error of landmark location was allowed for in the methodology (chapter five).

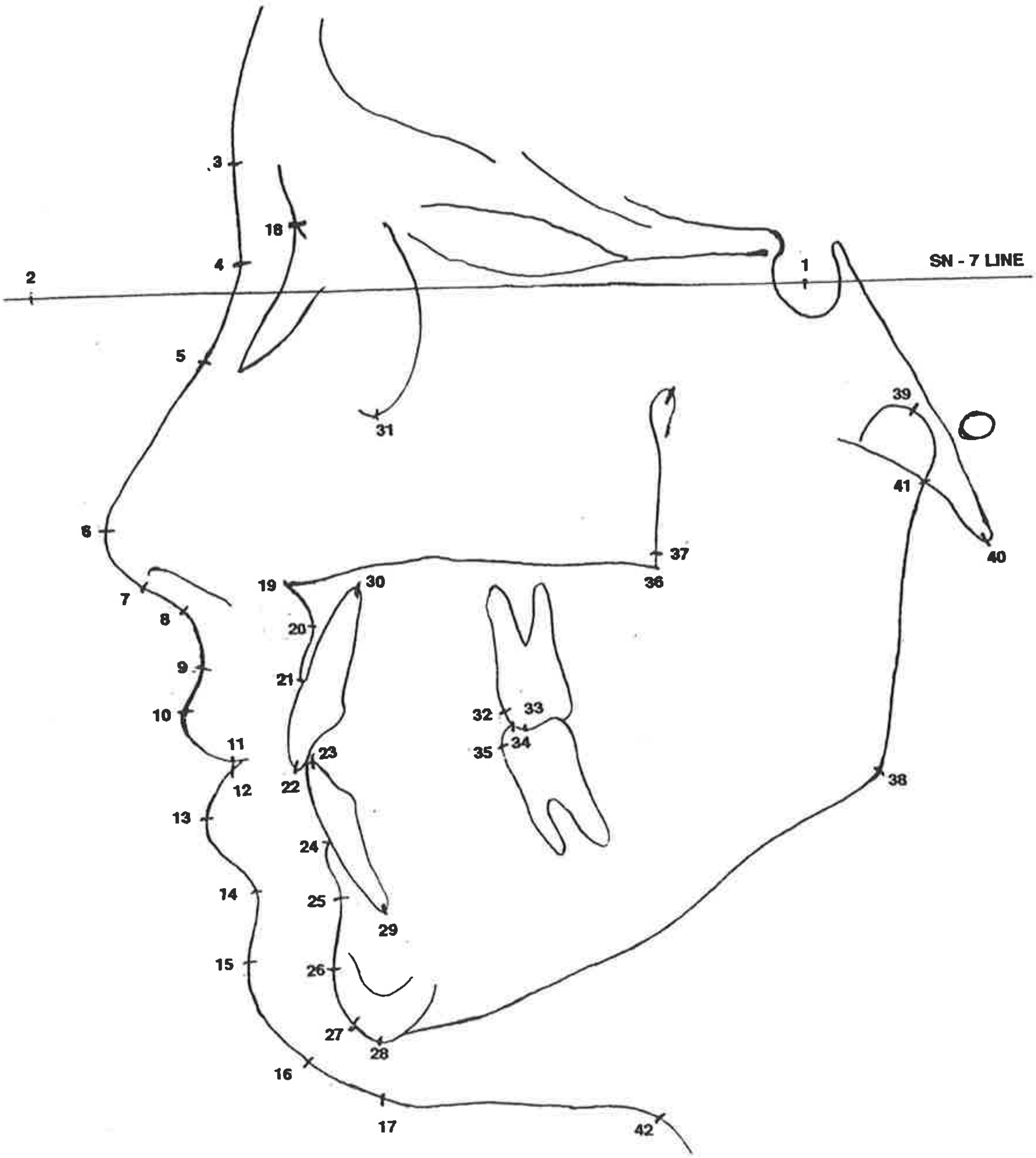


Fig.5.3 Soft and Hard Tissue points listed in order of digitising sequence

5.5 CALCULATION OF LINEAR AND ANGULAR VARIABLES

The variables were selected from those reported by Burstone (1980), Powell and Humphreys (1984).

5.5.1 ANGULAR VARIABLES

1. **Ramal angle (SN7 AR GO):** The angle formed between SN7 line and the line AR-GO.

2. **Mandibular plane angle (SN7 GO ME):** the angle formed between SN7 and the mandibular line.

3. **Gonial angle (AR GO GN):** the angle formed by a line tangent to the mandibular ramus and the mandibular line.

4. **SNA:** the angle formed between sella-nasion line and a line drawn through nasion and Down's A point.

5. **SNB:** the angle formed between sella-nasion line and line drawn through nasion and Down's B point.

6. **Upper incisor angle (UI-SN7):** the angle between SN7 and a line drawn through IES and RS.

7. **Lower incisor angle (LI-MP):** the angle between the mandibular line and the line IEI and RI.

8. **Nasolabial angle (NLA):** the angle formed by the points CM-SUN-LS.

9. **Labiomental angle (LMA):** the angle formed by the points LI-ILS-PGS.

10. **Nasofrontal angle (NFRA):** the angle between points G, NAS and R (Powell).

11. **Nasomental angle (NMA):** described by the angle formed by nasal dorsal line and the nasomental line i.e. between lines NAS-R and PN-PGS.

5.5.2 LINEAR VARIABLES

(N.B. X refers to X-axis and Y refers to Y-axis)

12. A point horizontal (X-A)

13. A point vertical (Y-A)

14. B point horizontal (X-B)

15. B point vertical (Y-B):

16. Upper incisor incisal edge horizontal (X-IES)

17. Upper incisor incisal edge vertical (Y-IES)

18. Lower incisor incisal edge horizontal (X-IEI)

19. Lower incisor incisal edge vertical (Y-IEI)

20. Upper molar mesial contact horizontal (X-MS)

21. Upper molar mesial contact vertical (Y-MS)

22. Lower molar mesial contact horizontal (X-MI)

23. Lower molar mesial contact vertical (Y-MI)

24. Posterior nasal spine horizontal (X-PNS)

25. Posterior nasal spine vertical (Y-PNS)

26. Pogonion horizontal (X-PG)

27. Pogonion vertical (Y-PG)

28. Pronasale horizontal (X-PN)

29. Pronasale vertical (Y-PN)

30. Subnasale horizontal (X-SUN)

31. Subnasale vertical (Y-SUN)

32. Superior labial sulcus horizontal (X-SLS)

33. Superior labial sulcus vertical (Y-SLS)

34. Labrale superius horizontal (X-LS)

35. Labrale superius vertical (Y-LS)

36. Labrale inferius horizontal (X-LI)

37. Labrale inferius vertical (Y-LI)

38. Inferior labial sulcus horizontal (X-ILS)

39. Inferior labial sulcus vertical (Y-ILS)

40. Soft tissue pogonion horizontal (X-PGS)

41. Soft tissue pogonion vertical (Y-PGS)

42. ULH - Upper lip height (SUN-STOMS):
    Y coordinate STOMS - Y coordinate SUN

43. LLH - Lower lip height (MES-STOMI):
    Y coordinate MES - Y coordinate STOMI

44. ULT - Upper lip thickness (A-SUN):
    X coordinate SUN - X coordinate A

45. LLT - Lower lip thickness (B-ILS):
X coordinate ILS - X coordinate B

5.6 METHODOLOGY

5.6.1 SUPERIMPOSITION TECHNIQUE

The technique used was that of Björk (1968) and Björk and Skieller (1983).

The procedure followed can be listed in stages:

1. A Björk transparent plastic sheet on which a thin black cross was marked was mounted on the viewing screen with tape.

2. The pretreatment radiograph was examined and sella and nasion were identified and the points marked lightly on the film.

3. The pretreatment radiograph was then secured with tape to the screen with sella at the centre of the cross and the X-axis lying 7 degrees below the sella nasion line.

4. Tracing paper was then secured to the screen with tape. Nasion, sella and X align were transferred to the tracing paper. A vertical reference line was drawn through sella perpendicular to the horizontal reference line (figure 5.4).

5. The other points listed in figure 5.3 were then identified and marked according to the definitions and location specifications in chapter five.

6. Relevant information was marked on the tracing paper, that is, the subjects name, age and identity number.

7. The tracing paper was removed.

8. The post-treatment radiograph was then superimposed on the pretreatment radiograph.

9. The pretreatment sella (intersection of the cross), a point (X-align) on the X-axis (SN -7 degree line) and the Y-axis were then marked lightly on the post-treatment film.

10. Both films were then removed from the screen.

11. The post-treatment film was then replaced with the origin (pretreatment sella) placed on the axis of the cross and X-align on the X-axis and secured with tape.

12. Tracing paper was then secured with tape.

13. The points for the reference axes and landmarks were then traced. The landmarks were identified and traced according to the definitions and specifications listed in chapter five.

14. The subjects identification was marked.

15. The radiograph was removed and the marks on both films were erased.

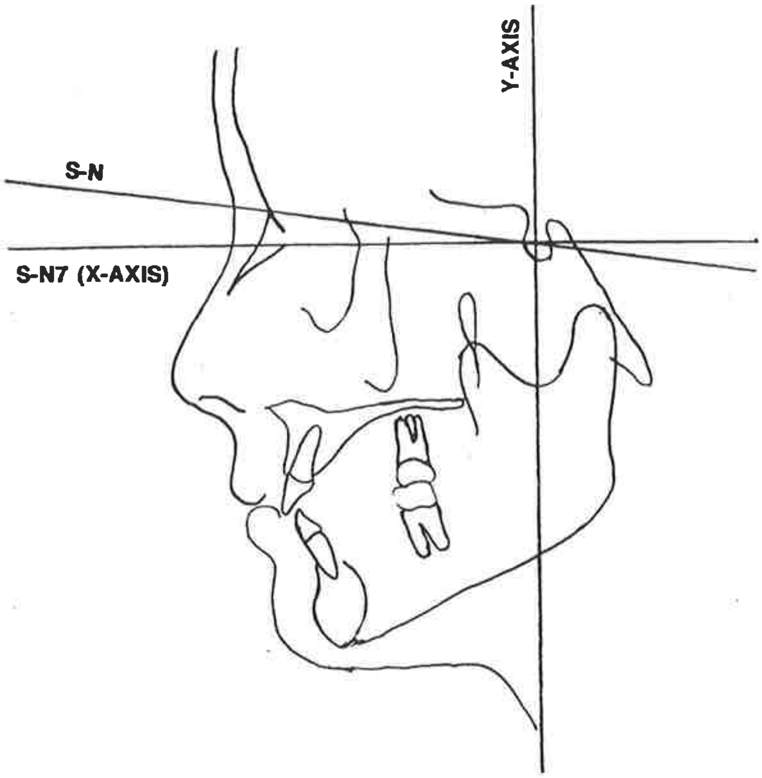


Fig. 5.4 Reference planes

All soft and hard tissue landmarks were located in the first, third and fourth quadrant of the Cartesian coordinate system.

The tracings were then digitised and analysed with the assistance of a Hewlett Packard 9874A digitiser using a Hewlett Packard 9815A controller, the data being stored on Hewlett Packard data tapes. Professor T. Brown coded programmes for the acquisition, plotting and transmission of digitised data for use on Hewlett Packard 9800 series equipment. Digitising 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 following digitising procedure was used:

1. Iso-propyl alcohol used to clean digitiser screen.
2. Data tape initialised and files constructed; one file per tracing.
3. Digitising programme loaded into controller.
4. Tracing mounted on screen using tape.
5. Programme run:
    a. Subject's identity and file numbers recorded.
    b. Axis alignment using two points on the sella-nasion 7° line (sella and x-align).
    c. Landmarks were digitised in a specific order 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. For each new tracing, the procedure was started again (Steps 1 to 5).

5.6.2 STATISTICAL ANALYSIS

Statistical analysis was carried out using S.P.S.S. (statistical package) on "ACHE" computer at the University of Adelaide. The parameters calculated are shown in Table 5.1.

To assess the significance of differences between the variances and means of two groups the students t-Test was used.

TABLE 5.1

SYMBOL	PARAMETER	DETERMINATION
$\overline{X}$	Arithmetic mean	$\frac{\Sigma X}{N}$
S	Standard deviation	$\sqrt{\frac{\Sigma (X - \overline{X})^2}{N - 1}}$
(X)	Standard error of the mean	$\frac{S}{\sqrt{N}}$
r_{xy}	Correlation coefficient	$\frac{\Sigma (X - \overline{X}) (Y - \overline{Y})}{\sqrt{\Sigma (X - \overline{X})^2 \, \Sigma (Y - \overline{Y})^2}}$

X and Y are observed scores and N is the number of observations

5.7 ERROR OF THE METHOD

(Text accompanies Appendix I and II)

The errors associated with this methodology could arise from:

- Cephalometric projection
- Landmark identification
- Tracing
- Digitisation
- Measurement by the described apparatus
- Superimposition of serial cephalograms

In an attempt to quantify the overall error, a random sample of seventeen sets of cephalograms was drawn from the main sample (i.e. a total of thirty-four films).

Each set consisted of films exposed at:

T2 - Presurgical cephalogram

T3 - Within six months postsurgery cephalogram

Tracing, superimposition and digitisation were repeated on a separate occasion by one observer and the results recorded. Landmarks were defined and located as described previously.

For each of the seventeen sets of films, data indicating the displacement in the X and Y axes between the two films were generated for each landmark of interest.

Houston (1983) has categorised errors of cephalometric research as:

1. Systematic errors - Such errors are systematically introduced into the data due to details of the experimental methodology, for example, subconscious weighting of data due to failure to use a blind sampling technique.

2. Random errors - Errors that are injected into the data in a random fashion, for example, inaccurate landmark determinations.

The total error involves a component of each of the above factors. Errors may be additive, or may tend to cancel each other out, so in any investigation, it is important to ascertain the magnitude of the overall error, rather than assuming that one component of the overall error is representative of the error of the method.

The differences between two determinations were analysed and expressed as the mean of the difference (M.diff), the standard deviation of the differences (S.D. diff), and the error of the mean differences (εM diff). The following formulae were used to determine the error statistics:

$$\text{M diff} = \frac{\sum d}{n}$$

$$\text{S.D. diff} = \sqrt{\frac{\sum (d - \text{M diff})^2}{n-1}}$$

$$\text{M diff} = \frac{\text{S.D. diff}}{\sqrt{n}}$$

where d = difference between two determinations,

n = number of double determinations.

In addition the method of Dahlberg (1940) was used to compute the standard deviation of a single determination ($S.D._s$) according to:

$$S.D._s = \sqrt{\frac{\Sigma d^2}{2n}}$$

where 2n = number of single determinations.

Students "t-test" was used to determine the probability that a mean difference differed significantly from zero, thereby indicating a systematic discrepancy between the two determinations. For the test, the 5% probability level was used and the mean differences were designated significant at the 5% level. The value of t was calculated according to the equation:

$$t = \frac{M\ diff}{\varepsilon M\ diff}$$

The extent to which the variability due to experimental error affected the observed variance was indicated by using the generality that component parts of a variance can be summed to equal the total variance.

Thus:

$$S_1^2 = S_t^2 + S_e^2$$

where S_1^2 = observed variance from sample as determined from the original values. This value includes variance due to measurement error.

S_t^2 = estimate of the true sample variance

S_e^2 = variance due to measurement error, termed error variance in this study. This value is determined as SD_s^2

where $S.D._s = \sqrt{\frac{\Sigma d}{2n}}$

The error variance was then expressed as a percentage of the observed variance.

The reliability of the digitisation process was investigated by redigitising one cephalometric tracing ten times, this should indicate the error related to the digitising hardware and software (refer to Appendix II).

CHAPTER SIX

RESULTS

6.1 INTRODUCTION

The detailed statistical tables providing results corresponding to this chapter have been placed in Appendices I to XI.

6.2 ERROR OF THE METHOD

6.2.1. Tracing and superimposition (systematic and random errors)

(Text accompanies Appendix I)

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 one degree of freedom. This enabled the hypothesis that the mean difference did not alter significantly from zero to be tested. The five percent level of probability was used to assess the significance.

Variables SN7ARGO, Y-A, Y-PN, Y-IES differed significantly from 0 at 5% level of probability. This finding indicates that the ramal angle, vertical location of A Point, vertical location of pronasale and vertical location of incisal edge superior were subject to significant component of error. Therefore, they were found to be variables requiring careful interpretation.

An examination of the E(var)% indicated that errors made a contribution to the total observed variance. The majority of variables were lower than 5%. Those exceeding 5% were: nasofrontal angle, horizontal location of molar inferior, vertical location of pronasale and vertical location of superior labial sulcus. This indicated that these variables were relatively more difficult to determine.

6.2.2. Digitising error

(Text accompanies Appendix II)

Digitising error was due to the uncertainty of the operator in placing the cursor of the digitiser 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 digitiser handbook the accuracy of the cursor is $\pm$0.00492" and of the stylus 0.01969" at temperatures of 10^{o} to 40^{o} C. The repeatability of the cursor is 0.00984" and of the stylus 0.01181".

Appendix II displays the statistics used to assess the significance and extent of digitising error. This was calculated by comparing ten repeated measurements of a single tracing. 95.6% of the repeated measures would be expected to fall within two standard deviations of the true value. The standard deviations for all the variables fall below 0.5 millimetres or degrees. The largest standard deviation (0.38 degrees) was found for the variable LMA and the smallest was found for the vertical axis of molar inferior (0.05 mm). The digitising error is minimal and did not bias the technique to any noticable extent.

6.3 SIGNIFICANCE TESTS OF MALES vs. FEMALES

6.3.1 Pre-operative

(Text accompanies Appendix III)

All variables calculated from the pre-operative records were compared between males and females using t tests. In general, there were significant differences between the male and female mean values before treatment. The variables which differed significantly between the sexes were(Fig. 6.1): X-A, X-B, Y-B, X-IES, X-IEI, X-MS, X-MI, X-PNS, Y-PG, X-PN, X-SUN, X-SLS, X-LS, X-LI, X-ILS, ULH.

The mean values in males were larger for all of the above variables.

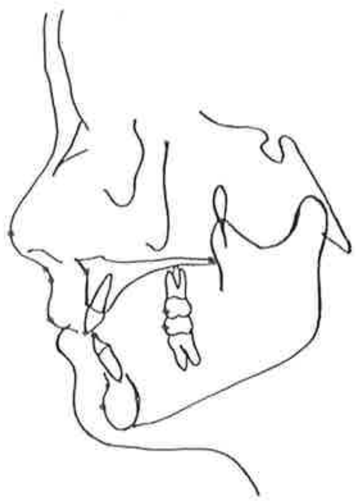


Fig. 6.1 Significant soft and hard tissue points that differed between males and females -preoperative

6.3.2. At 6 months post-operative

(Text accompanies Appendix IV)

The variables which differed significantly between the sexes were(Fig.6.2): X-A, X-B, X-IES, X-IEI, X-MS, X-MI, Y-MI, X-PG, Y-PG, X-PN, X-SUN, X-SLS, X-LS, X-LI, X-PGS, LLH.

The mean values in males were larger for all of the above variables.

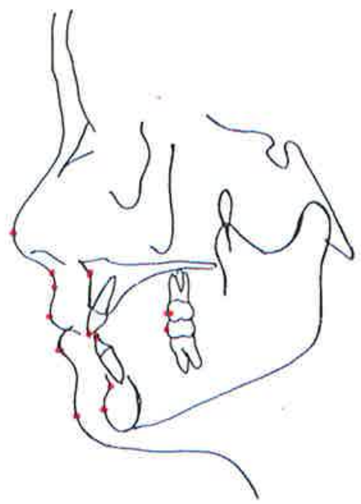


Fig. 6.2 Significant soft and hard tissue points that differed between males and females - at 6 months post surgery

6.3.3 At 12 months post-operative

(Text accompanies Appendix V)

The variables which differed significantly between the sexes were(Fig. 6.3): NLA, X-A, X-B, X-IES, X-IEI, X-MI, X-SUN, X-SLS, X-LS, X-LI, X-ILS, LLH.

The mean values in males were larger for all of the above variables except the variable NLA.

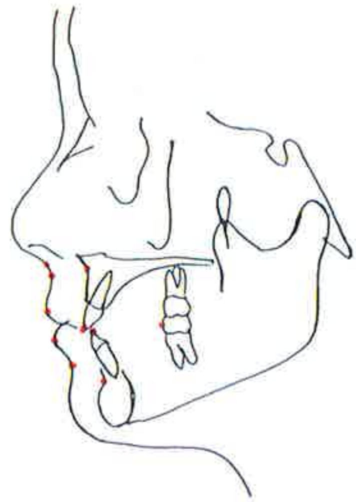


Fig. 6.3 Significant soft and hard tissue points that differed between males and females - at 12 months post surgery

6.3.4 At 24 months post-operative

(Text accompanies Appendix VI)

The variables which differed significantly between the sexes were(Fig. 6.4): X-PN, X-SUN, X-LI.

The mean values in males were larger for all of the above variables.

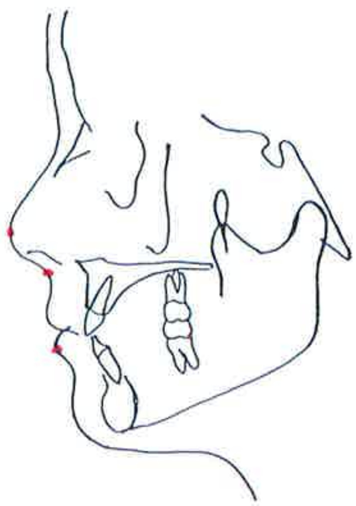


Fig. 6.4 Significant soft and hard tissue points that differed between males and females - at 24 months post surgery

6.3.5. At 36 months post-operative

(Text accompanies Appendix VII)

The variables which differed significantly between the sexes were(Fig.6.5): X-MI, X-PN, LLH.

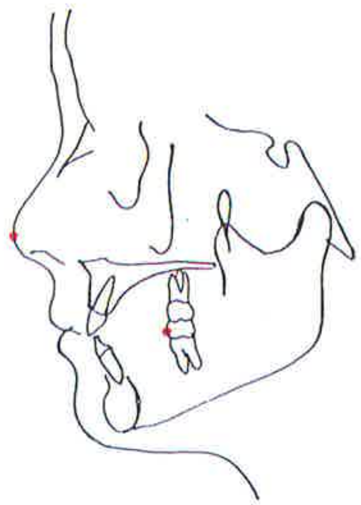


Fig. 6.5 Significant soft and hard tissue points that differed between males and females - at 36 months post surgery

6.4 SIGNIFICANCE TESTS OF DIFFERENCES BETWEEN STAGES

6.4.1. Stage differences

The t tests were used to assess the significance of differences between the stages for males and females. The t tests were calculated for the following stage differences: data calculated from the pretreatment minus post-treatment 6 months (T2-T3); post-treatment 6 months minus post-treatment 12 months (T3-T4); post-treatment 12 months minus post-treatment 24 months (T4-T5); post-treatment 24 months minus post-treatment 36 months (T5-T6).

(i) Pretreatment minus post-treatment 6 months (T2-T3): no significant differences were found between these two stages for either males or females at the 5% level. (Text accompanies Appendix VIII).

(ii) Post-treatment 6 months minus post-treatment 12 months (T3-T4): no significant differences were found between these two stages for either males or females at the 5% level. (Text accompanies Appendix IX).

(iii) Post-treatment 12 months minus post-treatment 24 months (T4-T5): a significant difference was found between these stages for the variable X-PNS (females) at the 5% level. (Text accompanies Appendix X).

(iv) Post-treatment 24 months minus post-treatment 36 months (T5-T6): no significant differences were found between these two stages for either males or females at the 5% level. (Text accompanies Appendix XI).

6.4.2 Statistical significance of the mean differences between the stages

The mean differences between the stages were calculated for all the variables to determine the variables which differed significantly from zero at the 5% level.

a. Male Sample

Pretreatment minus post-treatment 6 months (T2-T3)

The mean differences for the variables SN7GOME, UISN7, LIMP, SNA, SNB, NLA, LMA, NMA, X-A, Y-A, X-B, Y-B, X-IEI, X-MI, Y-PNS, X-PG, X-SUN, Y-SUN, Y-LS, X-SLS, Y-SLS, X-LS, Y-LS, X-LI, X-ILS, Y-ILS, X-PGS, Y-PGS, LLH, ULT, LLT differed significantly from zero at the 5% level.

Post-treatment 6 months minus post-treatment 12 months (T3-T4)

The mean differences for the variables SNB, UISN7, NLA, LMA, X-A, Y-A, X-B, X-PG, Y-SLS, X-ILS differed significantly from zero at the 5% level.

Post-treatment 12 months minus post-treatment 24 months (T4-T5)

The mean differences for the variables LIMP and X-IES differed significantly from zero at the 5% level.

Post-treatment 24 months minus post-treatment 36 months (T5-T6)

The mean difference for the variable Y-PNS differed significantly from zero at the 5% level.

b. Female Sample

Pretreatment minus post-treatment 6 months (T2-T3)

The mean differences for the variables SN7ARGO, SN7GOME, SNA, SNB, U1SN7, LIMP, NLA, LMA, NMA, X-A, Y-A, X-B, X-IEI, Y-IEI, X-MS, X-MI, X-PNS, Y-PNS, X-PG, Y-PN, X-SUN, Y-SUN, X-SLS, X-LS, X-LI, X-ILS, X-PGS, ULH, LLH, ULT differed significantly from zero at the 5% level.

Post-treatment 6 months minus post-treatment 12 months (T3-T4)

The mean differences for the variables U1SN7, LIMP, X-A, X-B, Y-B, X-PG, Y-SUN, X-SLS, X-LS, X-L1, LLH, ULT differed significantly from zero at the 5% level.

Post-treatment 12 months minus post-treatment 24 months (T4-T5)

The mean differences for the variables LMA, Y-IEI, X-MS, X-MI, X-PNS, differed significantly from zero at the 5% level.

Post-treatment 24 months minus post-treatment 36 months (T5-T6)

The mean difference for the variable X-IES differed significantly from zero at the 5% level.

6.5 RESPONSE OF LIPS (THIN VS THICK) TO SURGERY

(Tables showing detailed statistical analysis have not been included)

6.5.1 Upper lip (thin vs thick)

The variable ULT for male and female samples was not significantly different at the 5% level. Therefore, both male and female samples were combined to evaluate the response of thin and thick lips.

The sample was divided into two groups (i.e. thin lips and thick lips) with the thick lip group including subjects with lip thickness greater than the sample mean (17.8 mm) and the thin lip group having lip thickness thinner than 17.8 mms.

a. Thin lip group (N=12)

This group included all patients in the sample with upper lip thickness of less than 17.8 mms.

b. Thick lip group (N=11)

This group included all patients in the sample with upper lip thickness of more than 17.8 mms.

The results indicate that both thin and thick lips behaved in a similar manner in response to surgery. Both thin and thick lips thinned following surgery. The upper lip lengthened in both groups. However, this was not statistically significant.

6.5.2 Lower lip (thin vs thick)

The variable LLT for male and female samples was not significantly different at the 5% level. Therefore, both male and female samples were combined to evaluate the response of thin and thick lips.

The sample was divided into two groups (i.e. thin lips and thick lips) with the thick lip group including subjects with lip thickness greater than the sample mean (11.4 mm) and the thin lip group having lip thickness thinner than 11.4 mm.

a. Thin lip group (N=13)

This group included all patients in the sample with lower lip thickness of less than 11.4 mms.

b. Thick lip group (N=10)

This group included all patients in the sample with lower lip thickness of more than 11.4 mms.

The results indicate that both thin and thick lips behaved in a similar manner in response to surgery. Both thin and thick lips thickened following surgery. The lower lip shortened in both groups. However, this was not statistically significant

6.5.3 Lip response to the magnitude of surgical movement

a. Upper lip

The sample was divided into two groups. Group 1 (N=15) included subjects with surgical advancements greater than the sample mean (3.3 mm). Group 2 (N=8) included subjects with surgical advancements less than the sample mean (3.3 mm). For both groups, upper lip height and upper lip thickness was evaluated. In both groups the response was similar, the upper lip thinned and lengthened.

b. Lower lip

The sample was divided into two groups. Group 1 (N=10) included subjects with surgical setback of less than the sample mean (6.5 mm) and Group 2 (N=13) included subjects with surgical setback of more than 6.5 mm.

For both groups, lower lip height and lower lip thickness response was evaluated. In both groups the response was similar, lower lip thickness increased and the lip height reduced.

6.6 POST SURGICAL CHANGE

6.6.1 Skeletal changes - maxilla

a. Horizontal changes - A-point (X-A)

A-point horizontal increased by 2.39 mm ± 0.46 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$). An increase indicates a forward movement at A-point.

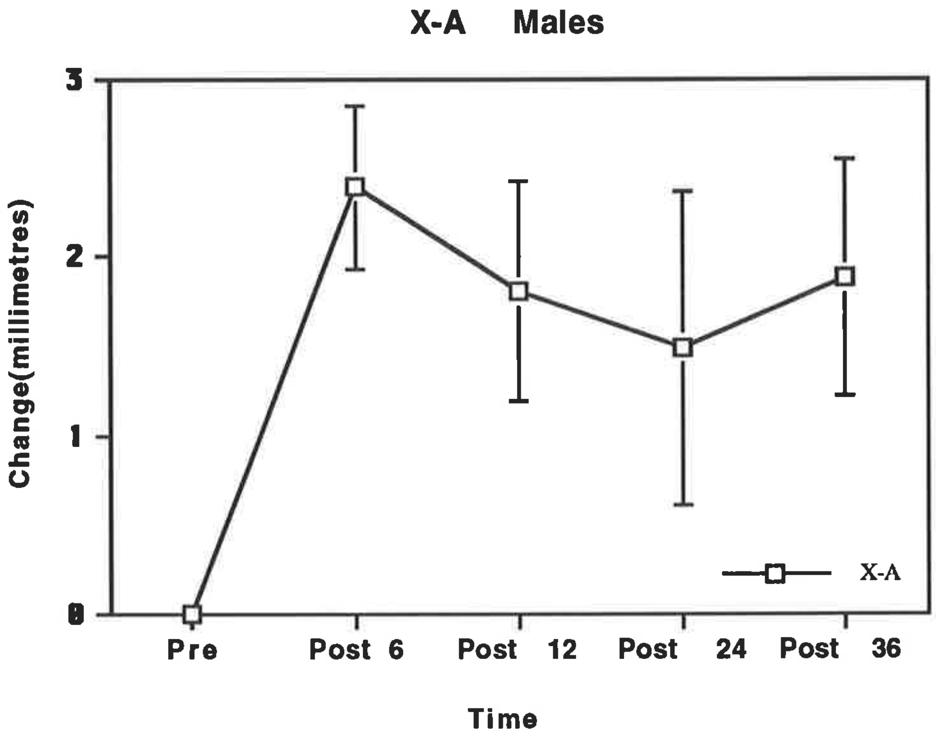


Fig. 6.6 Changes in X-A in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

A-point horizontal decreased by 0.58 mm ± 0.62 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$). A decrease during this period indicates a backward movement at A-point.

A-point horizontal decreased by 0.32 mm ± 0.88 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

A-point horizontal increased by 0.40 mm ± 0.66 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

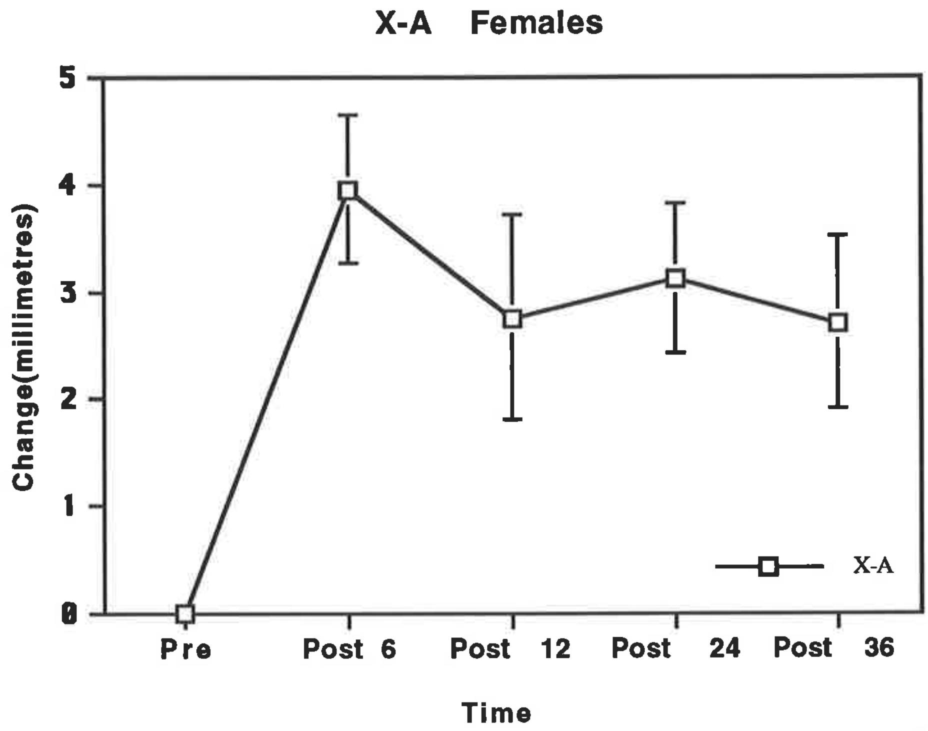


Fig. 6.7 Changes in X-A in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

A-point horizontal increased by 3.95 mm ± 0.68 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

A-point horizontal decreased by 1.20 mm ± 0.97 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

A-point horizontal increased by 0.36 mm ± 0.70 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

A-point horizontal decreased by 0.41 mm ± 0.81 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

b. Vertical changes - A point (Y-A)

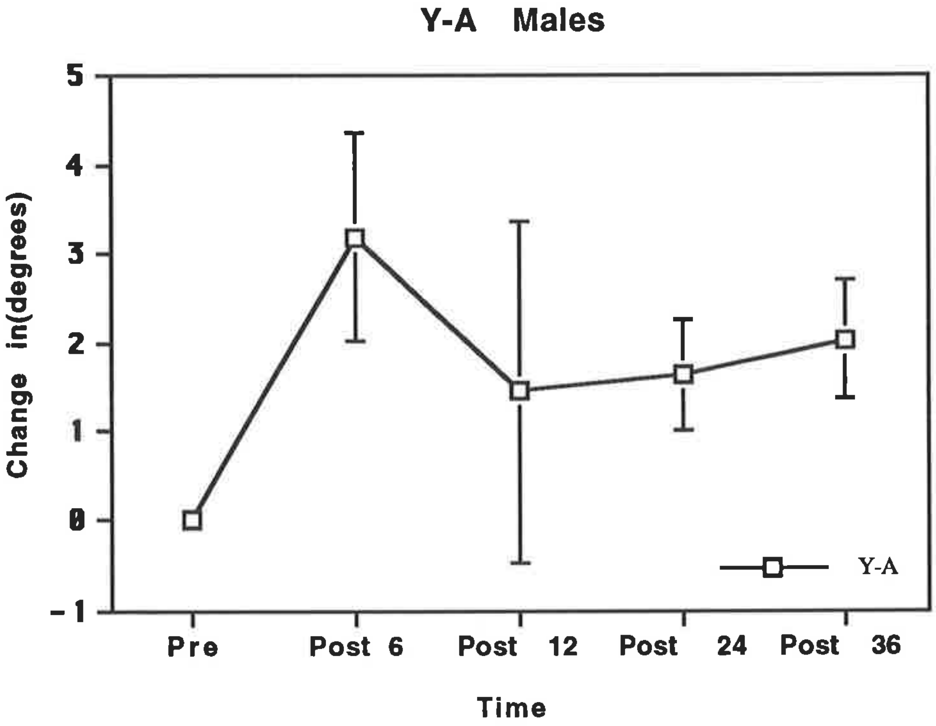


Fig. 6.8 Changes in Y-A in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-A increased by 3.19 mm ± 1.17 mm from preoperative to postoperative 6 months. This was statistically significant at ($p < 0.05$).

Y-A decreased by 1.75 mm ± 1.93 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

Y-A increased by 0.18 mm ± 0.63 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-A increased by 0.40 mm ± 0.67 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

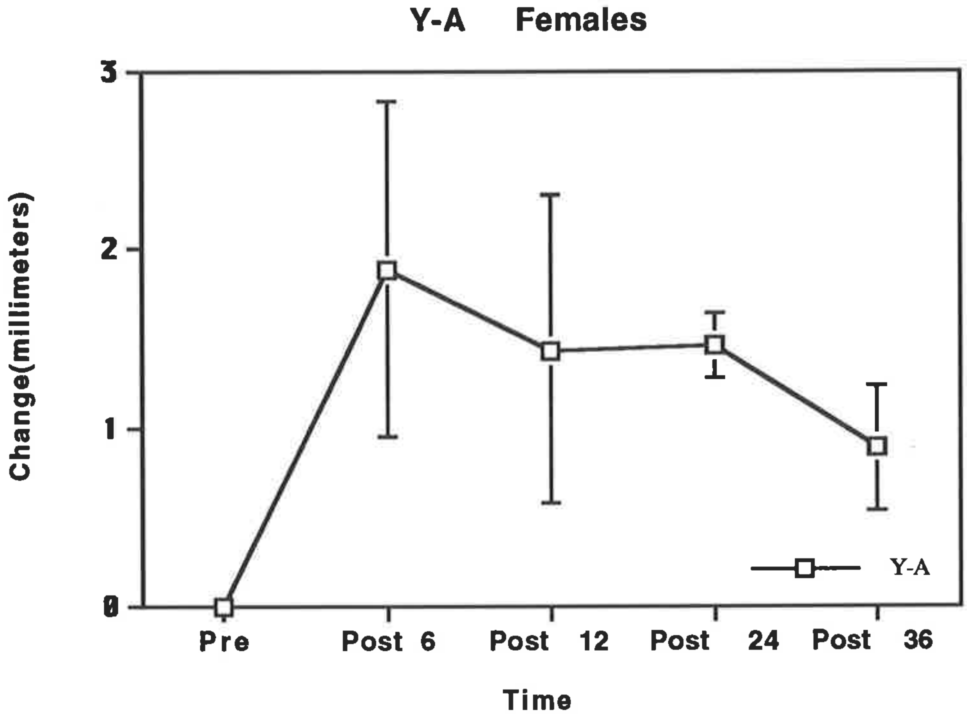


Fig. 6.9 Changes in Y-A in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-A increased by 1.89 mm ± 0.89 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

Y-A decreased by 0.45 mm ± 0.86 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-A increased by 0.03 mm ± 0.18 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-A decreased by 0.57 mm ± 0.35 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

c. SNA

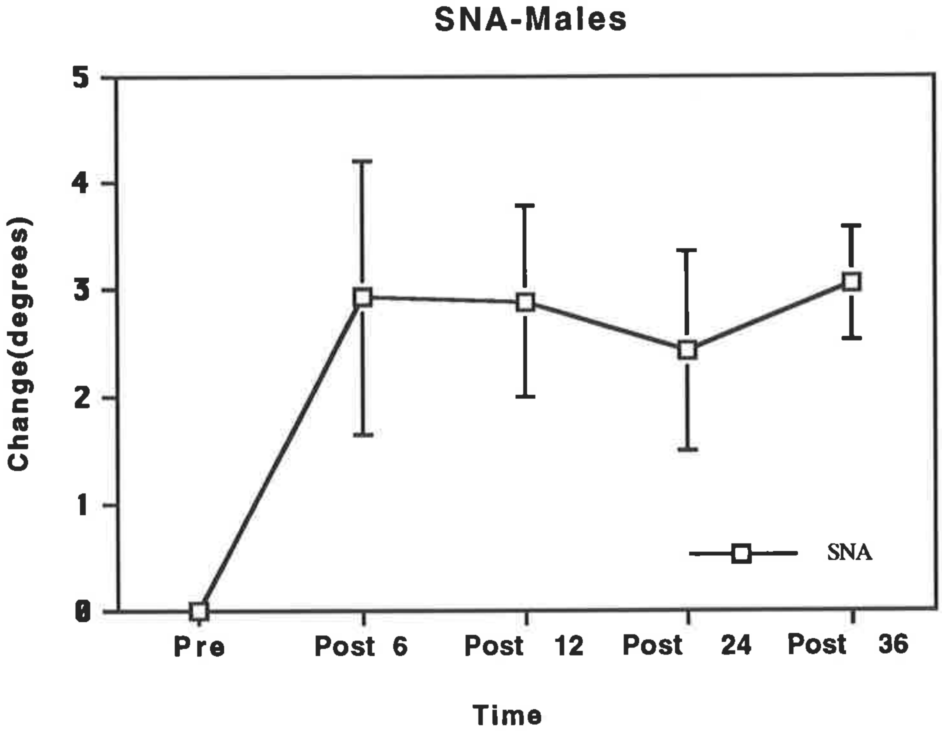


Fig. 6.10 Changes in SNA in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class III value for SNA 79.88° ± 3.23° (Ellis & McNamara, 1984)

Preoperative SNA Males 78.78°± 4.11°

SNA increased by 2.92°±1.27° from preoperative to postoperative 6 months. This change was statistically significant ($p < 0.05$).

SNA decreased by 0.05°±0.89° from postoperative 6 months to postoperative 12 months. This change was not statistically significant.

SNA decreased by 0.46°±0.92° from postoperative 12 months to post operative 24 months. This change was not statistically significant.

SNA increased by 0.62°±0.53° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

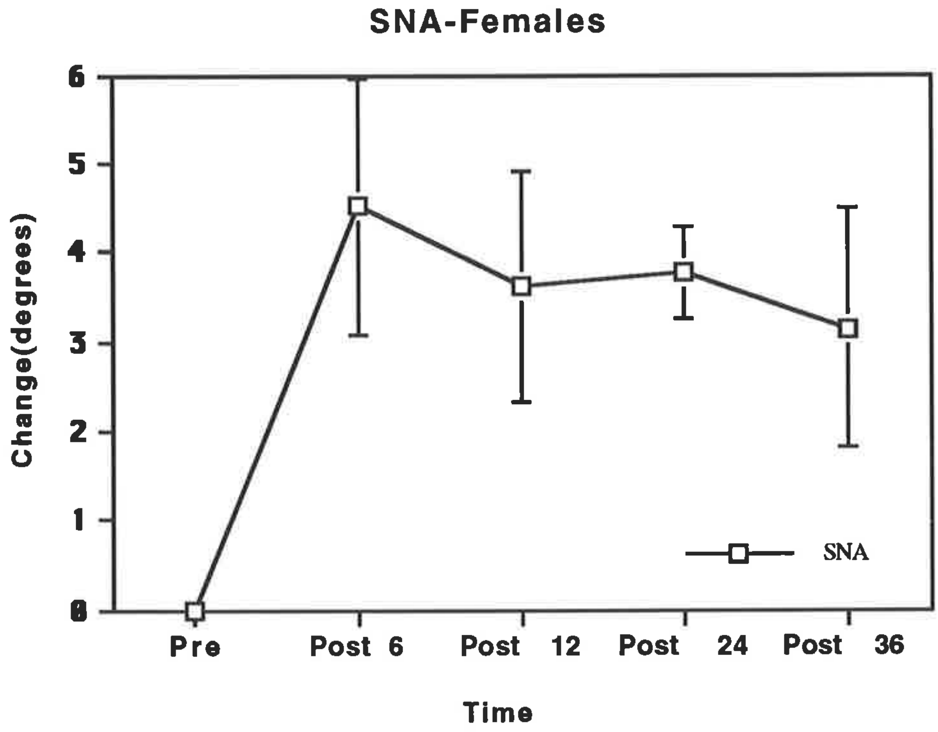


Fig. 6.11 Changes in SNA in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class III value for SNA 79.88° ± 3.23° (Ellis & McNamara, 1984)

Preoperative SNA Females 76.15° ± 3.74°

SNA increased by 4.51° ± 1.44° from preoperative to postoperative 6 months. This change was statistically significant ($p < 0.05$). Preoperative SNA suggests that the maxilla was more retrognathic in females requiring a greater anteroposterior change at surgery.

SNA decreased by 0.90°±1.29° from postoperative 6 months to postoperative 12 months. This was not statistically significant.

SNA increased by 0.15°±0.51° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

SNA decreased by 0.61°±1.33° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.2 Skeletal changes - mandible

a. Horizontal changes - B-point (X-B)

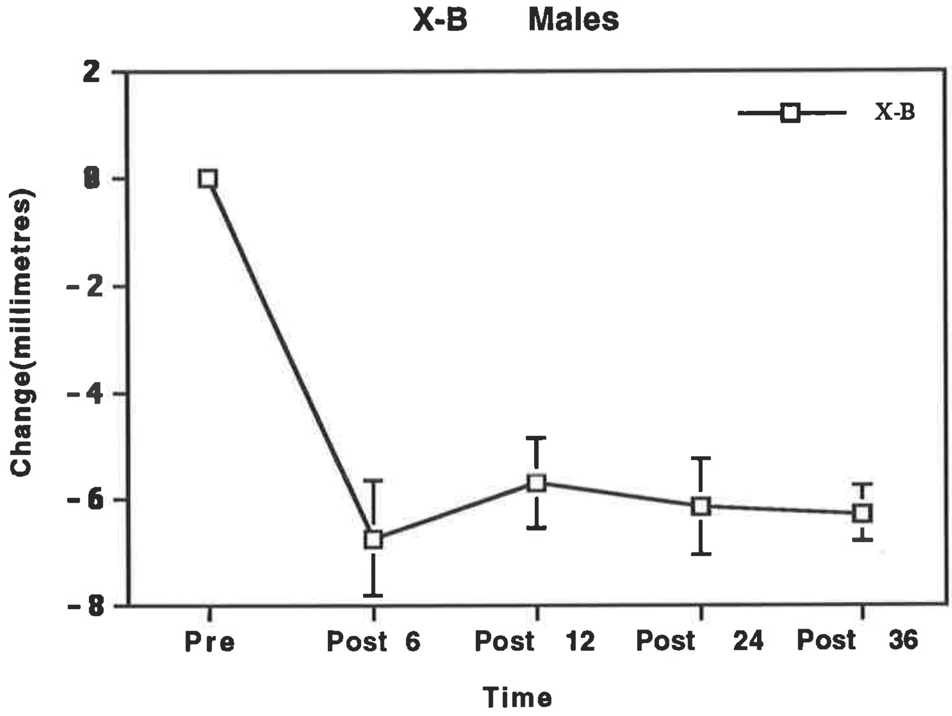


Fig. 6.12 Changes in X-B in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

B-point horizontal decreased by 6.75 mm ± 1.08 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

B-point horizontal decreased by 1.03 mm ± 0.84 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

B-point horizontal decreased by 0.45 mm ± 0.91mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

B-point horizontal decreased by 0.13 mm ± 0.54 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

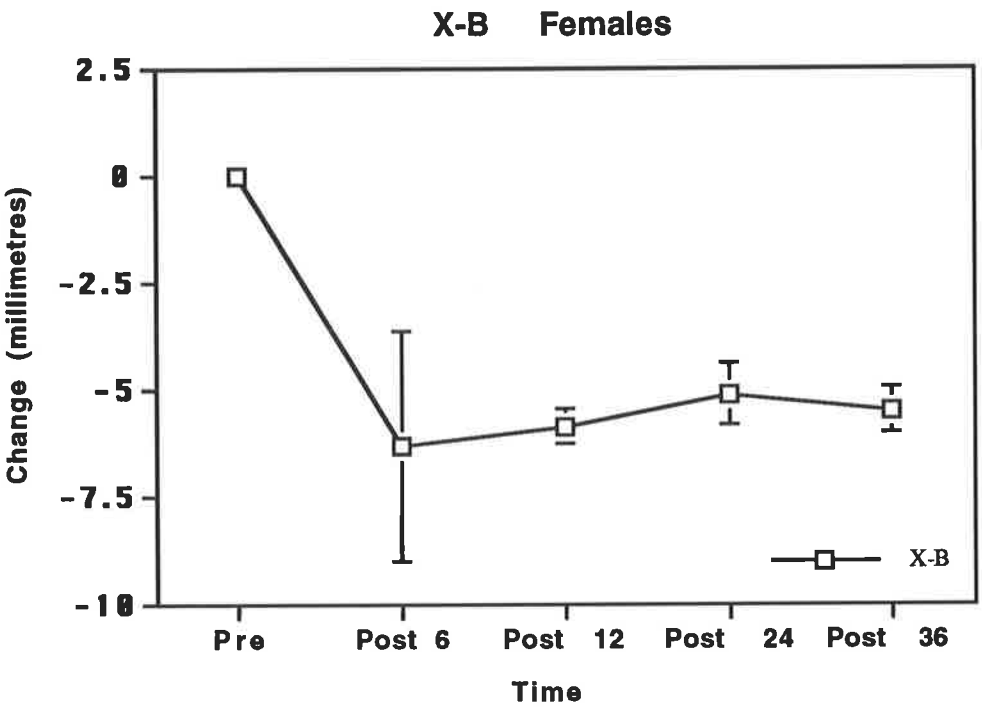


Fig. 6.13 Changes in X-B in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

B-point horizontal decreased by 6.35 mm ± 2.71 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

B-point horizontal increased by 0.47 mm ± 0.40 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

B-point horizontal increased by 0.74 mm ± 0.73 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

B-point horizontal decreased by 0.32 mm ± 0.51 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

b. **Vertical changes - B point (Y-B)**

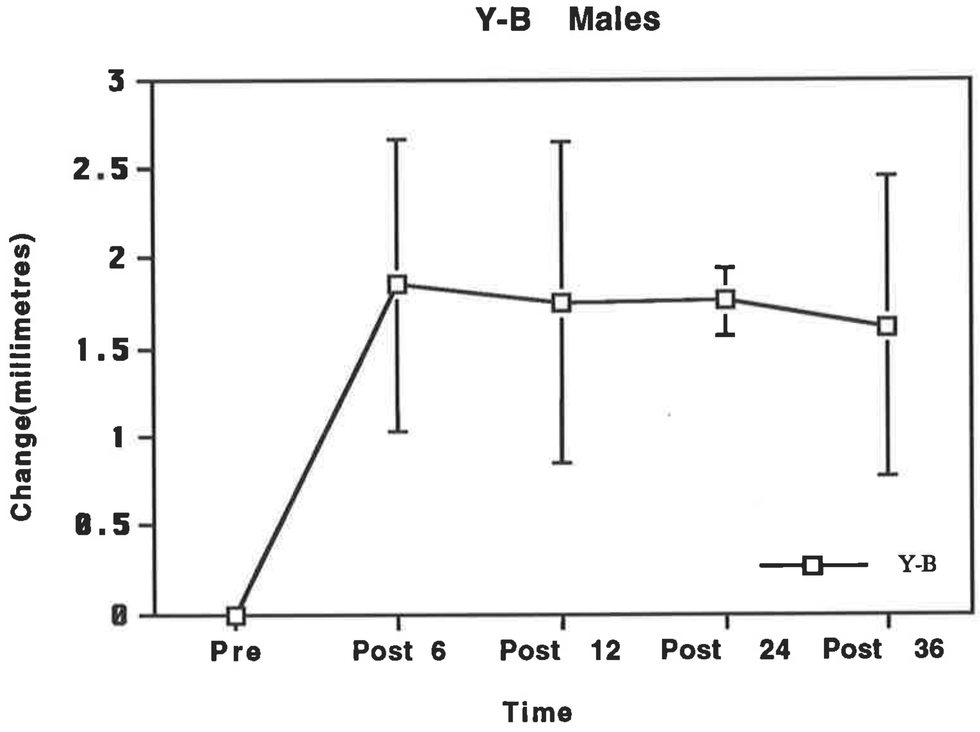


Fig. 6.14 Changes in Y-B in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-B increased in males by 1.85 mm ± 0.82 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-B decreased in males by 0.10 mm ± 0.90 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-B increased in males by 0.01 mm ±0.19 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-B decreased in males by 0.14 mm ± 0.84 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

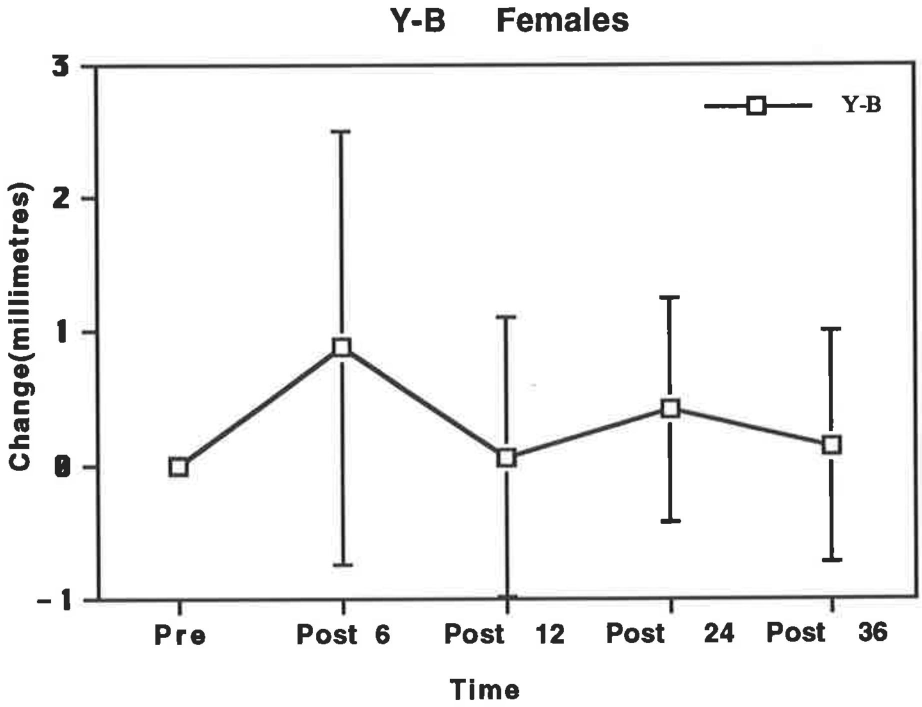


Fig. 6.15 Changes in Y-B in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-B increased in females by 0.88 mm ±1.62 mm from preoperative to postoperative 6 months. This was not statistically significant .

Y-B decreased in females by 0.82 mm ±1.04 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

Y-B increased in females by 0.35 mm ±0.83 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-B decreased in females by 0.28 mm ± 0.86 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

c. SNB

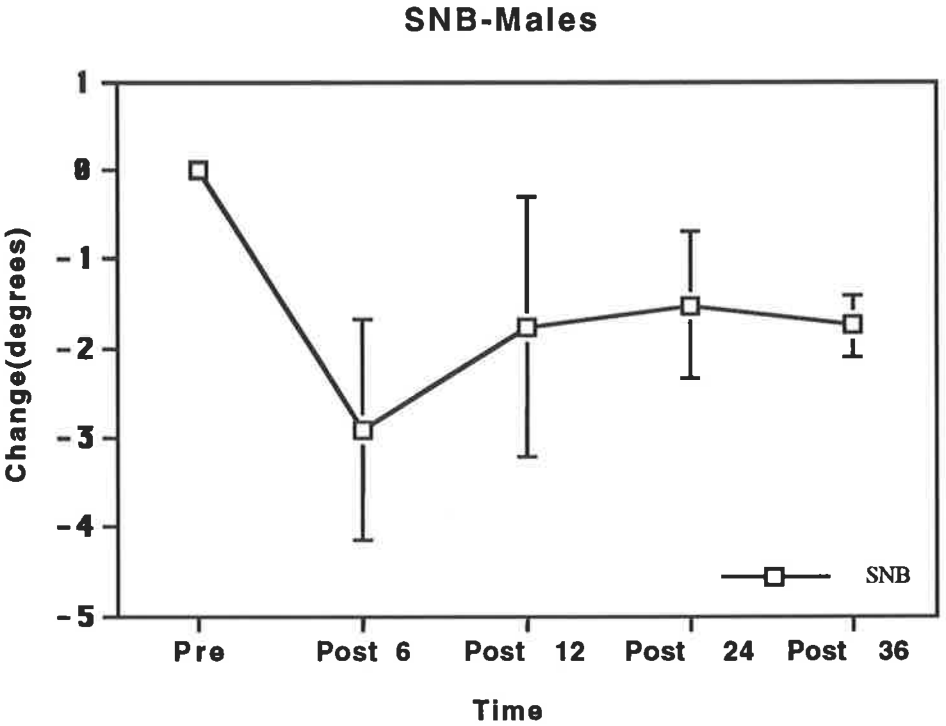


Fig. 6.16 Changes in SNB in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class III for SNB 83.48° ± 4.0° (Ellis & McNamara, 1984)

Preoperative SNB Males 84.12° ± 4.70°

SNB decreased by 2.91°±1.23° from preoperative to postoperative 6 months. This change was statistically significant ($p<0.05$).

SNB increased by 1.15°±1.46° from postoperative 6 months to postoperative 12 months. This change was statistically significant ($p<0.05$).

SNB increased by 0.24°±0.82° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

SNB decreased by 0.21°±0.34° from postoperative 24 months to postoperative 36 months . This was not statistically significant.

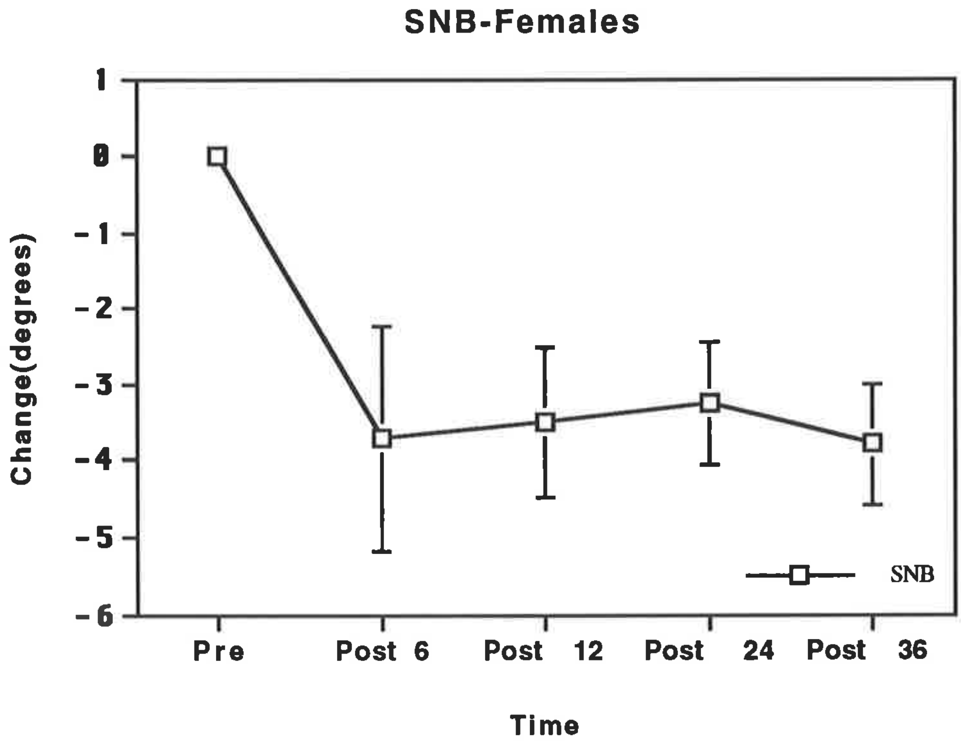


Fig. 6.17 Changes in SNB in females between stages
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class III value for SNB 83.48° ± 4.00° (Ellis & McNamara,1984).

Preoperative SNB Females 81.89° ± 3.06°

SNB decreased by 3.71°±1.46° from preoperative to postoperative 6 months. This change was statistically significant ($p<0.05$).

SNB increased by 0.22°±0.98° from postoperative 6 months to postoperative 12 months. This was not statistically significant.

SNB increased by 0.25°±0.81° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

SNB decreased by 0.53°±0.78° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

d. Horizontal changes - pogonion (X-PG)

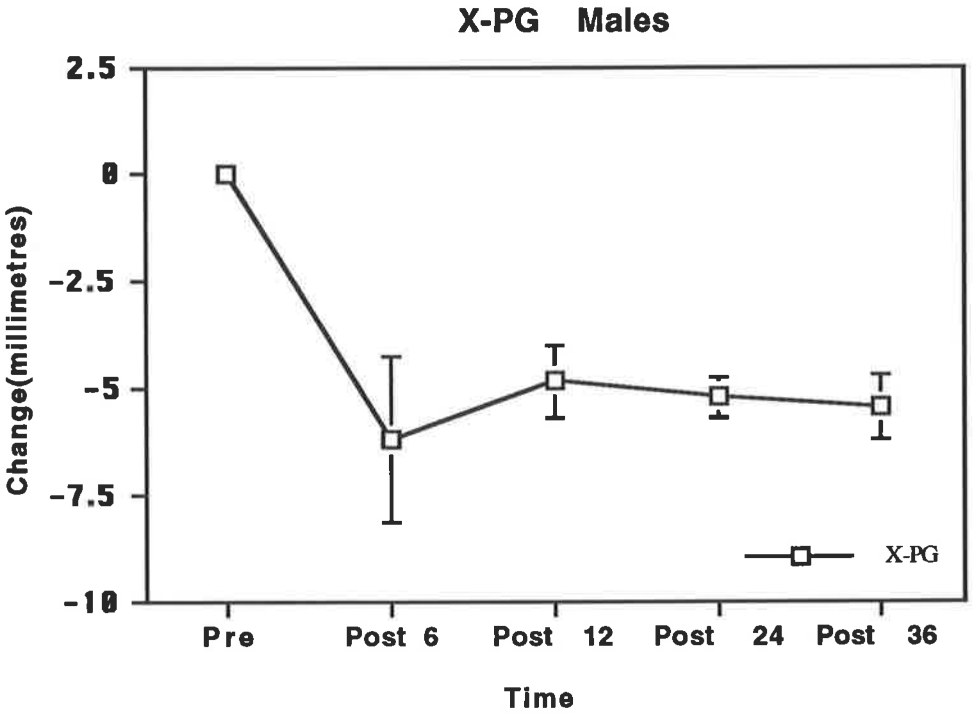


Fig. 6.18 Changes in X-PG in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Pogonion horizontal decreased by 6.23 mm ± 1.93 mm from preoperative to post operative 6 months. This was statistically significant ($p<0.05$).

Pogonion horizontal increased by 1.37 mm ± 0.84 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

Pogonion horizontal decreased by 0.38 mm ± 0.48 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Pogonion horizontal increased by 0.23 mm ± 0.76 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

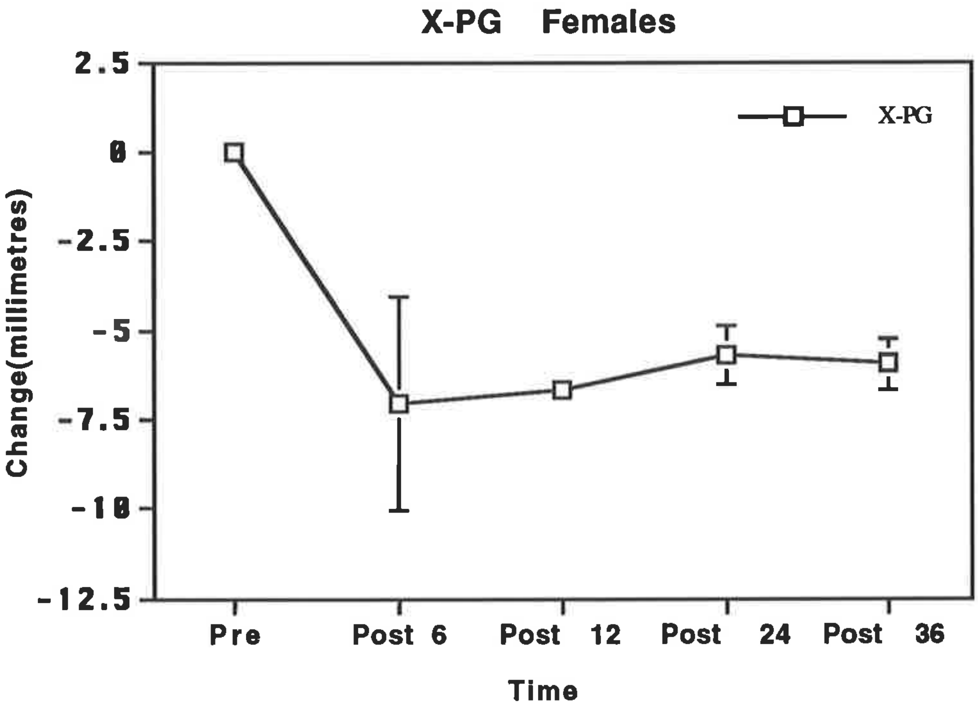


Fig. 6.19 Changes in X-PG in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Pogonion horizontal decreased by 7.04 mm ± 2.99 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Pogonion horizontal increased by 0.37 mm ± 0.34 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

Pogonion horizontal increased by 0.98 mm ± 0.82 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Pogonion decreased by 0.27 mm ± 0.71 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

e. Vertical changes - pogonion (Y-PG)

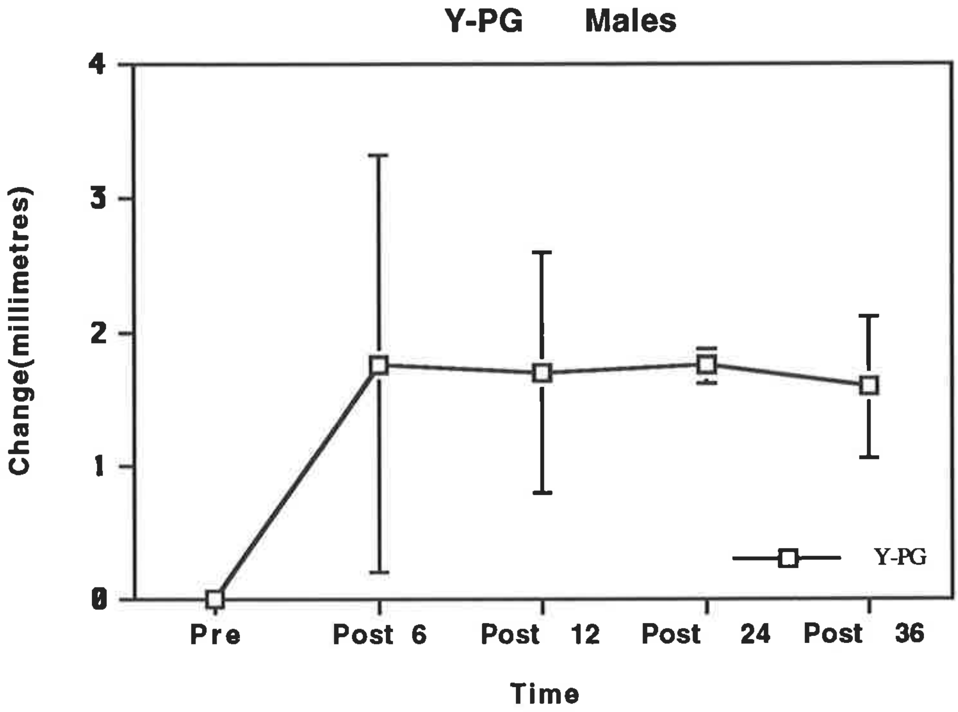


Fig. 6.20 Changes in Y-PG in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-PG increased in males by 1.76 mm ± 1.56 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-PG decreased in males by 0.06 mm ±0.90 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-PG increased in males by 0.05 mm ± 0.13 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-PG decreased in males by 0.16 mm ± 0.53 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

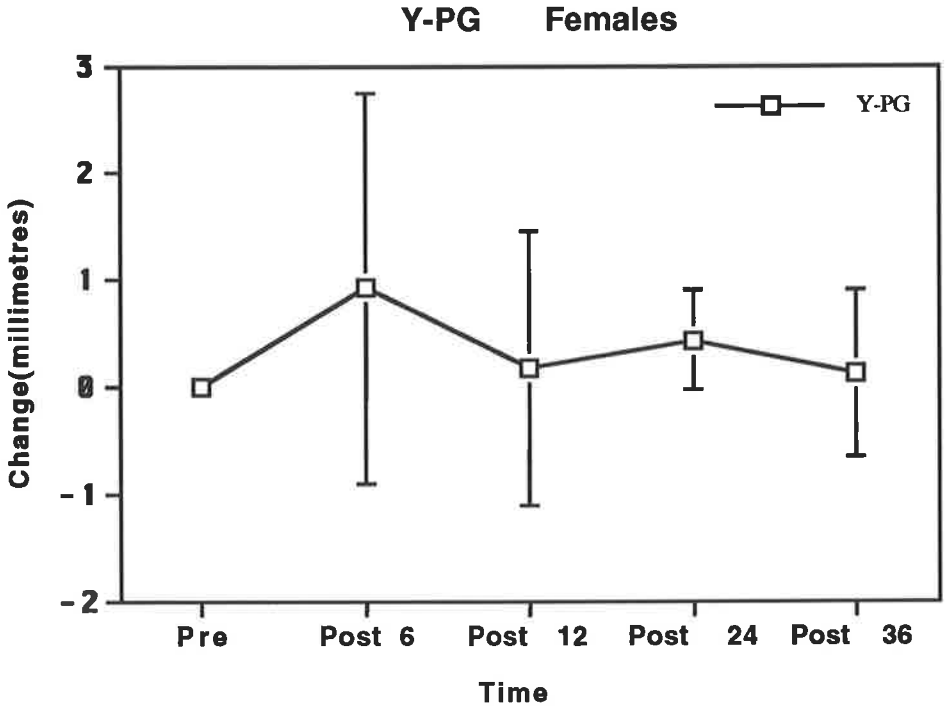


Fig. 6.21 Changes in Y-PG in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-PG increased in females by 0.91 mm ±1.82 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-PG decreased in females by 0.74 mm ± 1.27 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-PG increased in females by 0.25 mm ± 0.46 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-PG decreased in females by 0.30 mm ± 0.78 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

f. Mandibular plane angle (SN7GOME)

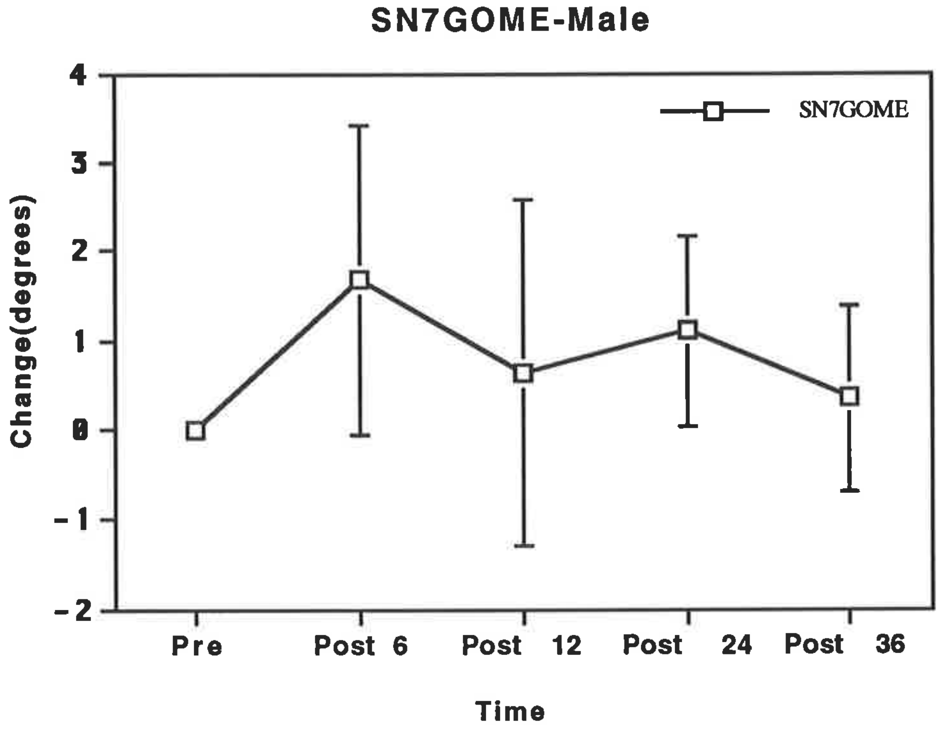


Fig. 6.22 Changes in SN7GOME in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class III value for mandibular plane angle (MPA) 34.5° ± 6.84° (Ellis & McNamara, 1984).

Preoperative MPA Males 35.07° ± 2.49°

MPA increased by 1.69°±1.74° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

MPA decreased by 1.04°±1.93° from post operative 6 months to postoperative 12 months. This was not statistically significant .

MPA increased by 0.46°±1.07° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

MPA decreased by 0.75°±1.04° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

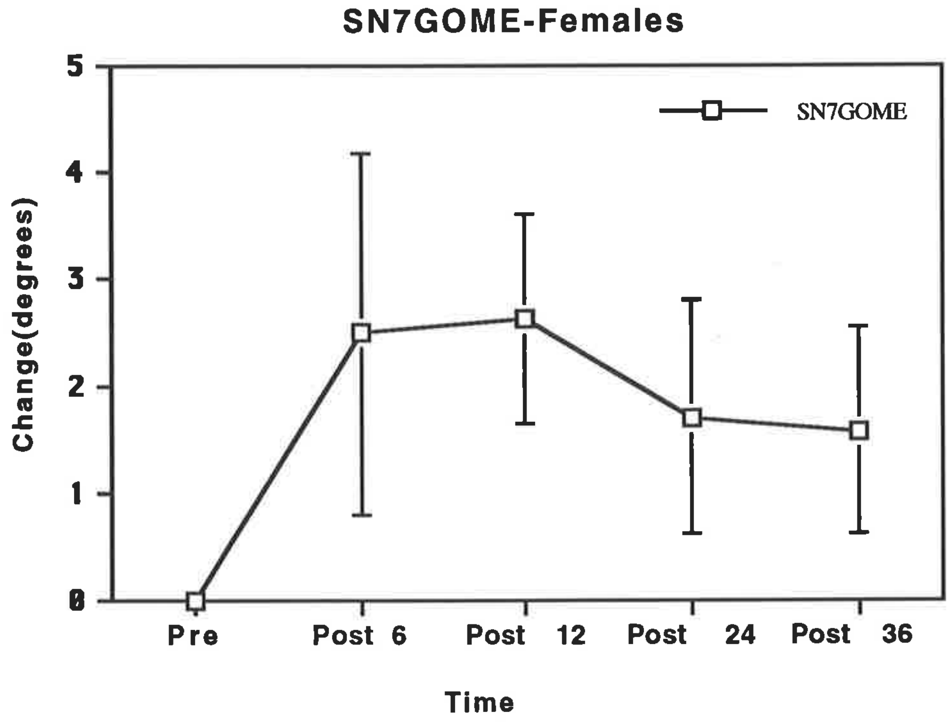


Fig. 6.23 Changes in SN7GOME in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class III value for mandibular plane angle (MPA) 34.5° ± 6.84° (Ellis & McNamara, 1984)

Preoperative MPA Females 35.31° ± 2.73°

MPA increased by 2.50°±1.68° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

MPA increased by 0.13°±0.98° from postoperative 6 months to postoperative 12 months. This change was not statistically significant.

MPA decreased by 0.91°±1.08° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

MPA decreased by 0.13°±0.96° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.3 Dental changes - maxillary

a. Upper incisor angle (UISN7)

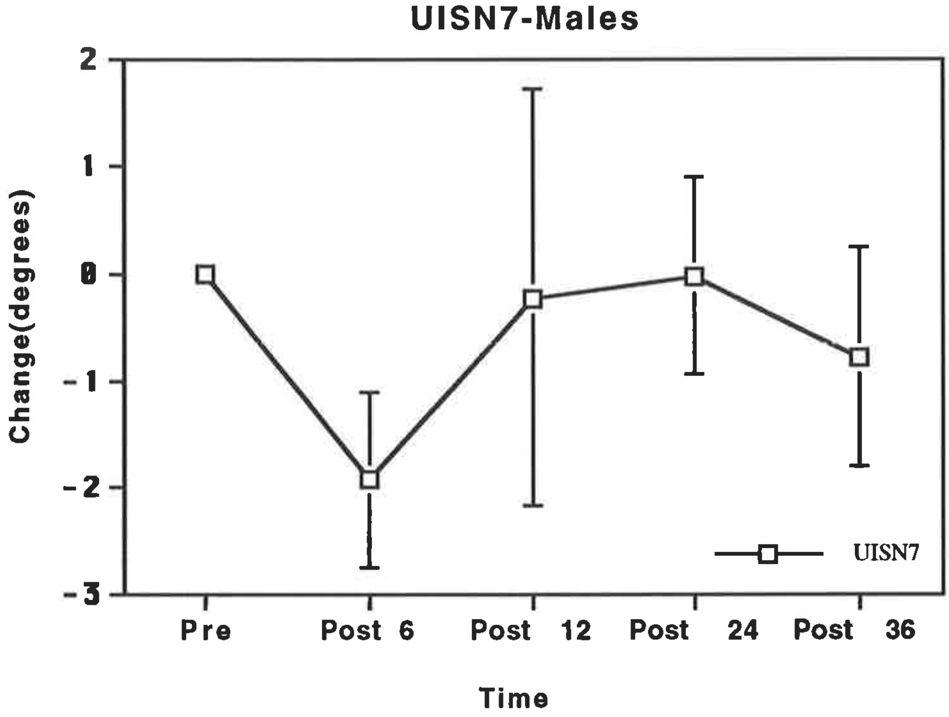


Fig. 6.24 Changes in UISN7 in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class III value for U1SN 108.90° ± 7.70° (McNamara, 1986)

Preoperative U1SN Males 107.28° ± 2.20°

U1SN7 decreased by 1.93°±0.82° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

U1SN7 increased by 1.70°±1.95° from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$). An increase of U1SN7 suggests proclination of upper incisors.

U1SN7 increased by 0.20°±0.91° from postoperative 12 months to postoperative 24 months. This was not statistically significant . This suggest a further proclination of upper incisors but this change was minimal.

U1SN7 decreased by 0.75°±1.03° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

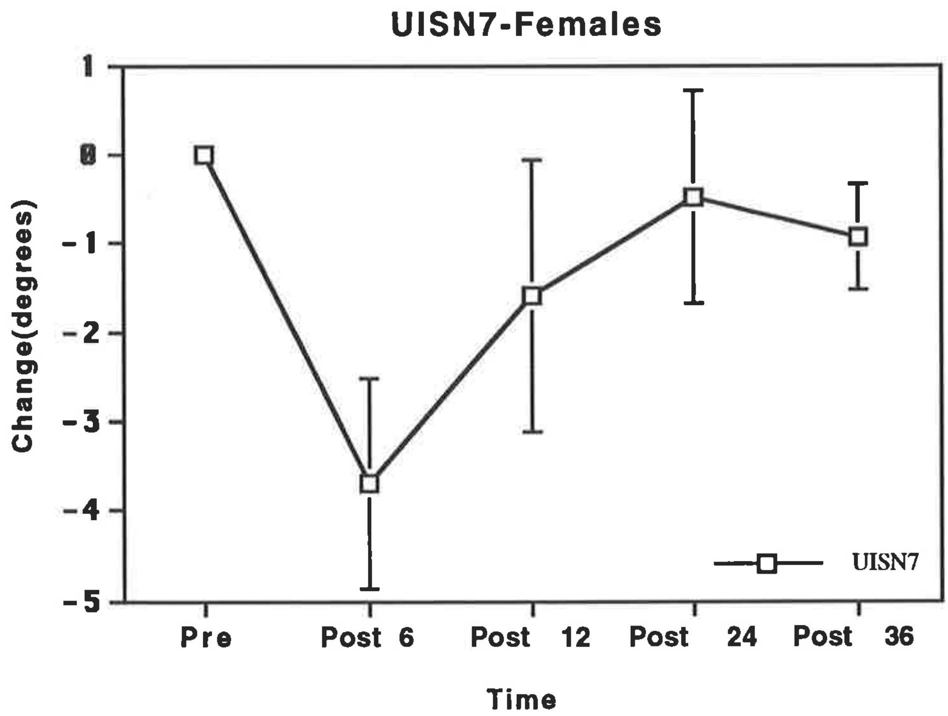


Fig. 6.25 Changes in UISN7 in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class III value for U1SN 108.90° ± 7.70° (McNamara, 1986)

Preoperative U1SN Females 105.75° ± 2.82°

U1SN7 decreased by 3.70°±1.17° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

U1SN7 increased by 2.10°±1.54° from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

U1SN7 increased by 1.10°±1.20° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

U1SN7 decreased by 0.45°±0.60° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.4 Dental changes - mandibular

a. Lower incisor angle (LIMP)

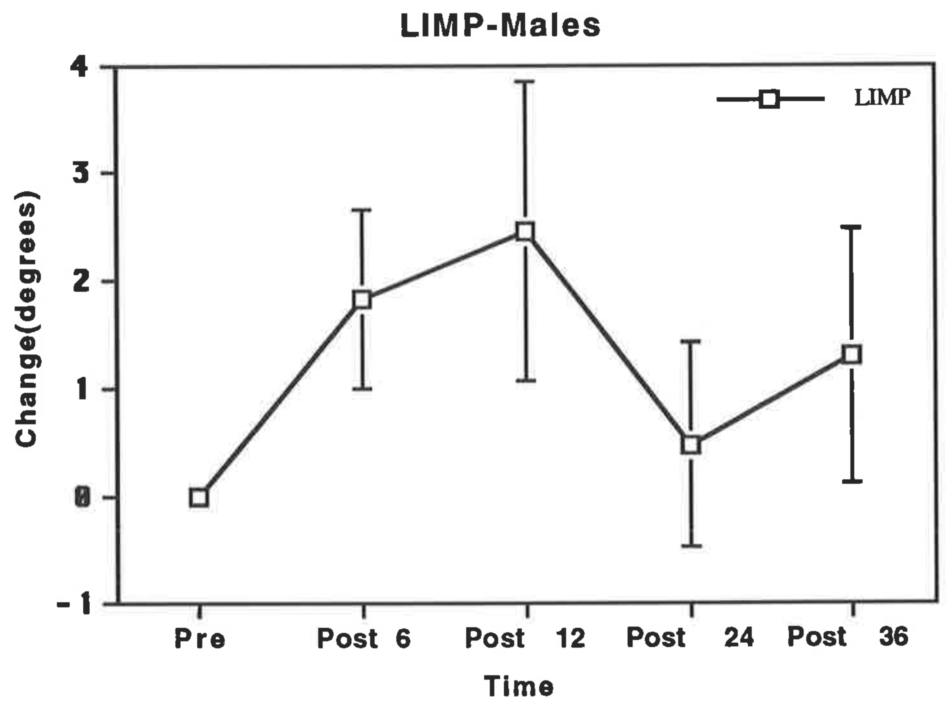


Fig. 6.26 Changes in LIMP in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class III value for lower incisor angle (LIMP) 72° ± 7.49° (Ridell et al., 1971)

Preoperative LIMP Males 78.93° ± 2.34°

LIMP increased by 1.81°±0.82° from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

LIMP increased by 0.64°±1.38° from postoperative 6 months to postoperative 12 months. This was not statistically significant.

LIMP decreased by 1.98°±0.95° from postoperative 12 months to postoperative 24 months. This was statistically significant ($p < 0.05$).

LIMP increased by 0.82°±1.17° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

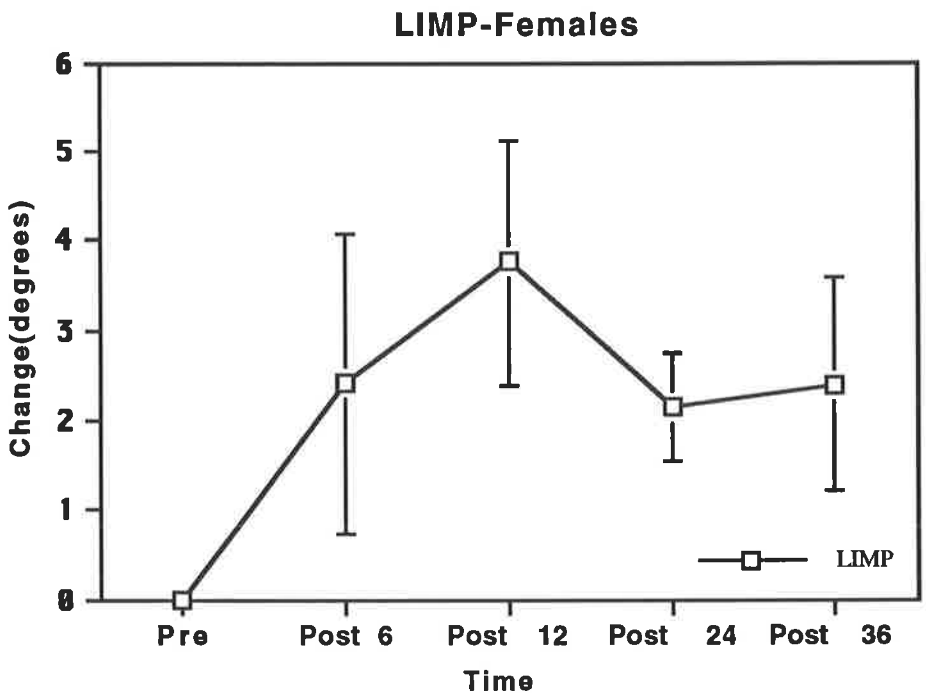


Fig. 6.27 Changes in LIMP in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class III value for lower incisor angle (LIMP) 74.80° ± 9.05° (Ridell et al., 1971).

Preoperative LIMP Females 84.54° ± 2.84°

LIMP increased by 2.41°±1.67° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

LIMP increased by 1.36°±1.13° from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

LIMP decreased by 1.60°±0.60° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LIMP increased by 1.24°±1.20° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.5 Soft tissue changes - lips

a. Horizontal changes - upper lip (X-SUN, X-SLS, X-LS)

X-SUN increased by 1.93 mm ± 0.65 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-SUN decreased by 0.34 mm ± 0.87 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-SUN decreased by 0.32 mm ±0.53 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

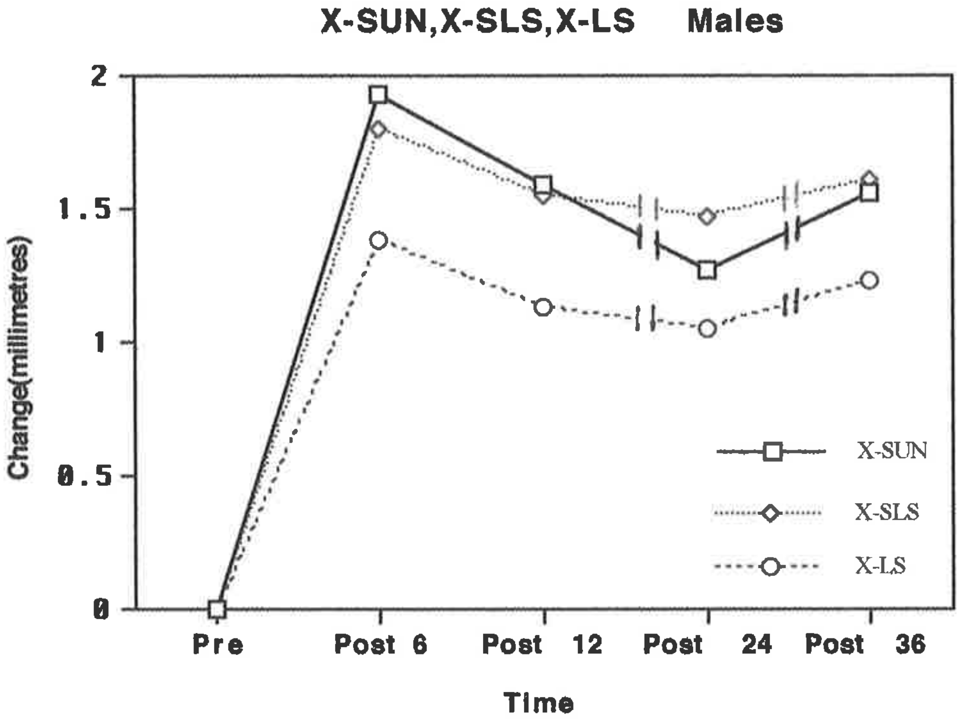


Fig. 6.28 Changes in X-SUN,X-SLS,X-LS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

X-SUN increased by 0.29 mm ± 0.32 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

X-SLS increased for males by 1.80 mm ± 0.69 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-SLS decreased for males by 0.25 mm ± 0.87 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-SLS decreased for males by 0.08 mm ± 0.11 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-SLS increased for males by 0.14 mm ± 0.63 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant .

X-LS increased for males by 1.38 mm ± 0.69 mm from preoperative to post operative 6 months. This was statistically significant ($p<0.05$).

X-LS decreased for males by 0.25 mm ± 0. 84 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-LS decreased for males by 0.08 mm ± 0.11 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-LS increased for males by 0.18 mm ± 0.56 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

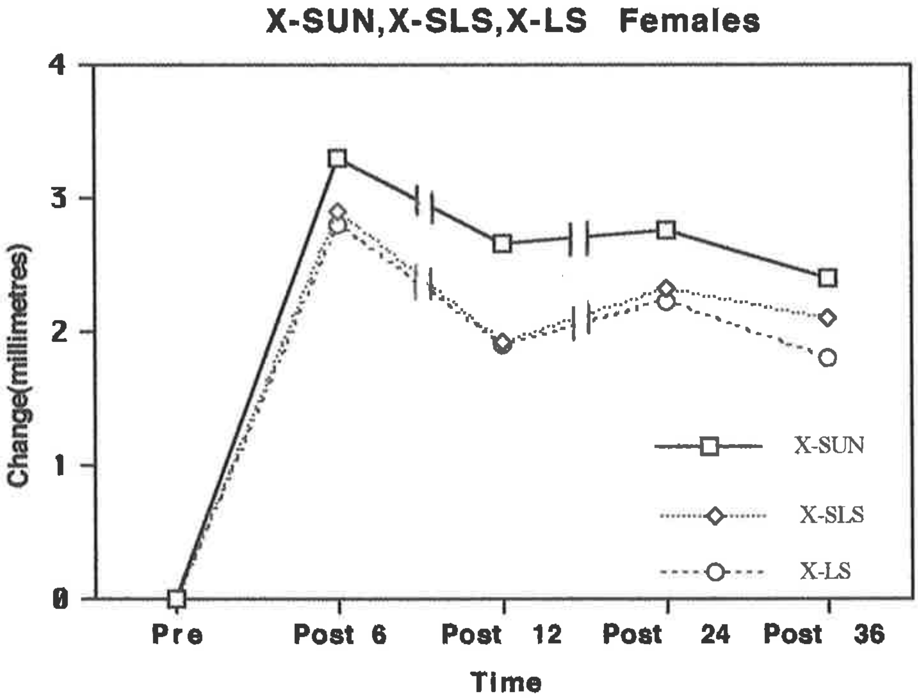


Fig. 6.29 Changes in X-SUN, X-SLS, X-LS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

X-SUN increased by 3.30 mm ± 1.46 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-SUN decreased by 0.65 mm ± 0.94 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-SUN increased by 0.10 mm ± 0.52 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-SUN decreased by 0.35 mm ± 0.76 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

X-SLS increased for females by 2.90 mm ± 0.88 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-SLS decreased for females by 0.99 mm ± 0.94 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

X-SLS increased for females by 0.40 mm ± 0.60 mm from postoperative 12 months to postoperative 24 months. This was statistically significant ($p<0.05$).

X-SLS decreased for females by 0.22 mm ± 0.27 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

X-LS increased for females by 2.20 mm ± 1.51 mm from preoperative to post operative 6 months. This was not statistically significant.

X-LS decreased for females by 0.91 mm ± 0.79 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

X-LS increased for females by 0.33 mm ± 0.98 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-LS decreased for females by 0.43 mm ± 0.39 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

b. Vertical changes - upper lip (Y-SUN, Y-SLS, Y-LS)

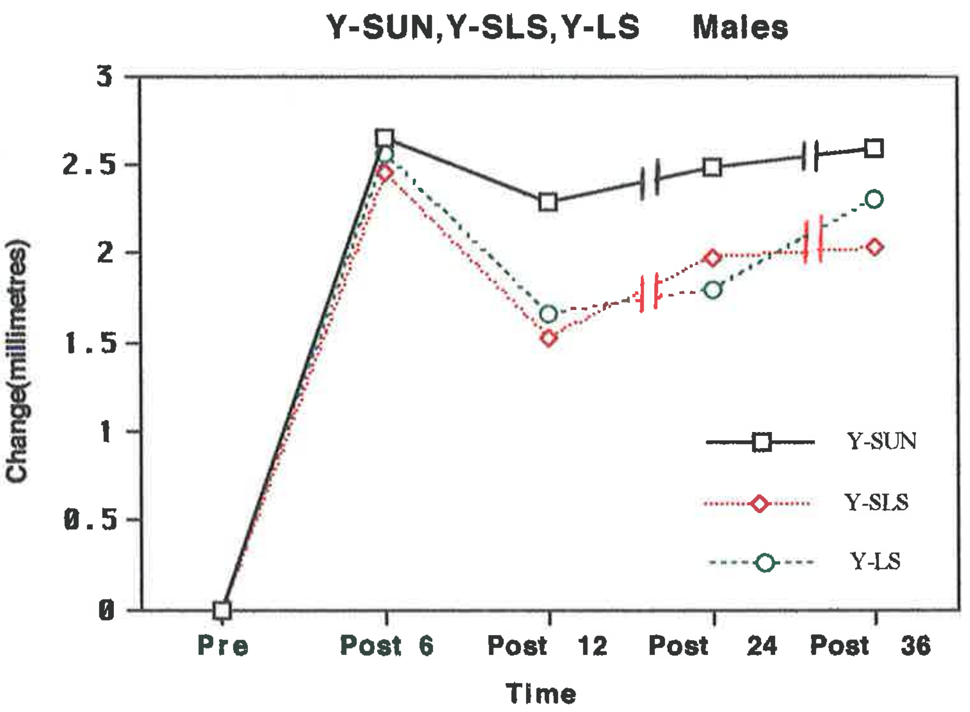


Fig. 6.30 Changes in Y-SUN, Y-SLS, Y-LS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-SUN increased in males by 2.65 mm ± 1.37 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

Y-SUN decreased in males by 0.56 mm ± 0.94 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-SUN increased in males by 0.20 mm ± 0.64 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-SUN increased in males by 0.10 mm ± 0.50 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-SLS increased in males by 2.45 mm ± 1.62 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-SLS decreased in males by 0.92 mm ± 1.04 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

Y-SLS increased in males by 0.45 mm ± 0.65 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-SLS increased in males by 0.05 mm ± 0.16 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-LS increased in males by 2.56 mm ± 1.72 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-LS decreased in males by 0.17 mm ± 0.90 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-LS increased in males by 0.06 mm ± 0.14 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-LS increased in males by 0.15 mm ± 0.51 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

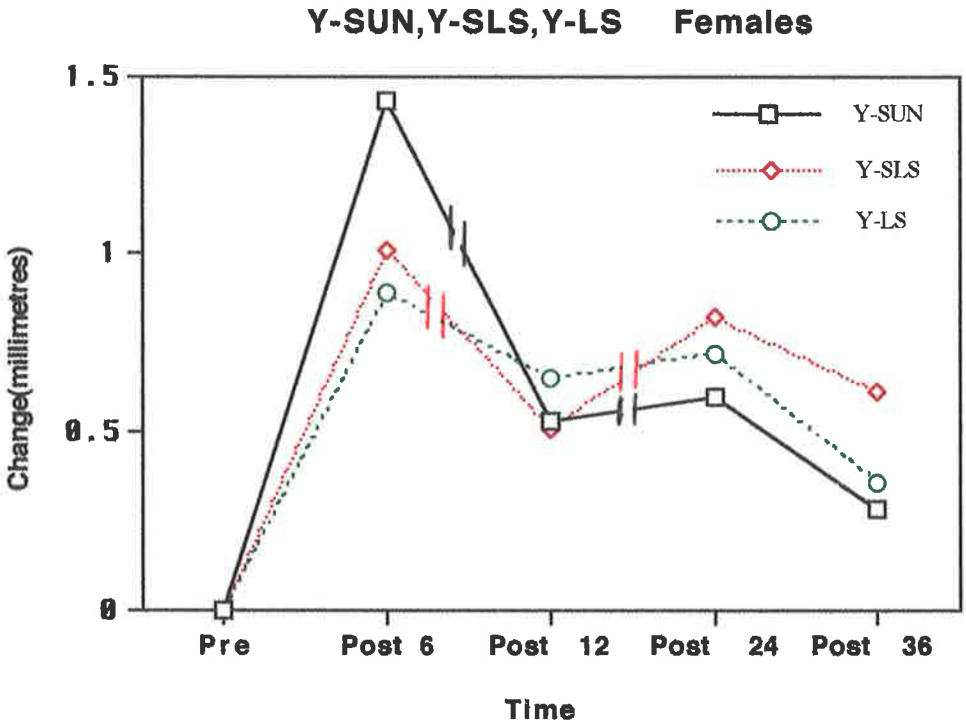


Fig. 6.31 Changes in Y-SUN, Y-SLS, Y-LS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-SUN increased in females by 1.43 mm ± 1.24 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

Y-SUN decreased in females by 0.90 mm ± 0.95 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

Y-SUN increased in females by 0.07 mm ± 0.25 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-SUN decreased in females by 0.32 mm ± 0.69 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-SLS increased in females by 1.01 mm ± 1.61 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

Y-SLS decreased in females by 0.50 mm ± 0.97 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-SLS increased in females by 0.31 mm ± 0.65 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-SLS decreased in females by 0.21 mm ± 0.94 from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-LS increased in females by 0.89 mm ± 1.52 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-LS decreased in females by 0.24 mm ± 0.86 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-LS increased in females by 0.07 mm ± 0.35 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-LS decreased in females by 0.38 mm ± 0.53 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

c. Upper lip thickness (ULT)

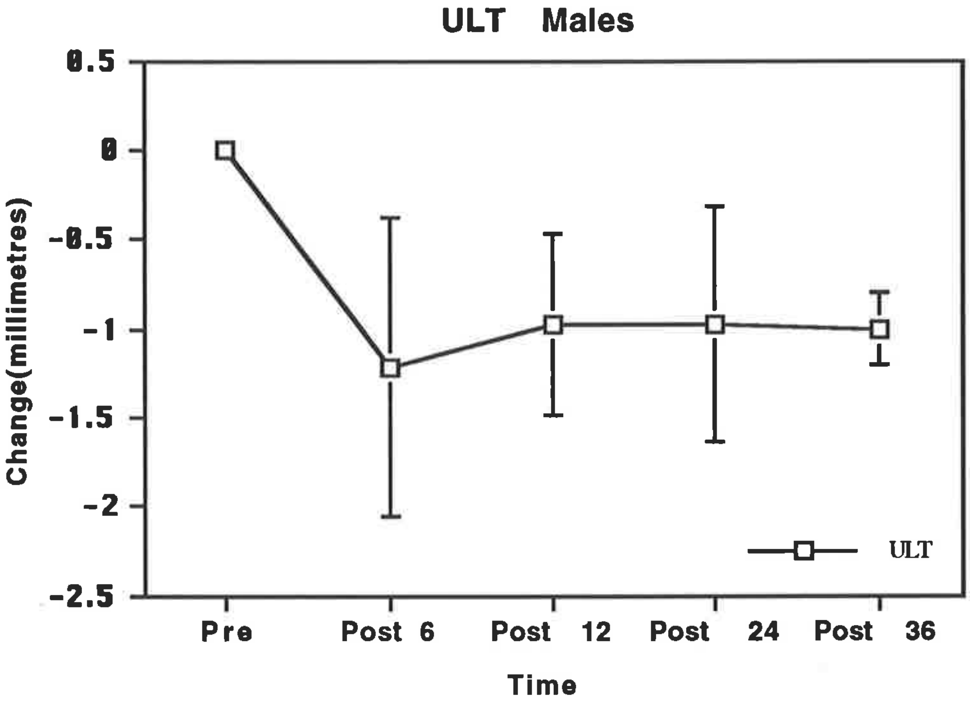


Fig. 6.32 Changes in ULT in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

ULT decreased in males by 1.22 mm ± 0.84 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

ULT increased in males by 0.24 mm ± 0.51 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

ULT showed no change (0.00mm ± 0.66 mm) in males from postoperative 12 months to postoperative 24 months.

ULT increased in males by 0.04 mm ± 0.20 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

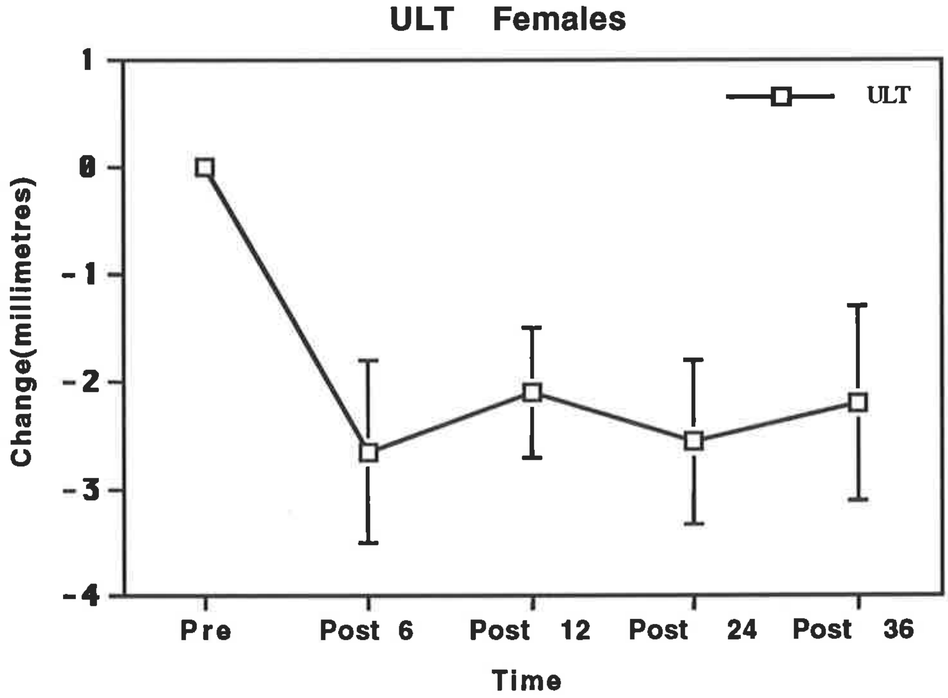


Fig.6.33 Changes in ULT in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

ULT decreased in females by 2.65 mm ± 0.85 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

ULT increased in females by 0.55 mm ± 0.60 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

ULT decreased in females by 0.47 mm ± 0.77 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

ULT increased in females by 0.36 mm ± 0.89 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

d. Upper lip length (ULH)

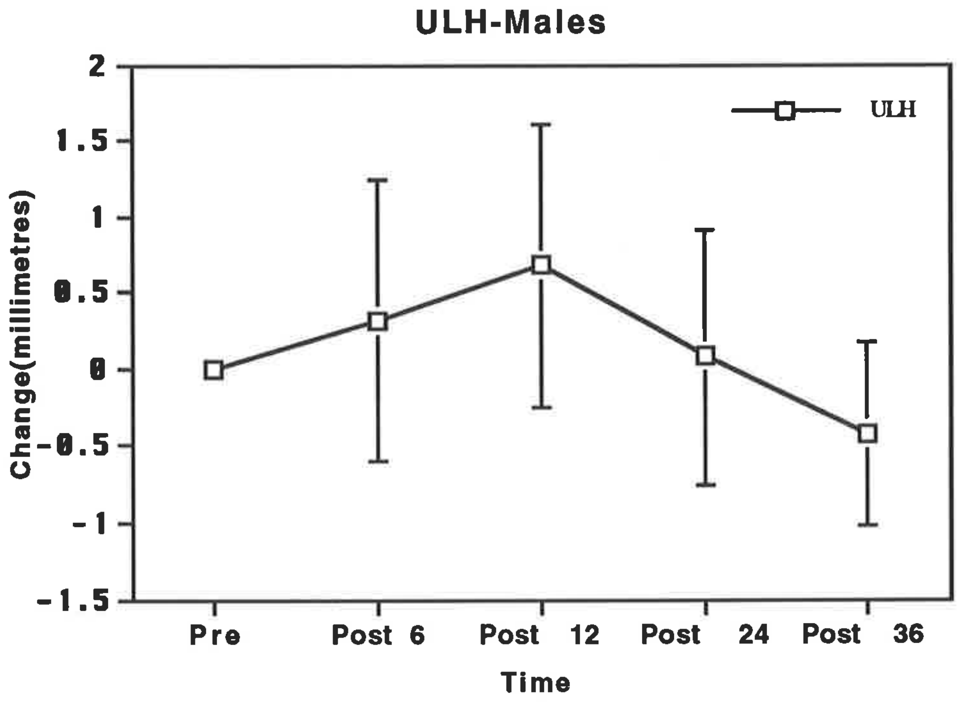


Fig. 6.34 Changes in ULH in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

ULH increased in males by 0.32 mm ± 0.92 mm from preoperative to postoperative 6 months. This was not statistically significant.

ULH increased in males by 0.36 mm ± 0.93 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

ULH decreased in males by 0.60 mm ± 0.83 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

ULH decreased in males by 0.51 mm ± 0.60 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

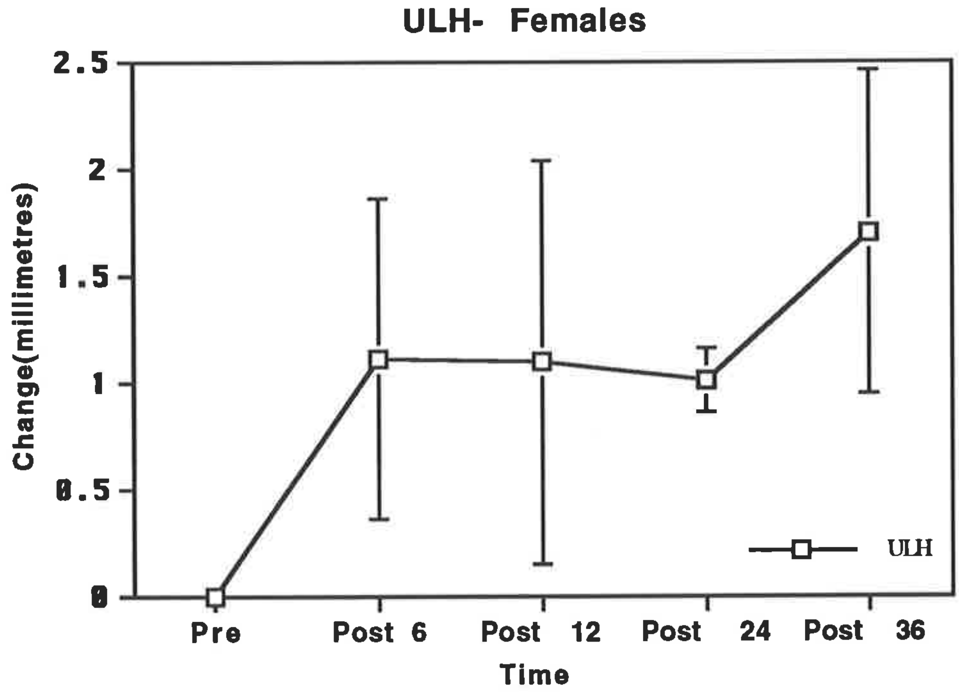


Fig. 6.35 Changes in ULH in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

ULH increased in females by 1.11 mm ± 0.75 mm from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

ULH decreased in females by 0.03 mm ± 0.94 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

ULH decreased in females by 0.08 mm ± 0.15 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

ULH increased in females by 0.69 mm ± 0.76 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

e. Horizontal changes - lower lip (X-LI,X-ILS)

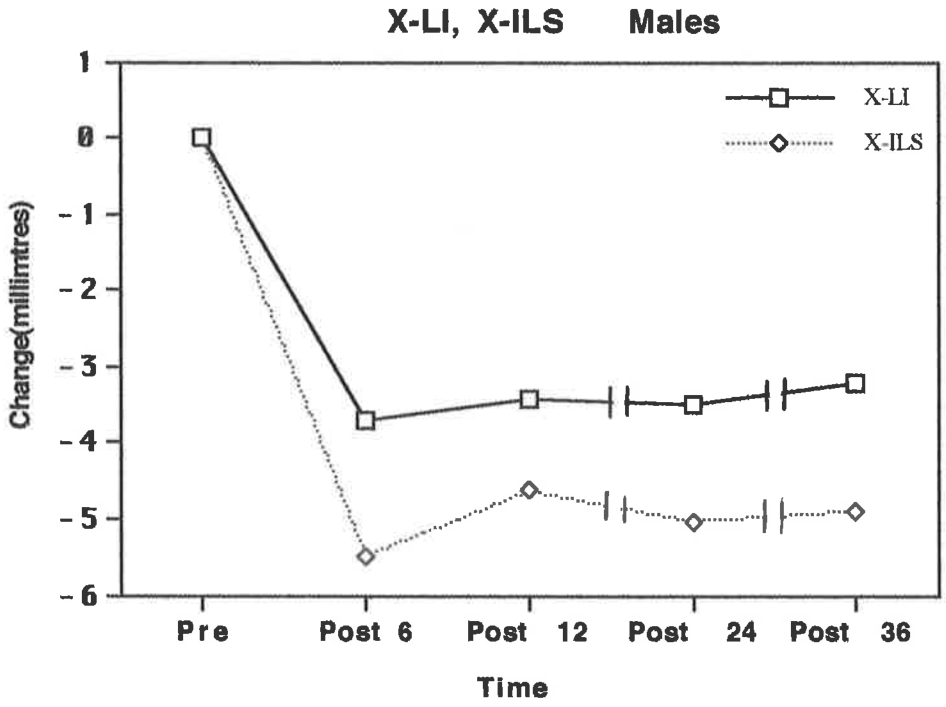


Fig. 6.36 Changes in X-LI,X-ILS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

X-LI decreased by 3.71 mm ± 1.72 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-LI increased by 0.29 mm ± 0.96 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-LI decreased by 0.07 mm ± 0.16 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-LI increased by 0.27 mm ± 0.56 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

X-ILS decreased for males by 5.48 mm ± 1.72 mm from preoperative to post operative 6 months. This was statistically significant ($p < 0.05$).

X-ILS increased for males by 0.85 mm ± 0.51 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

X-ILS decreased for males by 0.40 mm ± 0.74 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-ILS increased for males by 0.14 mm ± 0.65 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

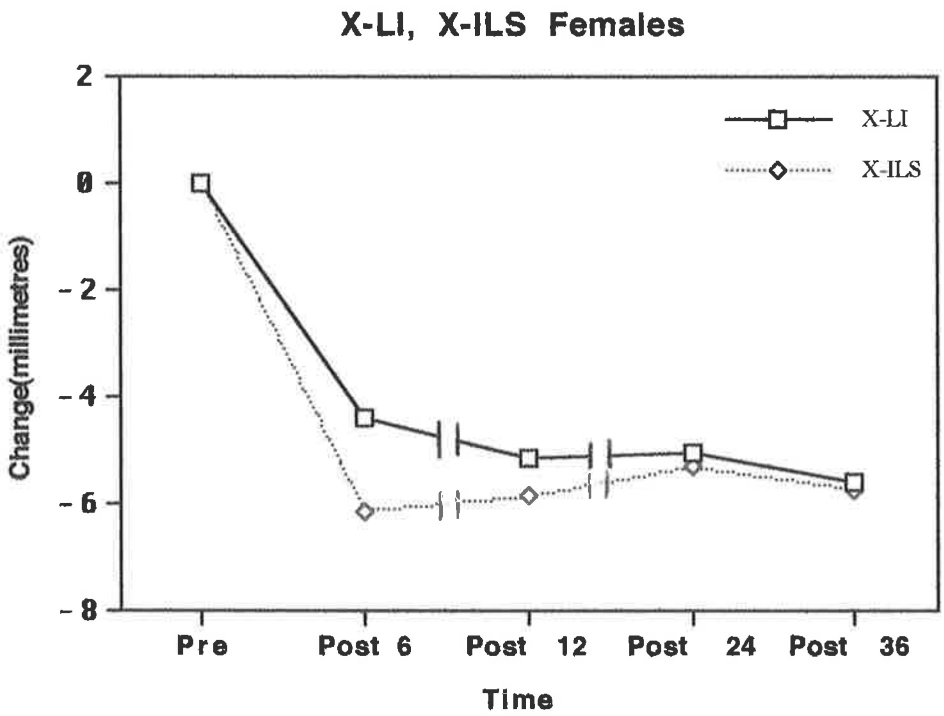


Fig. 6.37 Changes in X-LI, X-ILS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

X-LI decreased by 4.40 mm ± 1.37 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

X-LI decreased by 0.77 mm ± 1.06 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

X-LI increased by 0.12 mm ± 0.24 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-LI decreased by 0.55 mm ± 0.48 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

X-ILS decreased for females by 6.16 mm ± 1.28 mm from preoperative to post operative 6 months. This was statistically significant ($p<0.05$).

X-ILS increased for females by 0.27 mm ± 0.39 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-ILS increased for females by 0.55 mm ± 0.65 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-ILS decreased for females by 0.42 mm ± 0.48 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

f. Vertical changes - lower lip (Y-LI, Y-ILS)

Y-LI increased in males by 0.98 mm ± 1.09 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-LI decreased in males by 0.18 mm ± 0.93 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

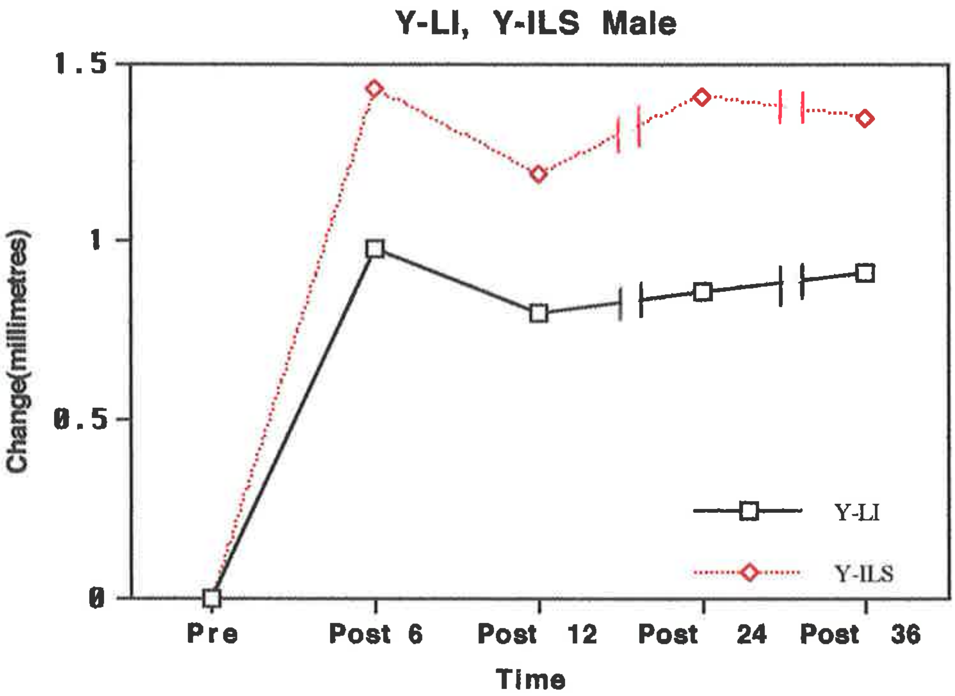


Fig. 6.38 Changes in Y-LI, Y-ILS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-LI increased in males by 0.06 mm ± 0.19 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-LI increased in males by 0.05 mm ± 0.26 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-ILS increased in males by 1.43 mm ± 1.08 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-ILS decreased in males by 0.24 mm ± 0.93 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-ILS increased in males by 0.22 mm ± 0.56 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-ILS decreased in males by 0.06 mm ± 0.23 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

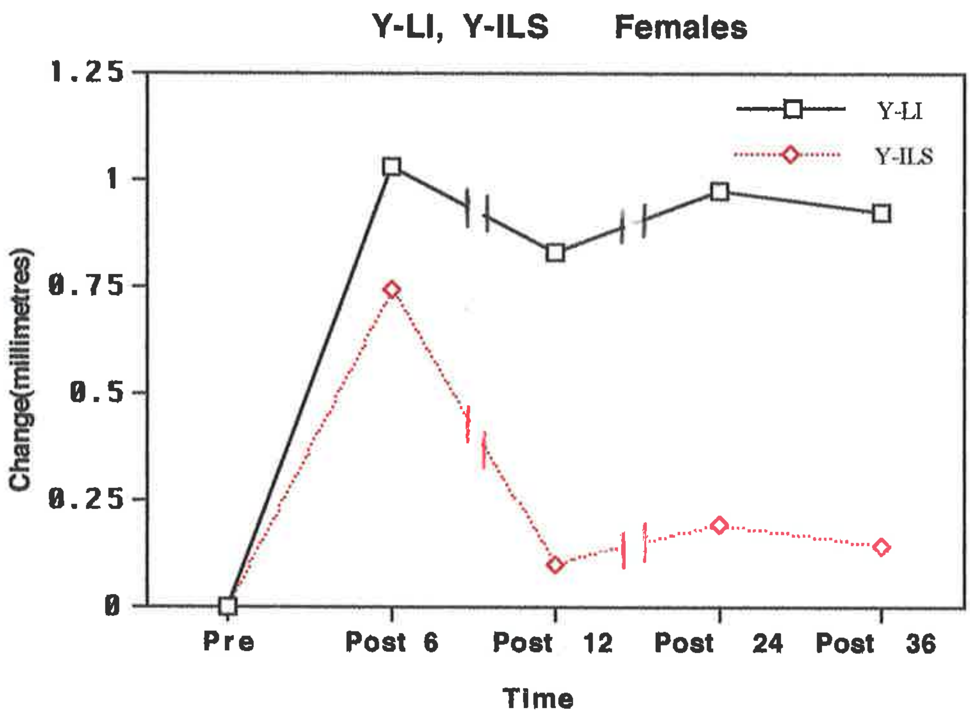


Fig. 6.39 Changes in Y-LI, Y-ILS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-LI increased in females by 1.03 mm ± 1.90 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-LI decreased in females by 0.20 mm ± 0.90 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-LI increased in females by 0.14 mm ± 0.48 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-LI decreased in females by 0.05 mm ± 0.14 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

Y-ILS increased in females by 0.74 mm ± 1.12 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-ILS decreased in females by 0.64 mm ± 1.06 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-ILS increased in females by 0.09 mm ± 0.16 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-ILS decreased in females by 0.05 mm ± 0.27 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

g. Lower lip thickness (LLT)

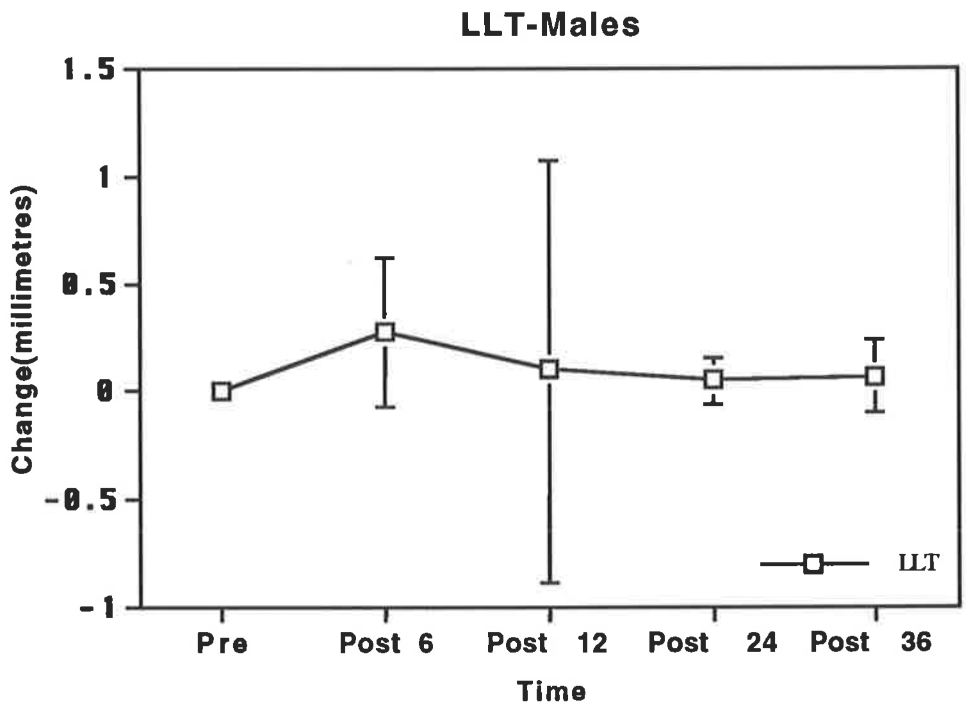


Fig. 6.40 Changes in LLT in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

LLT increased in males by 0.27 mm ± 0.35 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

LLT decreased in males by 0.18 mm ± 0.98 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

LLT decreased in males by 0.05 mm ± 0.11 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LLT decreased in males by 0.02 mm ± 0.17 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

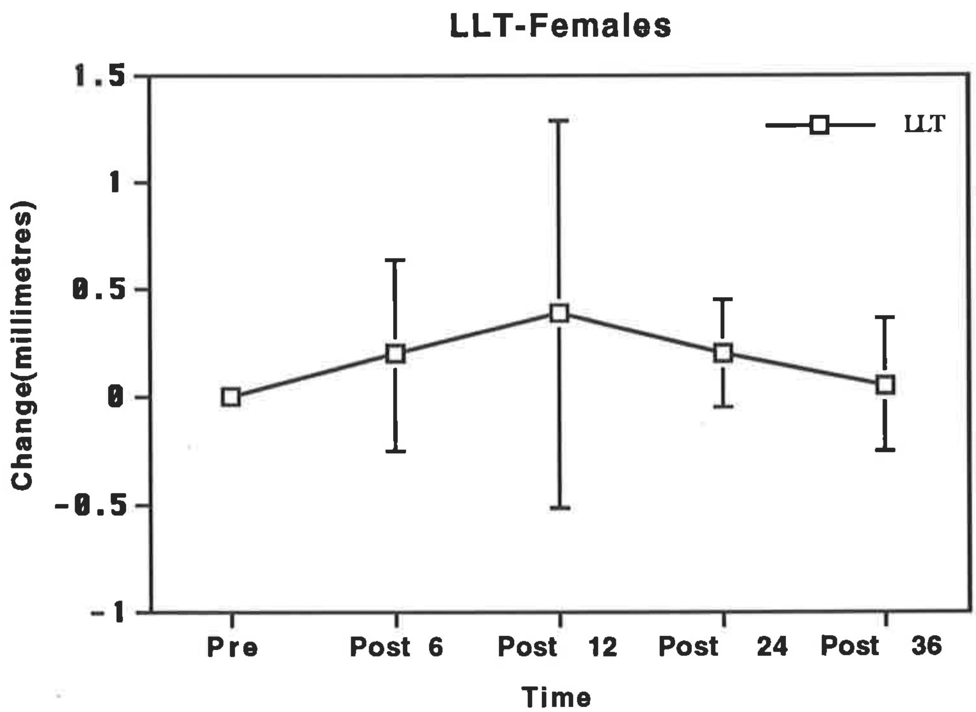


Fig. 6.41 Changes in LLT in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

LLT increased in females by 0.19 mm ± 0.44 mm from preoperative to postoperative 6 months. This was not statistically significant.

LLT decreased in females by 0.19 mm ± 1.32 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

LLT decreased in females by 0.19 mm ± 0.25 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LLT decreased in females by 0.14 mm ± 0.31 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

h. Lower lip length (LLH)

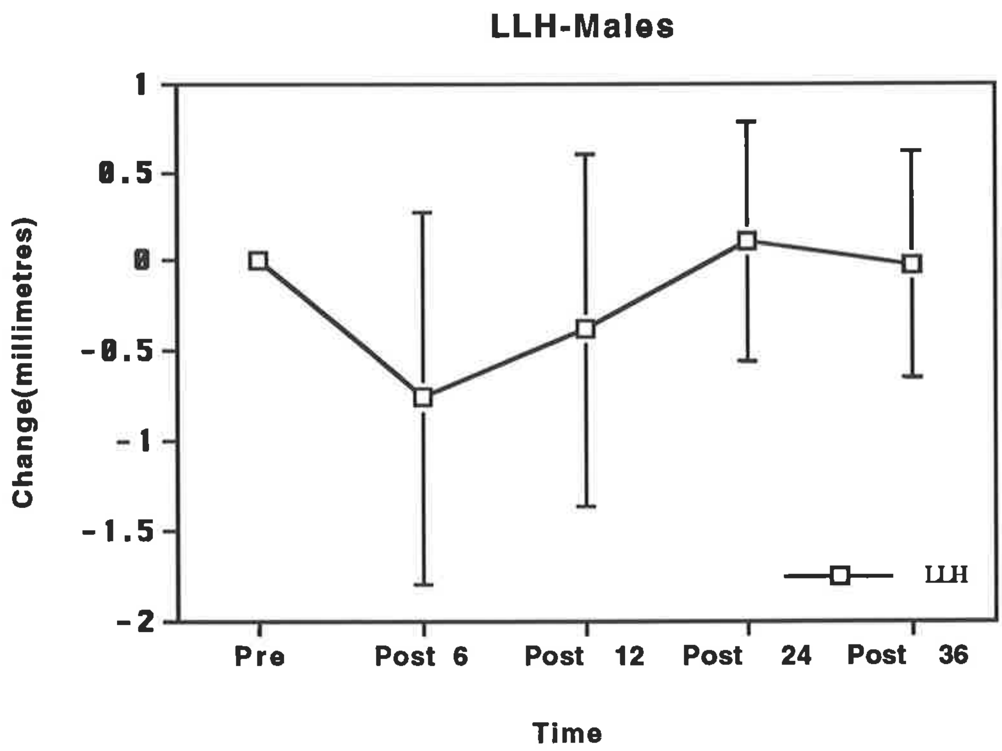


Fig. 6.42 Changes in LLH in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

LLH decreased in males by 0.76 mm ± 1.04 mm from preoperative to postoperative 6 months. This was statistically significant (p‹0.05).

LLH increased in males by 0.38 mm ± 0.98 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

LLH increased in males by 0.49 mm ± 0.67 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LLH decreased in males by 0.13 mm ± 0.64 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

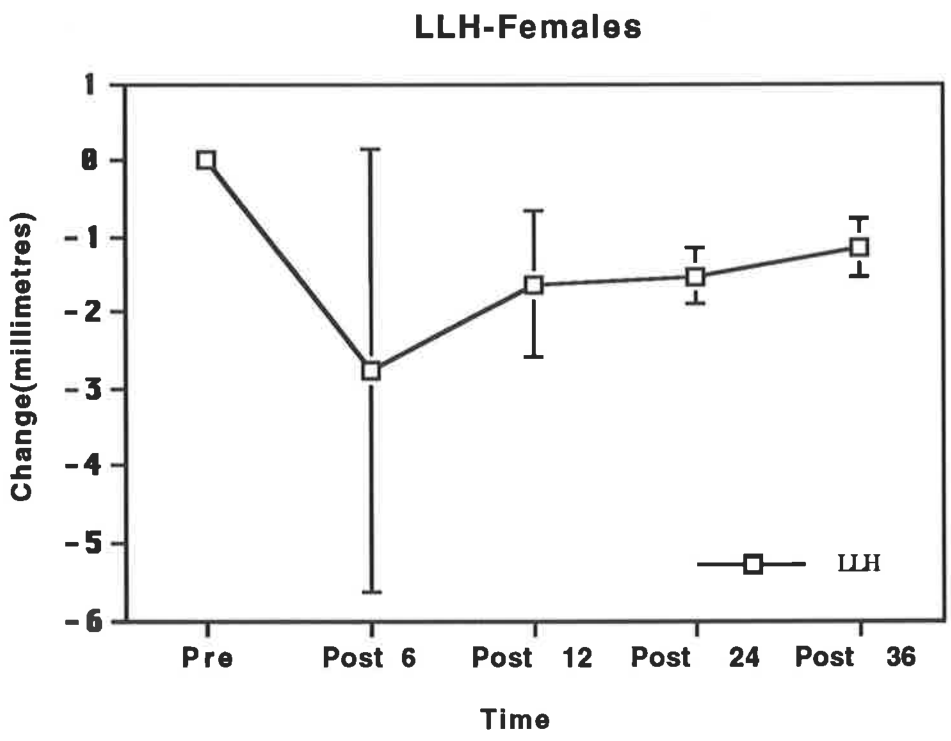


Fig. 6.43 Changes in LLH in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

LLH decreased in females by 2.75 mm ± 2.89 mm from preoperative to postoperative 6 months. This was statistically significant (p‹0.05).

LLH increased in females by 0.88 mm ± 0.96 mm from postoperative 6 months to postoperative 12 months. This was statistically significant ($p < 0.05$).

LLH increased in females by 0.11 mm ± 0.37 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LLH increased in females by 0.37 mm ± 0.53 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.6 Soft tissue changes - chin

a. Horizontal changes - chin (X-PGS)

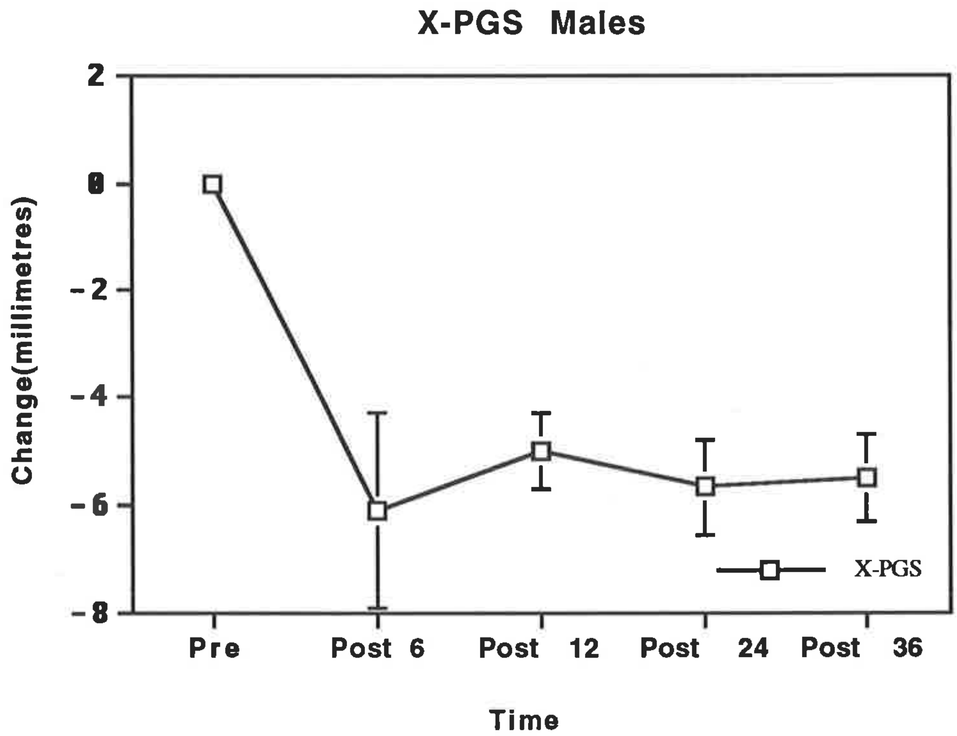


Fig. 6.44 Changes in X-PGS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

X-PGS decreased for males by 6.12 mm ± 1.79 mm from preoperative to post operative 6 months. This was statistically significant ($p < 0.05$). A decrease indicates a posterior movement at soft tissue pogonion.

X-PGS increased for males by 1.10 mm ± 0.68 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant . An increase indicates a forward movement at soft tissue pogonion.

X-PGS decreased for males by 0.66 mm ± 0.88 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-PGS increased for males by 0.21 mm ± 0.78 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

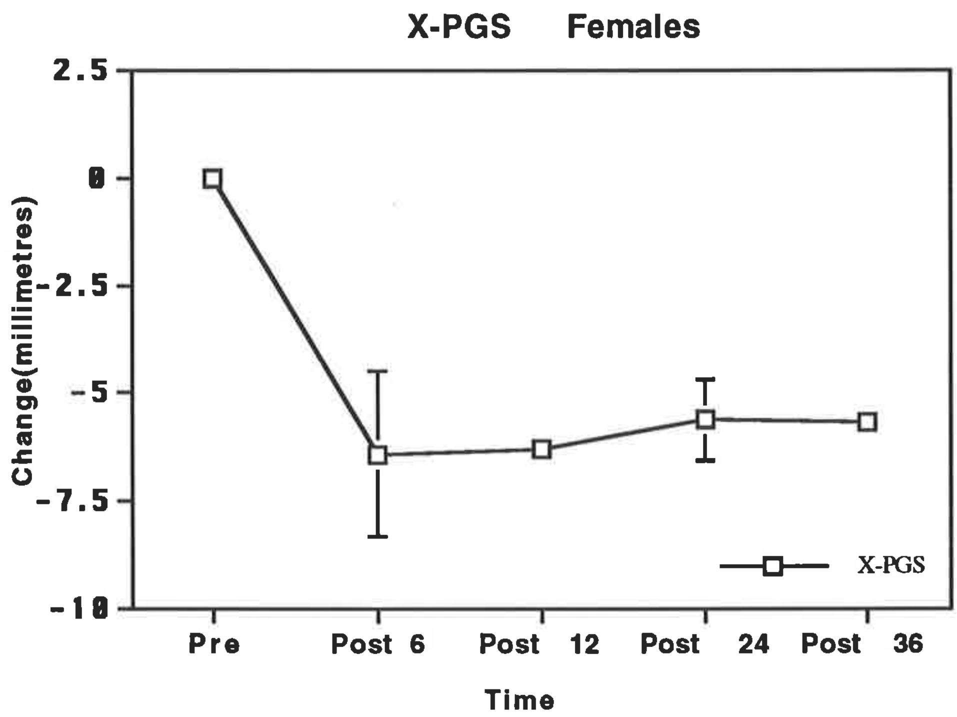


Fig. 6.45 Changes in X-PGS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

X-PGS decreased for females by 6.46 mm ± 1.91 mm from preoperative to post operative 6 months. This was statistically significant ($p < 0.05$).

X-PGS increased for females by 0.09 mm ± 0.26 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

X-PGS increased for females by 0.71 mm ± 0.94 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

X-PGS decreased for females by 0.16 mm ± 0.21 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

b. Vertical changes - soft tissue chin (Y-PGS)

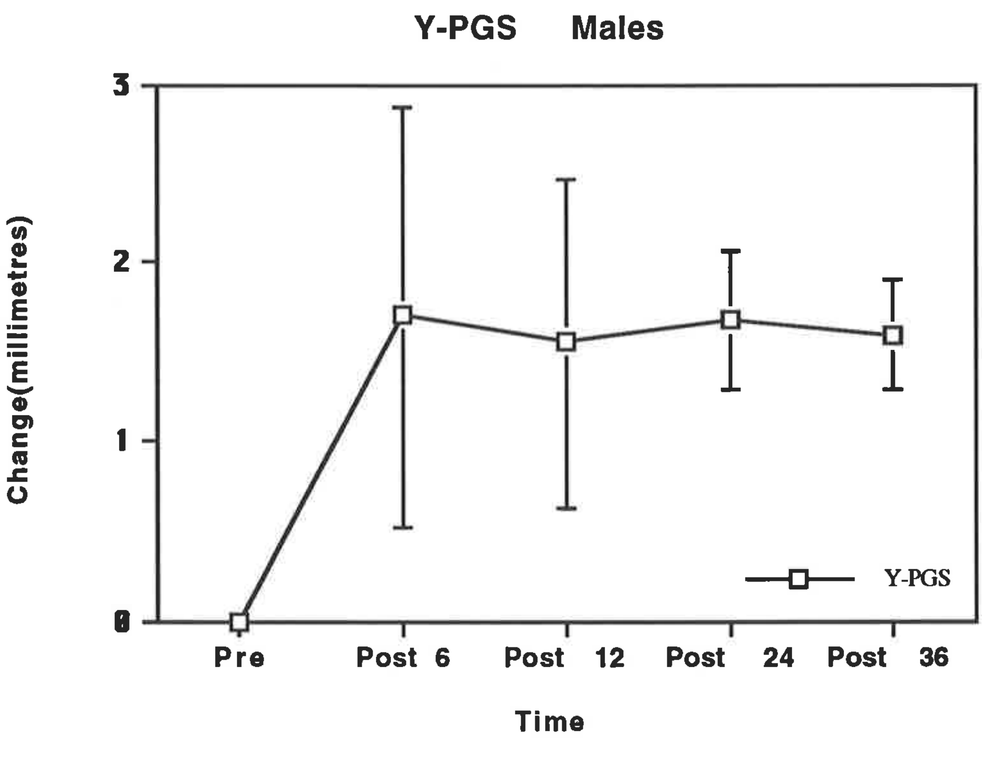


Fig.6.46 Changes in Y-PGS in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Y-PGS increased in males by 1.70 mm ± 1.18 mm from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

Y-PGS decreased in males by 0.15 mm ± 0.92 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-PGS increased in males by 0.13 mm ± 0.39 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-PGS decreased in males by 0.09 mm ± 0.31 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

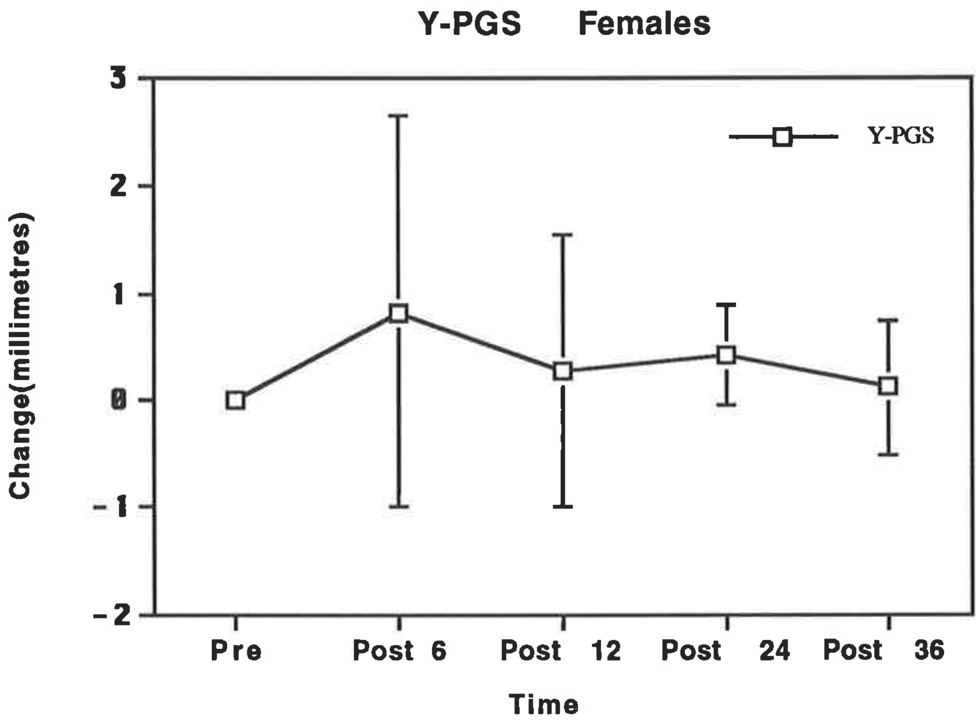


Fig. 6.47 Changes in Y-PGS in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Y-PGS increased in females by 0.81 mm ± 1.82 mm from preoperative to postoperative 6 months. This was not statistically significant.

Y-PGS decreased in females by 0.54 mm ± 1.27 mm from postoperative 6 months to postoperative 12 months. This was not statistically significant.

Y-PGS increased in females by 0.14 mm ± 0.47 mm from postoperative 12 months to postoperative 24 months. This was not statistically significant.

Y-PGS decreased in females by 0.30 mm ± 0.64 mm from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.7 Nasolabial fold

a. Nasolabial angle (NLA)

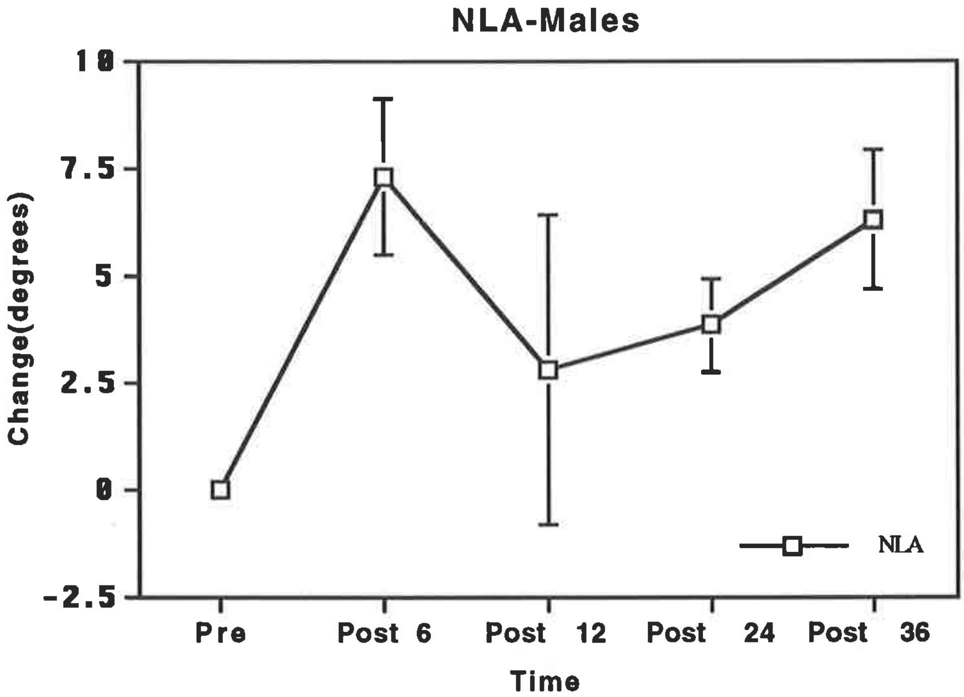


Fig. 6.48 Changes in NLA in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class I value for nasolabial angle (NLA) 102° ± 8° (Legan & Burstone, 1988)

Preoperative NLA Males 97.50° ±3.65°

NLA increased by 7.29°±1.82° from preoperative to postoperative 6 months. This was statistically significant ($p < 0.05$).

NLA decreased by 4.51°±3.63° from postoperative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

NLA increased by 1.05°±1.09° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

NLA increased by 2.45°±1.63° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

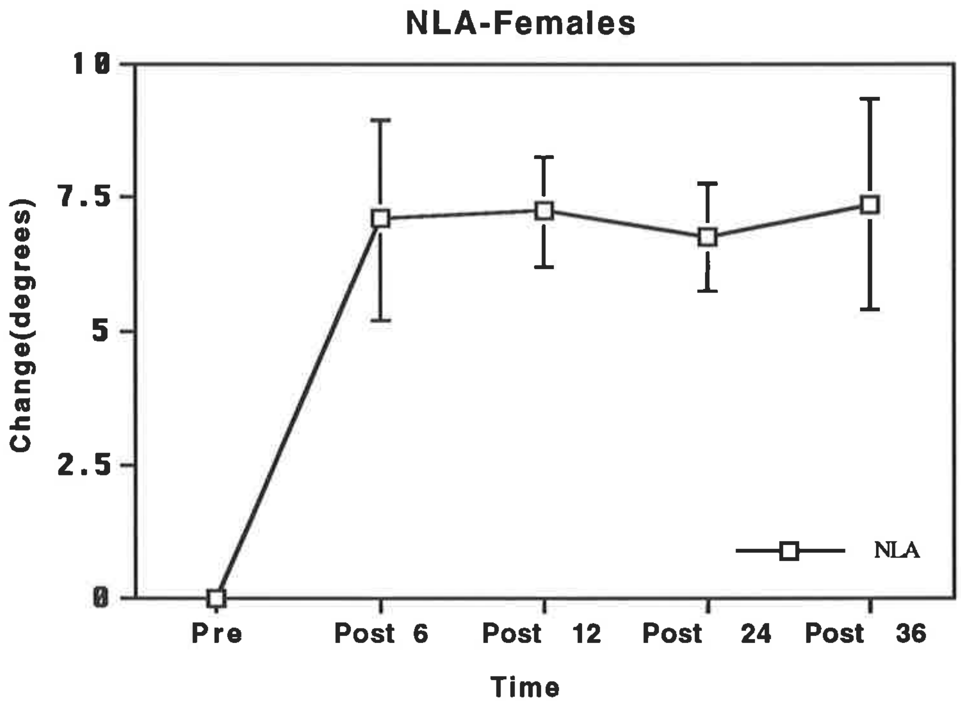


Fig. 6.49 Changes in NLA in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class I value for nasolabial angle (NLA) 102° ± 6° (Legan & Burstone, 1988)

Preoperative NLA Females 106.62° ± 3.41°

NLA increased by 7.06°±1.86° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$).

NLA increased by 0.14°±1.03° from postoperative 6 months to postoperative 12 months. This was not statistically significant.

NLA decreased by 0.48°±0.98° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

NLA increased by 0.62°±1.97° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

6.6.8 Labiomental fold

a. Labiomental angle (LMA)

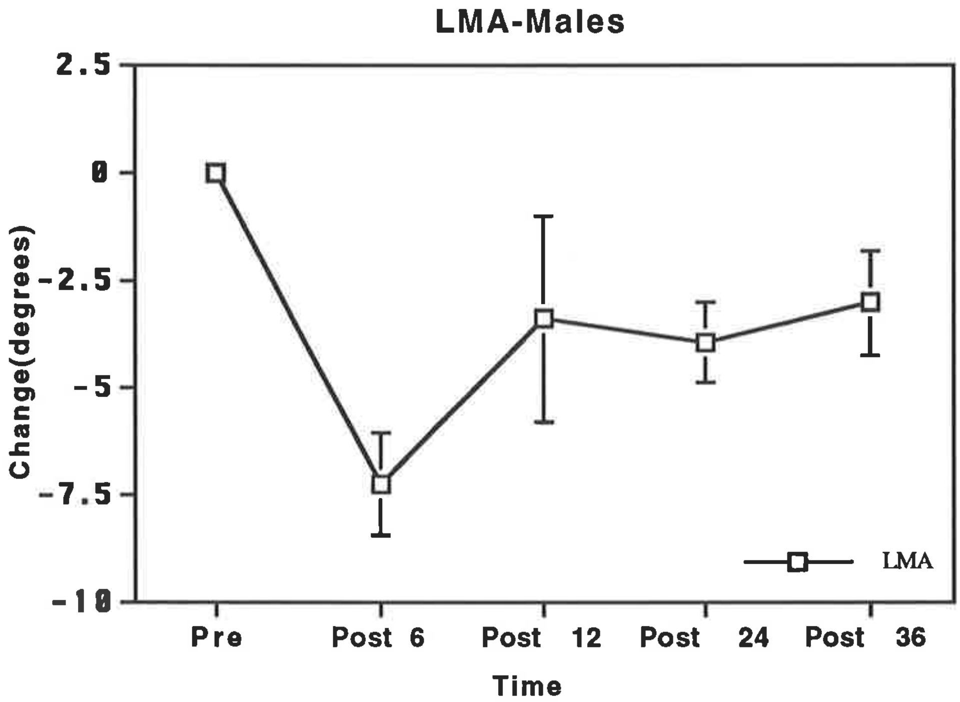


Fig. 6.50 Changes in LMA in males
n (pre) =10 ,n (post 6) =10, n (post 12) =10, n (post 24) =5, n (post 36) =4

Normative Class I value for labiomental angle (LMA) 134°±9.80° (McNamara, 1992).

Preoperative LMA Males 141.62° ± 3.48°

LMA decreased by 7.29°±1.20° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$). Labio-mental fold was made more concave .

LMA increased by 3.88°±2.41° from post operative 6 months to postoperative 12 months. This was statistically significant ($p<0.05$).

LMA decreased by 0.54°±0.94° from postoperative 12 months to postoperative 24 months. This was not statistically significant.

LMA increased by 0.91°±1.21° from postoperative 24 months to postoperative 36 months. This was not statistically significant.

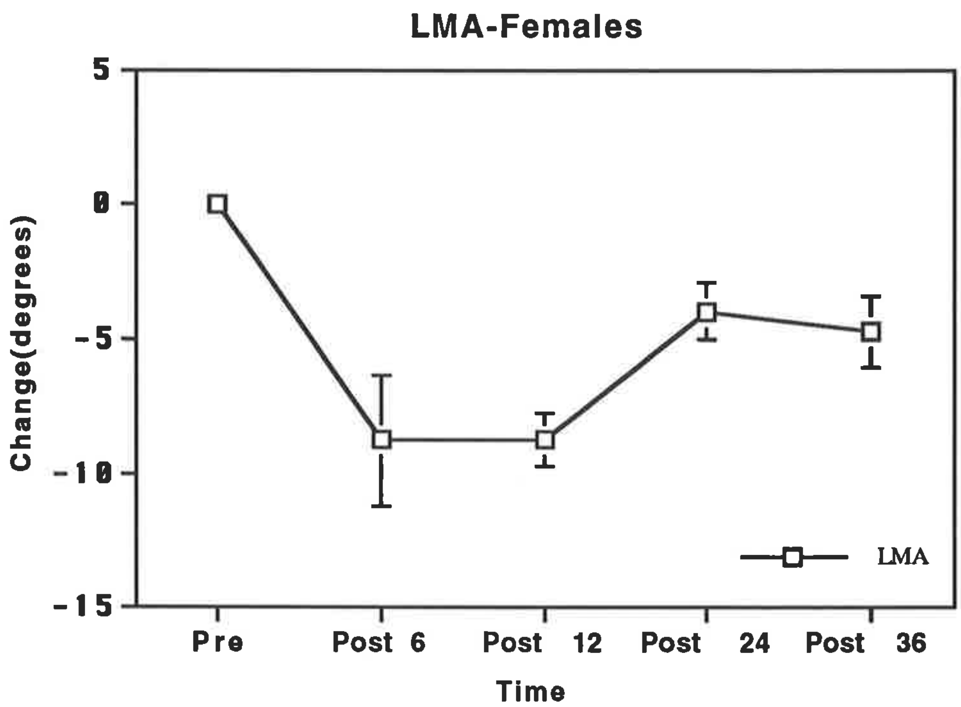


Fig. 6.51 Changes in LMA in females
n (pre) =13 ,n (post 6) =13, n (post 12) =10, n (post 24) =5, n (post 36) =5

Normative Class I value for labiomental angle (LMA) 133.30° ± 10.10° (McNamara, 1992)

Preoperative LMA Females 142.11°

LMA decreased by 8.79°±2.48° from preoperative to postoperative 6 months. This was statistically significant ($p<0.05$). Labio-mental fold was made more concave .

LMA increased by 0.09°±1.01° from postoperative 6 months to postoperative 12 months. This was not statistically significant .

LMA increased by 4.69°±1.06° from postoperative 12 months to postoperative 24 months. This was statistically significant ($p<0.05$).

LMA decreased by 0.74°±1.31° from postoperative 24 months to postoperative 36 months. This was not statistically significant .

6.7 HARD TISSUE TO SOFT TISSUE RATIOS AND CORRELATION COEFFICIENTS

6.7.1 A-point to upper lip

a. Horizontal hard tissue to soft tissue ratios

(i) A-point to subnasale 1:0.81 ($r=0.80$, $p<0.05$).

(ii) A-point to superior labial sulcus 1:0.74 ($r=0.59$, $p<0.01$).

(iii) A-point to labrale superius 1:0.53 ($r=0.68$, $p<0.01$).

b. Vertical hard tissue to soft tissue ratios

(i) A-point to subnasale 1:0.79 ($r=0.43$, $p<0.05$).

(ii) A-point to superior labial sulcus 1:0.64 ($r=0.18$).

(iii) A-point to labrale superius 1:0.66 ($r=0.33$).

6.7.2 B-point to lower lip

a. Horizontal hard tissue to soft tissue ratios

(i) B-point to labrale inferius 1:0.50 ($r=0.69$, $p<0.01$).

(ii) B-point to inferior labial sulcus1:0.69 ($r=0.93$, $p<0.01$).

b. Vertical changes hard tissue to soft tissue ratios

B-point to inferior labial sulcus 1:0.80 ($r=0.56$, $p<0.01$).

6.7.3 Hard tissue pogonion to soft tissue pogonion

Horizontal changes

Pogonion to soft tissue pogonion 1:0.94 ($r=0.94$, $p<0.01$).

6.8 AGE OF PATIENT AT TIME OF SURGERY

The female sample was divided into two groups and comparisons were made between those who were older than the mean chronological age of 20 years and those who were younger than the mean chronological age of 20 years.

The male sample was divided in a similar manner and comparisons were made between those who were older than the mean chronological age of 20 years and those who were younger than the mean chronological age of 20 years.

Soft tissue response was similar in both groups for male and female samples.

CHAPTER SEVEN

DISCUSSION

7.1 SAMPLE

7.1.1 Selection of subjects

Several problems were encountered in selecting the sample. The only way of identifying cases that may have been suitable for study was to refer to the post-graduate students' treatment folders. 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 60 patients who underwent LeFort I advancement and VSSO setback were identified with a total of 23 patients eventually accepted into the study.

The remainder of the patients were excluded for one or more of the following reasons:

(i) incomplete radiographic records necessary for detailed analysis;
(ii) syndromic patients;
(iii) craniofacial anomalies requiring extensive surgery;
(iv) unsatisfactory radiographic quality;
(v) patients who underwent genioplasty.

Ten males and thirteen females were included in the study. Of necessity, the patients were in the post-adolescent group, such that minimal growth potential could be expected. Thus, changes occurring should be mainly due to treatment rather than growth. The only way to minimise the effect of growth would have been to use an untreated control sample of similar ages, facial patterns and sex and compare these values with the present study. The female sample ages ranged from 16 years, 2 months to 35 years, 5 months with a mean age of 20 years. The male sample ages ranged from 16 years, 5 months to 59 years, 5 months with a mean age of 20 years.

The patients comprising the sample were treated by a wide variety of consultants and students. As the surgical and orthodontic procedures were carried out in the hospital post-graduate system, there would still be some consistency, due to similarity of technique, despite variation of operators. The small sample used in the present study is larger than many reported in the literature.

Many studies of the soft tissue response to the different types and vector of maxillary and mandibular surgery have been performed. It is difficult to assess the usefulness and validity of these investigations because of differences in methodology and clinical design.

The present study is unique in that it looks at:

(a) patients who have had Le Fort I maxillary advancements and vertical subsigmoid setback of the mandible

(b) no patients had genioplasty or hard tissue contouring

(c) no concomitant or prior soft tissue surgery

(d) fixed orthodontic appliances were removed within six months post surgery

(e) follow-up time of least one year, and in some cases, over three years.

Previous studies included patients who had VSSO and BSSO setback (Willmot 1981, Moss and Willmot 1984) and patients who had Le Fort I Kufner osteotomy, VSSO and BSSO setbacks (Proffit et al. 1991; McCance 1992a and 1992c). Some of the previous studies of stability with two jaw surgery have focussed on patients with skeletal openbite problems (Moser and Freihofer 1980, LaBanc et al. 1982, Hennes et al. 1988, Satrom et al. 1991, Turvey et al. 1988). Therefore, it is difficult to compare the results of the present study with previous studies reported.

7.2 MEASUREMENTS

In the present study, superimposition of radiographs was done using the technique described by Björk (1968) and Björk and Skieller (1983). The basis for choosing this superimpostion method was the stability of the bony structures of the anterior cranial base in later growth (from at least 10 years of age onwards). This method, which utilised stable structures of the anterior cranial base, had a sound biological rationale and was of acceptable accuracy. It was, therefore, preferred to the constructed methods of superimpositon and measurement used in most previous soft tissue studies. Baumrind et al. (1976) noted that the primary errors associated with superimposition on sella-nasion were found to be slightly greater than those associated with superimposition on structures of the anterior cranial base. Farrer (1984) was the first to use this method of superimposition for soft tissue profile analysis and found it to be reliable. Nasion-sella 7 degree line (Burstone [1978] and Marcotte [1981])was chosen as the horizontal reference plane as this would be expected to be more reproducible and accurate than, for example, Frankfort horizontal.

The landmark definitions listed in chapter five were derived from the standard references of Riolo et al. (1974), De Laat (1974), Legan and Burstone (1980) and Holdaway (1983) in order to provide accurate definitions and clarification of any inconsistencies.

All points were located on the mid-sagittal plane except gonion, articulare, condylion and pterygomaxillare so that the magnification factor was constant. A study of the influence of error of landmark location was allowed for in the methodology (chapter five). The double determinations allowed for the reliability of all parameters to be assessed. An examination of random error and the E(var)% indicated that the the error of the method of tracing, superimposing and digitising was negligible. An examination of the E(var)% indicated that random or systematic errors made a small contribution to the total observed variance. In general, variables requiring careful interpretation were those measured in the vertical dimension. In the present study, landmark location for soft tissues seems comparable to that of hard tissue and is in agreement with that reported by Farrer (1984).

Coordinate values could be determined quickly and accurately and computer entry and storage of the data in coordinate form simplified subsequent processing and analysis. The use of the Hewlett Packard 9874A digitiser and 9815A controller in the present study allowed coordinate values to be obtained instead of conventional measurements, thus reducing one significant source of error. The reason for using the digitiser for measurements from cephalograms was that machine computation of linear and angular measurement has almost totally eliminated errors of mensuration. The digitising error in the present study was calculated by comparing ten repeated measures of a single tracing. The digitising error in the present study was minimal (below 0.4 mm and 0.4

degrees for angular variables) and did not bias the technique to any noticeable extent. Farrer (1984) using the same digitiser reported similar values.

7.3 OUTCOMES

7.3.1 Significant differences between males and females

Presurgically there were significant differences between males and females. These differences appear to be mainly due to the fact that males were of slightly larger frame. The immediate presurgical angular variables (i.e. mandibular plane angle, SNA, SNB) were similar to those reported by Ridell et al. (1971) and, Ellis and McNamara (1984) for a normative Class III population. The immediate presurgical upper incisor inclination was less than the normative Class III values and the immediate presurgical lower incisor inclination was more than the normative Class III values. This is due to orthodontic decompensation prior to surgery. The presurgical nasolabial angle and labiomental angle fell within the normative Class I values reported by Legan and Burstone (1988) and McNamara (1992). Class III normative values for nasolabial angle and labiomental angle have not been reported previously.

It can be concluded that the sample under investigation in the present study does not contain any unusual Class III subjects.

7.4 TREATMENT EFFECTS (PRE-SURGERY TO POST-SURGERY SIX MONTHS)

7.4.1 Skeletal changes - maxilla

On average, the maxilla was advanced and inferiorly repositioned (moved down) at A-point. Proffit et al. (1991b) and Ching (1995) reported similar findings.

7.4.2 Skeletal changes - mandible

On average, the mandible (B-point) moved back and inferiorly. Proffit et al. (1991b) and Willmot (1981) in their studies, reported a greater mandibular setback at B-point. In the present study, the mandible has been set back with a slight downward and backward rotation in both male and female samples. This is in agreement with that reported by Willmot (1981). This downward movement most likely reflects the downward vertical movement of the maxilla. This may also be due to alteration in the position of gonion at surgery since this point was often close to the site of surgery. Moss and Willmot (1984) reported this observation.

7.4.3 Dental changes - maxillary

Upper incisors retroclined at surgery. This change was most likely attributable to tipping of the maxilla during surgical repositioning. Ching (1995) reported retroclination of upper incisors at surgery.

7.4.4 Dental changes - mandibular

Lower incisors proclined at surgery. This change was probably attributable to orthodontic tooth movement. However, this may also be due to alteration in the position of gonion at surgery since this point was often close to the site of surgery and could have influenced the lower incisor to mandibular plane angle.

7.4.5 Soft tissue changes - upper lip

Horizontal soft tissue changes of the upper lip were positively correlated to the hard tissue changes at A-point. Soft tissues generally lagged behind the hard tissues. Hard tissue to soft tissue ratios of the present study are within the range of those reported by the following authors: Lines and Steinhauser (1974); Dann et al. (1976); Mansour et al. (1983); Wolford (1985) and McCance et al. (1992a and 1992c). Vertical hard tissue to soft tissue ratios of the upper lip were positively correlated to the hard tissue changes at A-point. Soft tissues generally lagged behind the hard tissues. These ratios were generally higher than that reported by Dann et al. (1976).

7.4.6 Soft tissue changes - lower lip

Horizontal soft tissue changes of the lower lip were positively correlated to the hard tissue changes at B-point. Soft tissues generally lagged behind the hard tissues. Hard to soft tissue ratios in the present study were slightly lower than those reported by Hershey and Smith (1974) and Willmot (1981). Vertical soft tissue ratios for the lower lip were positively correlated to the hard tissue changes at B-point. Soft tissues generally lagged behind the hard tissues. This finding is in agreement with Robinson et al. (1972).

7.4.7 Soft tissue changes - chin

Soft tissue pogonion followed the hard tissue pogonion very closely, this was positively correlated. These values were similar to those reported by Willmot (1981) and Suckiel and Kohn (1978).

7.4.8 Lip thickness

Generally, the upper lip thinned following maxillary advancement. For every 1 mm of maxillary advancement (at A-point), the upper lip thickness reduced by 0.61 mm ($r=0.71$, $p<0.01$). This is in agreement with Lines and Steinhauser (1974); Dann et al. (1976); Freihofer (1977); Araujo (1978); Bell and Jacobs (1980).

The lower lip thickened following surgery. This change was minimal and was not highly correlated to the hard tissue movement. This is at variance with Fromm and Lundberg (1970) who reported that lower lip thickness did not change at surgery.

7.4.9 Lip length

The upper lip lengthened but the change was minimal. This may be due to the fact that upper lip is away from the functioning lower incisors after surgery. This finding is in agreement with Freihofer (1976).

The lower lip length shortened. This change was minimal and may be due to the fact that the lower lip comes under the influence of the upper lip following surgery and lip competency is established following surgery.

Fromm and Lundberg (1970) reported that lower lip length did not alter after mandibular setback surgery.

7.4.10 Thin lips versus thick lips

Thin and thick upper lips responded to surgery in a similar manner. This finding is at variance with Freihofer (1976) who reported that subjects with thin lips showed a greater soft tissue response than subjects with thick lips.

Thin and thick lower lips responded in a similar manner following surgery. The literature does not report regarding this finding.

7.4.11 Nasolabial fold

The increase of nasolabial angle following maxillary advancement and mandibular setback would suggest a flattening of the upper lip and a change in the columella tangent. Willmot (1981) reported flattening of the upper lip in patients following mandibular setback. Change in columella tangent was reported by Freihofer (1977). Lew et al. (1991) are in agreement with the finding of an increase in nasolabial angle following mandibular setback.

7.4.12 Labiomental fold

Labiomental angle decreased following surgery suggesting a deepening of the labiomental fold which is in agreement with Moshiri et al. (1982) and Willmot (1981).

7.5 MAGNITUDE OF THE SURGICAL MOVEMENT AND SOFT TISSUE RESPONSE

7.5.1 Maxilla and upper lip

Magnitude of the surgical advancement did not affect the soft tissue response of the upper lip. Freihofer (1976) is in agreement with this finding.

7.5.2 Mandible and lower lip

Magnitude of the surgical setback did not affect the soft tissue response of lower lip. Moss and Willmot (1984) found a trend indicating more relapse occurred in those cases where the setback was greatest but no significant correlations were found.

7.6 TREATMENT EFFECTS (SIX MONTHS TO TWELVE MONTHS FOLLOWING SURGERY)

In general, the majority of the hard and soft tissue changes took place within the six to twelve months period following surgery.

7.6.1 Maxilla

In general, the maxilla moved back 28% (at A-point) and 43 % superiorly. Proffit et al. (1991b) and Ching (1995) reported similar findings. The movement of the maxilla superiorly may be associated with superior movement of the mandible.

7.6.2 Mandible

In general, the mandible moved forward 11% (at B-point) and 34% superiorly. Similar findings were reported by Proffit et al. (1991b). This is also supported by the fact that the mandibular plane angle reduced during this period. Ching (1995) reported similar findings.

7.6.3 Dental changes - maxillary

The upper incisors proclined during this period. This may be due to the forward movement of the mandibular arch and posterior superior movement of the maxilla.. Ching (1995) reported upper incisor proclination.

7.6.4 Dental changes - mandibular

The lower incisors proclined slightly during this period. This may be due to alteration in the position of gonion at surgery since this point was often close the the site of surgery and could have influenced the lower incisor to mandibular plane angle. Ching (1995) reported proclination of lower incisors during this period.

7.7 TREATMENT EFFECTS (TWELVE MONTHS TO TWENTY-FOUR MONTHS FOLLOWING SURGERY)

In general, minimal hard tissue and soft tissue changes took place during this period, indicating stability of skeletal and dental tissues. Most of the correction was maintained at 12 months postsurgery This is in agreement with the findings of Proffit et al. (1991b). Upper and lower lip form established within the 12 months following surgery was maintained during this period in the present study.

7.8 TREATMENT EFFECTS (TWENTY-FOUR MONTHS TO THIRTY-SIX MONTHS FOLLOWING SURGERY)

In general, minimal hard tissue and soft tissue changes took place during this period, indicating stability of skeletal and dental tissues. Most of the correction was maintained at 12 months postsurgery. However, the sample size is very small by this stage. Proffit et al. (1991) and Ching (1995) is in agreement with this finding.

CHAPTER EIGHT

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 standardised method of landmark location, an electronic digitiser 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, superimposition and digitisation was low. The error of digitisation alone was not significant.

2. The sample size was small but larger than most published reports of soft tissue studies of a similar nature. Therefore, the results need to be interpreted with some degree of caution. The data was normally distributed allowing the application of routine statistical procedures.

3. Some statistically significant differences were found between the mean value of the male and female groups calculated from the presurgical data. The changes following surgery were generally not statistically significant between males and females.

4. As far as can be determined, the present study is unique in that it is the first known cephalometric evaluation of soft tissue profile for Le Fort I advancement and vertical subsigmoid setback. However, the soft and hard tissue changes appear comparable with other studies using different techniques.

5. Horizontal soft tissue changes of the upper lip were positively correlated to horizontal hard tissue changes of the maxilla:

A:SUN	1:0.81 ($r=0.80$, $p<0.05$)
A:SLS	1:0.74 ($r=0.59$, $p<0.01$)
A:LS	1:0.53 ($r=0.68$, $p<0.01$)

Soft tissues generally lagged behind the hard tissues.

Horizontal soft tissue changes of the upper lip were positively correlated to horizontal hard tissue changes of the maxilla: A:SUN 1:0.79 ($r=0.43$, $p<0.05$); A:SLS 1:0.64 ($r=0.18$); A:LS 1:0.66 ($r=0.33$).

Horizontal and vertical soft tissue changes of the lower lip were positively correlated with horizontal and vertical changes at B-point.

Horizontal	B:LI	1:0.50 ($r=0.69$, $p<0.01$)
	B:ILS	1:0.69 ($r=0.93$, $p<0.01$)
Vertical	B:ILS	1:0.80 ($r=0.56$, $p<0.01$)

Changes of the soft tissue chin were positively correlated with changes at pogonion: 1:0.94 ($r=0.94$, $p<0.01$).

These correlations need to be interpreted cautiously as the sample size is small.

6. The upper lip thinned following maxillary advancement. On average, for every 1 mm of maxillary advancement (at A-point), the upper lip thickness reduces by 0.61 mm ($r=0.71$, $p<0.01$). The upper lip lengthened following surgery but this was not statistically significant.

7. The lower lip length reduced following surgery by a minimal amount but this was not statistically significant. This may be due to the lower lip coming

under the influence of the upper lip following surgery. Lip competency is established following surgery.

8. Nasolabial angle increased in the period presurgery to postsurgery six months. Labiomental fold deepened in the period presurgery to postsurgery six months. Lip form established at surgery appears to be maintained in the longer term.

9. During the period six months to twelve months postsurgery, the maxilla moved 43% superiorly and 28% backwards. The mandible moved 11% forwards and 34% superiorly. Upper and lower incisor proclination occurred during this period. The upper incisor proclination may be due to forward movement of the mandibular arch.

10. Thick and thin upper lips responded similarly to surgery. Thick and thin lower lips also responded similarly to surgery.

11. The magnitude of surgical advancement of the maxilla did not affect the upper lip response. The magnitude of surgical setback did not affect the lower lip response. The soft tissue response is consistent and proportional to the skeletal change.

12. Age and sex do not appear to have a bearing on the soft tissue response of lips following surgery.

13. Minimal skeletal, dental and soft tissue changes were noted 12 months postsurgically indicating stability of the Le Fort I and vertical subsigmoid osteotomy procedure. Most of the correction was maintained at 12 months postsurgery. However, some degree of caution is required when

interpreting the data at 24 months and 36 months postsurgery as sample size becomes extremely small.

14. As a result of this study, the following avenue of further research is proposed:

(1) long term follow-up of patients in this study to assess long term soft and hard tissue changes;

(2) a similar study of a larger sample of patients with long term follow up;

(3) establishment of a control group of untreated Class III patients matched for age, sex and facial pattern and/or evaluation of serial cephalometric radiographs prior to treatment to assess growth related changes.

APPENDIX I

RANDOM AND SYSTEMATIC ERROR

VARIABLE	M.diff	S.E.diff	S.e	Error%
SN7ARGO	-0.47*	0.22	0.81	3.43
SN7GOME	0.03	0.32	0.03	0.11
ARGOGN	0.49	0.33	0.04	0.16
SNA	0.22	0.28	0.02	0.09
SNB	-0.01	0.24	0.86	4.72
UISN7	-0.10	0.24	0.95	2.18
LIMP	-0.53	0.49	0.17	0.26
NLA	-0.68	0.74	0.86	0.50
LMA	1.62	0.91	0.02	0.02
NFRA	0.25	0.59	32.44	35.20**
NMA	-1.13	0.99	0.03	0.03
X-A	-0.65	0.42	0.10	0.45
Y-A	-0.53*	0.24	0.01	0.09
X-B	-0.48	0.54	0.24	0.37
Y-B	-0.22	0.27	0.01	0.05
X-IES	-0.62	0.42	0.10	0.31
Y-IES	-0.13*	0.06	0.01	0.02
X-IEI	-0.23	0.35	0.04	0.11
Y-IEI	-0.13	0.15	0.16	0.72
X-MS	-0.15	0.22	0.61	1.96
Y-MS	-0.17	0.17	0.22	1.21
X-MI	-0.24	0.33	3.49	11.25**
Y-MI	-0.09	0.13	0.08	0.40
X-PNS	-0.08	0.21	0.55	3.89
Y-PNS	-0.10	0.17	0.24	0.95
X-PG	-0.63	0.67	0.58	0.73
Y-PG	-0.35	0.38	0.06	0.13
X-PN	-0.72	0.61	0.42	1.39
Y-PN	-0.62*	0.27	1.97	11.36**
X-SUN	-0.57	0.41	0.08	0.35
Y-SUN	-0.35	0.23	0.84	4.09
X-SLS	-0.32	0.20	0.50	1.67

APPENDIX I (continued)

VARIABLE	M.diff	S.E.diff	S .e	Error%
Y-SLS	0.13	0.27	1.57	7.59**
X-LS	-0.33	0.18	0.33	0.87
Y-LS	-0.27	0.13	0.10	0.39
X-LI	-0.24	0.32	0.03	0.06
Y-LI	0.49*	0.20	0.61	1.66
X-ILS	-0.32	0.38	0.06	0.10
Y-ILS	-0.11	0.16	0.16	0.38
X-PGS	-0.42	0.53	0.22	0.28
Y-PGS	0.20	0.26	1.24	2.11
ULH	-0.36	0.32	0.03	0.24
LLH	0.26	0.21	0.53	1.62
ULT	-0.05	0.10	0.03	0.43
LLT	-0.16	0.17	0.00	0.12

S .e = variance due to measurement error, termed error variance

Error % = error variance expressed as a percentage

* indicates variables with significant systematic errors ($p < 0.05$)

** indicates variables with significant random errors contributing more 5% to the total observed variation

Angular variables measured in degrees

Linear variables measured in millimetres

APPENDIX II

DIGITISING ERROR

VARIABLE	MEAN	S.E	S.D
SN7ARGO	73.01	0.02	0.05
SN7GOME	29.47	0.02	0.08
ARGOGN	134.12	0.04	0.13
SNA	80.65	0.03	0.09
SNB	78.43	0.02	0.06
UISN7	103.68	0.10	0.30
LIMP	94.11	0.07	0.21
NLA	102.03	0.07	0.23
LMA	126.15	0.12	0.38
NFRA	158.38	0.12	0.37
NMA	147.84	0.06	0.19
X-A	-62.77	0.02	0.05
Y-A	-43.03	0.02	0.08
X-B	-57.26	0.02	0.06
Y-B	-89.97	0.03	0.10
X-IES	-64.97	0.03	0.10
Y-IES	-68.82	0.03	0.08
X-IEI	-64.13	0.02	0.07
Y-IEI	-68.80	0.03	0.08
X-MS	-40.85	0.02	0.06
Y-MS	-60.06	0.03	0.08
X-MI	-43.46	0.03	0.09
Y-MI	-67.83	0.02	0.05
X-PNS	-21.65	0.02	0.06
Y-PNS	-39.22	0.02	0.07
X-PG	-57.86	0.03	0.09
Y-PG	-100.40	0.02	0.06
X-PN	-95.26	0.02	0.07
Y-PN	-36.14	0.02	0.07
X-SUN	-79.90	0.02	0.06
Y-SUN	-46.72	0.03	0.08

APPENDIX II (continued)

VARIABLE	MEAN	S.E	S.D
X-SLS	-79.77	0.02	0.07
Y-SLS	-56.26	0.02	0.07
X-LS	-83.76	0.02	0.06
Y-LS	-64.25	0.03	0.09
X-LI	-77.29	0.02	0.06
Y-LI	-74.08	0.02	0.06
X-ILS	-70.53	0.02	0.07
Y-ILS	-86.57	0.02	0.08
X-PGS	-77.71	0.03	0.08
Y-PGS	-101.67	0.03	0.09

S.E = standard error of the mean

S.D = standard deviation

Angular variables measured in degrees

Linear variables measured in millimetres

- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX III

PRE-SURGERY

VARIABLE	Male T2 n=10		Female T2 n=13		
	Mean	S.D	Mean	S.D	t Value
SN7ARGO	76.28	4.88	76.10	3.73	0.10
SN7GOME	28.07	2.49	28.31	2.73	0.12
ARGOGN	129.46	4.51	130.10	4.63	0.33
SNA	78.78	4.11	76.15	3.74	1.61
SNB	84.12	4.70	81.89	3.06	1.30
UISN7	114.28	2.20	112.75	2.82	1.01
LIMP	78.93	2.34	84.54	2.84	1.55
NLA	97.50	3.65	106.62	3.41	1.82
LMA	141.62	3.48	142.11	3.07	0.09
NFRA	142.86	4.16	149.62	4.32	1.85
NMA	140.53	3.89	141.50	3.65	0.24
X-A	-65.41	3.86	-58.28	2.99	5.00*
Y-A	-46.99	2.21	-45.77	4.07	0.92
X-B	-72.79	2.62	-62.83	2.17	3.35*
Y-B	-92.78	4.76	-85.59	4.86	3.55*
X-IES	-69.02	4.98	-62.35	3.32	4.20*
Y-IES	-70.11	4.90	-68.51	4.07	1.93
X-IEI	-75.80	6.03	-68.59	3.15	3.43*
Y-IEI	-72.62	4.17	-68.83	4.34	2.11
X-MS	-46.67	4.33	-38.40	3.52	5.06*
Y-MS	-64.59	4.35	-61.53	4.12	1.72
X-MI	-55.47	5.56	-47.85	4.05	3.81*
Y-MI	-73.53	3.78	-69.09	3.79	2.79
X-PNS	-20.72	3.16	-16.59	2.60	3.45*
Y-PNS	-42.54	3.04	-41.07	3.60	1.04
X-PG	-73.96	2.49	-65.45	2.62	2.74
Y-PG	-108.35	2.75	-99.48	2.35	2.99*
X-PN	-99.41	2.33	-92.06	3.89	3.23*
Y-PN	-37.60	2.79	-35.49	3.20	0.54

APPENDIX III (continued)

VARIABLE	Male T2 n=10		Female T2 n=13		
	Mean	S.D	Mean	S.D	t Value
X-SUN	-82.61	2.87	-76.05	3.32	4.08*
Y-SUN	-48.48	2.75	-47.46	2.22	0.48
X-SLS	-82.17	2.63	-73.87	2.81	5.54*
Y-SLS	-56.57	3.86	-53.91	4.95	1.39
X-LS	-85.67	2.98	-76.61	2.50	5.70*
Y-LS	-63.56	3.63	-59.97	2.67	2.01
X-LI	-88.72	2.94	-79.16	2.41	4.80*
Y-LI	-79.02	2.69	-72.44	3.48	2.81
X-ILS	-83.35	2.41	-74.20	3.33	3.63*
Y-ILS	-89.49	3.92	-82.85	2.05	2.64
X-PGS	-86.10	2.04	-77.09	2.78	2.86
Y-PGS	-103.54	3.18	-95.71	3.67	2.49
ULH	21.54	1.88	17.82	3.57	3.22*
LLH	53.71	2.06	48.24	3.90	2.49
ULT	17.96	2.61	17.77	2.14	0.20
LLT	11.57	1.37	11.38	1.47	0.32

S.D = standard deviation

* indicates significant t value for the differences between males and females ($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

\- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX IV

POST SURGERY 6 MONTHS

VARIABLE	Male T3 n=10		Female T3 n=13		t Value
	Mean	S.D	Mean	S.D	
SN7ARGO	77.11	4.99	78.45	4.61	0.67
SN7GOME	29.76	2.06	30.81	2.57	0.52
ARGOGN	130.20	5.08	130.14	4.50	0.03
SNA	81.70	2.74	80.66	2.87	0.58
SNB	81.21	2.27	78.18	3.11	1.97
UISN7	112.35	2.52	109.05	2.97	1.80
LIMP	80.74	2.99	86.95	2.70	1.99
NLA	104.80	3.90	113.68	3.16	1.69
LMA	134.33	3.96	133.31	3.21	0.19
NFRA	141.21	3.04	150.05	3.42	1.97
NMA	133.79	4.72	136.66	4.01	0.73
X-A	-67.79	2.01	-62.23	3.39	3.60*
Y-A	-50.18	2.63	-47.66	3.56	1.88
X-B	-66.04	2.69	-56.48	2.23	4.19*
Y-B	-94.63	2.23	-86.47	2.21	2.93
X-IES	-71.62	4.61	-66.17	3.41	4.46*
Y-IES	-73.39	3.56	-70.35	4.71	2.25
X-IEI	-69.00	4.73	-61.61	3.19	4.26*
Y-IEI	-73.22	3.64	-69.81	4.87	2.26
X-MS	-48.97	4.24	-46.95	3.92	4.11*
Y-MS	-64.97	3.18	-60.96	4.51	2.50
X-MI	-48.93	3.59	-41.77	3.59	4.75*
Y-MI	-72.00	3.34	-66.72	4.07	3.33*
X-PNS	-23.20	3.07	-20.02	2.97	2.51
Y-PNS	-41.35	1.92	-39.91	2.99	1.40
X-PG	-67.73	2.62	-58.41	2.04	3.23*
Y-PG	-110.11	2.04	-100.39	2.20	3.32*
X-PN	-99.80	6.00	-92.37	3.82	3.42*
Y-PN	-37.02	4.96	-34.36	3.34	1.46

APPENDIX IV (continued)

VARIABLE	Male T3 n=10		Female T3 n=13		
	Mean	S.D	Mean	S.D	t Value
X-SUN	-84.54	2.35	-79.35	3.08	4.64*
Y-SUN	-51.13	2.71	-48.89	2.71	0.84
X-SLS	-83.97	2.50	-76.77	2.47	5.61*
Y-SLS	-59.02	2.57	-54.92	2.07	0.93
X-LS	-87.05	2.17	-79.41	2.12	5.09*
Y-LS	-66.12	3.59	-60.85	3.82	2.15
X-LI	-85.02	2.83	-74.76	3.71	5.77*
Y-LI	-80.00	2.56	-73.47	2.29	1.73
X-ILS	-77.87	2.19	-68.04	3.85	4.28*
Y-ILS	-90.92	2.71	-83.19	3.68	2.05
X-PGS	-79.98	3.79	-70.63	3.66	3.31*
Y-PGS	-105.24	2.75	-96.51	3.28	2.34
ULH	21.86	2.16	18.93	2.66	2.40
LLH	52.95	2.95	45.49	2.09	4.18*
ULT	16.75	2.10	15.12	2.20	1.47
LLT	11.84	1.86	11.56	1.69	0.37

S.D = standard deviation

* indicates significant t value for the differences between males and females ($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX V

POST SURGERY 12 MONTHS

VARIABLE	Male T4 n=10		Female T4 n=10		
	Mean	S.D	Mean	S.D	t Value
SN7ARGO	76.18	3.79	78.04	5.95	0.83
SN7GOME	28.71	2.82	31.62	2.45	1.14
ARGOGN	130.04	4.80	131.39	4.78	0.63
SNA	81.65	2.84	79.54	2.51	1.05
SNB	82.36	2.98	78.20	2.03	2.32
UISN7	114.05	2.46	110.77	2.60	1.36
LIMP	81.38	2.07	87.28	2.52	1.94
NLA	100.29	3.35	116.69	3.32	3.53*
LMA	138.20	3.07	130.92	3.87	1.84
NFRA	141.09	4.21	149.01	4.79	1.86
NMA	135.89	3.50	136.24	3.79	0.08
X-A	-67.21	2.60	-61.41	2.41	3.70*
Y-A	-48.43	3.11	-47.56	2.26	0.07
X-B	-67.07	2.66	-56.94	2.68	3.88*
Y-B	-94.53	3.83	-85.65	2.19	1.78
X-IES	-72.05	4.97	-63.91	4.13	3.98*
Y-IES	-73.16	4.07	-70.44	5.02	1.33
X-IEI	-69.75	4.56	-62.66	3.97	4.23*
Y-IEI	-72.62	3.48	-69.42	5.29	1.12
X-MS	-49.03	4.60	-47.74	3.88	3.83
Y-MS	-64.95	3.18	-62.35	4.67	1.46
X-MI	-49.42	3.61	-41.97	3.63	4.60*
Y-MI	-71.73	3.39	-68.06	4.16	2.16
X-PNS	-23.60	4.37	-19.31	2.41	2.72
Y-PNS	-41.80	2.21	-41.13	2.79	0.59
X-PG	-69.10	2.43	-58.64	2.12	2.96
Y-PG	-110.05	2.88	-99.65	2.03	1.89
X-PN	-99.52	5.63	-93.96	2.69	2.82
Y-PN	-37.12	5.30	-35.17	3.43	0.47

APPENDIX V (continued)

VARIABLE	Male T4 n=10		Female T4 n=10		
	Mean	S.D	Mean	S.D	t Value
X-SUN	-84.20	2.01	-78.80	2.69	4.27*
Y-SUN	-50.85	2.56	-48.31	2.32	0.51
X-SLS	-83.72	3.31	-75.44	2.03	4.72*
Y-SLS	-58.10	2.57	-55.62	2.56	0.63
X-LS	-86.66	2.13	-78.60	2.88	4.59*
Y-LS	-65.95	2.22	-60.01	2.77	0.96
X-LI	-85.30	2.10	-74.27	3.71	5.53*
Y-LI	-79.82	2.11	-74.57	2.81	0.98
X-ILS	-78.72	3.97	-67.84	2.71	4.17*
Y-ILS	-90.65	2.83	-82.55	2.27	1.87
X-PGS	-81.08	2.26	-71.32	2.30	2.80
Y-PGS	-105.05	2.59	-95.97	2.92	1.58
ULH	22.22	2.02	18.53	3.78	2.72
LLH	53.33	3.16	46.20	3.72	3.55*
ULT	16.98	2.86	16.27	1.65	0.68
LLT	11.65	1.05	11.49	1.61	0.26

S.D = standard deviation

* indicates significant t value for the difference between males and females ($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX VI

POST SURGERY 24 MONTHS

Variable	Male T5 n=5		Female T5 n=5		t Value
	Mean	S.D	Mean	S.D	
SN7ARGO	75.10	5.59	77.61	6.77	1.15
SN7GOME	25.89	3.40	31.06	3.20	1.45
ARGOGN	130.26	6.45	131.44	3.93	0.35
SNA	82.63	2.63	79.84	2.82	1.36
SNB	83.85	2.19	77.95	3.57	2.40
UISN7	115.98	3.34	112.78	3.26	0.85
LIMP	79.72	3.74	85.11	3.14	0.95
NLA	99.23	3.87	114.40	4.71	2.22
LMA	142.20	4.06	138.59	4.28	0.53
NFRA	142.79	5.35	148.54	3.08	0.87
NMA	136.11	4.40	136.43	4.66	0.05
X-A	-67.61	1.92	-62.16	2.64	3.74
Y-A	-48.26	3.93	-47.41	3.51	0.36
X-B	-69.47	2.42	-56.64	2.12	3.42
Y-B	-94.54	3.86	-85.95	2.16	1.47
X-IES	-72.71	3.24	-64.93	3.56	3.61
Y-IES	-72.53	2.53	-69.10	2.58	0.98
X-IEI	-70.91	3.94	-62.08	3.56	3.72
Y-IEI	-72.73	2.63	-70.40	2.13	0.99
X-MS	-49.84	1.64	-43.40	3.99	3.33
Y-MS	-65.65	3.80	-60.89	2.75	1.75
X-MI	-51.07	3.86	-42.79	3.26	3.67
Y-MI	-71.92	3.51	-67.28	2.38	1.85
X-PNS	-22.66	2.12	-21.07	3.58	0.65
Y-PNS	-42.01	1.95	-40.70	3.12	0.80
X-PG	-72.62	2.44	-58.28	2.86	3.23
Y-PG	-110.10	2.07	-99.90	2.24	1.77
X-PN	-99.32	2.26	-93.91	1.71	4.27*
Y-PN	-36.08	2.61	-34.18	2.80	0.59

APPENDIX VI (continued)

Variable	Male T5 n=5		Female T5 n=5		
	Mean	S.D	Mean	S.D	t Value
X-SUN	-83.81	1.20	-78.90	2.69	4.67*
Y-SUN	-50.93	2.00	-48.90	1.80	0.06
X-SLS	-82.89	1.77	-75.94	2.06	3.82
Y-SLS	-54.26	3.72	-55.46	3.31	0.34
X-LS	-85.96	2.01	-78.90	3.20	3.40
Y-LS	-64.95	3.34	-61.29	3.27	0.05
X-LI	-86.60	3.95	-74.21	4.58	4.29*
Y-LI	-79.90	3.01	-73.98	2.80	0.32
X-ILS	-80.81	3.63	-68.31	2.57	3.48
Y-ILS	-90.87	2.50	-82.64	3.33	0.60
X-PGS	-80.51	2.03	-71.46	2.10	2.67
Y-PGS	-105.18	2.32	-96.11	2.28	1.14
ULH	21.23	2.29	19.81	2.72	0.60
LLH	53.65	5.87	47.08	5.05	2.76
ULT1	16.20	2.43	15.51	1.68	0.52
LLT1	11.35	1.17	11.67	1.83	0.33

S.D = standard deviation

* indicates significant t value for the differences between males and females ($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX VII

POST SURGERY 36 MONTHS

VARIABLE	Male T6 n=4		Female T6 n=4		
	Mean	S.D	Mean	S.D	t value
SN7ARGO	73.13	5.76	74.68	3.77	0.47
SN7GOME	26.52	2.05	29.07	2.33	0.74
ARGOGN	130.65	2.73	131.57	4.44	0.19
SNA	83.94	2.57	80.53	2.49	1.44
SNB	83.92	2.65	79.75	2.98	1.88
UISN7	115.12	3.61	112.57	3.92	0.72
LIMP	79.72	4.17	82.92	4.46	0.51
NLA	102.09	4.65	111.42	4.80	0.94
LMA	150.18	2.10	136.91	4.81	3.26
NFRA	137.61	7.70	148.67	4.63	2.32
NMA	128.57	4.17	136.51	4.32	1.40
X-A	-69.81	3.15	-62.51	2.85	3.65
Y-A	-47.58	2.32	-46.97	3.78	0.30
X-B	-70.73	2.45	-59.74	2.17	2.82
Y-B	-94.40	3.68	-85.67	3.44	1.85
X-IES	-74.96	3.94	-65.62	3.62	3.28
Y-IES	-72.46	3.24	-68.78	3.27	1.13
X-IEI	-72.84	4.78	-62.94	4.09	3.36
Y-IEI	-71.97	3.14	-70.07	2.42	1.20
X-MS	-51.98	5.64	-42.59	4.57	2.77
Y-MS	-65.64	2.77	-60.98	4.62	1.88
X-MI	-51.92	2.56	-43.59	3.15	4.27*
Y-MI	-72.26	3.14	-67.18	4.25	1.99
X-PNS	-24.95	3.48	-19.67	3.49	2.26
Y-PNS	-43.14	2.26	-41.05	2.94	1.16
X-PG	-72.74	3.07	-62.95	2.17	2.24
Y-PG	-109.94	3.45	-99.60	2.69	2.32
X-PN	-102.85	3.17	-95.16	2.28	4.25*
Y-PN	-37.90	4.78	-35.39	3.14	0.91

APPENDIX VII (continued)

VARIABLE	Male n=4		Female T6 n=5		
	Mean	S.D	Mean	S.D	t value
X-SUN	-86.04	2.67	-78.54	2.88	4.00
Y-SUN	-49.49	2.09	-48.70	3.22	0.13
X-SLS	-83.05	3.34	-75.30	2.28	3.33
Y-SLS	-53.78	3.65	-55.26	3.91	0.52
X-LS	-86.12	2.21	-78.97	2.58	2.33
Y-LS	-65.60	4.54	-61.61	2.39	1.12
X-LI	-87.80	3.32	-75.80	2.40	3.22
Y-LI	-79.95	3.93	-73.28	2.22	0.97
X-ILS	-82.51	2.71	-71.02	3.82	2.96
Y-ILS	-90.81	3.26	-82.59	2.18	2.02
X-PGS	-80.20	2.32	-75.28	3.79	1.91
Y-PGS	-105.09	3.24	-95.75	2.63	2.28
ULH	20.80	3.61	17.50	2.60	1.17
LLH	55.22	1.80	46.05	3.96	4.61*
ULT	16.29	1.87	15.96	0.98	0.33
LLT	11.83	2.07	11.26	1.72	0.46

S.D = standard deviation

* indicates significant t value for the differences between males and females ($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

\- indicates linear variables measured in the 3rd quadrant of the cartesian coordinate system

APPENDIX VIII

TREATMENT CHANGES

PRE-SURGERY MINUS POST-SURGERY 6 MONTHS (T2-T3)

VARIABLE	Male differences T2-T3		Female differences T2-T3		
	MEAN T2-T3	S.D	MEAN T2-T3	S.D	t Value
SN7ARGO	-0.83	3.32	-2.35*	2.71	1.21
SN7GOME	-1.69*	1.74	-2.50*	1.68	0.54
ARGOGN	-0.75	3.37	-0.04	4.20	0.43
SNA	-2.92*	1.27	-4.51*	1.44	1.60
SNB	2.91*	1.23	3.71*	1.46	0.99
UISN7	1.93*	0.82	3.70*	1.17	0.77
LIMP	-1.81*	0.82	-2.41*	1.67	0.52
NLA	-7.29*	1.82	-7.06*	1.86	0.06
LMA	7.29*	1.20	8.79*	2.48	0.32
NFRA	1.65	5.91	-0.43	3.55	0.98
NMA	6.74*	4.46	4.84*	2.86	1.17
X-A	2.39*	0.46	3.95*	0.68	1.44
Y-A	3.19*	1.17	1.89*	0.94	1.52
X-B	-6.75*	1.08	-6.35*	2.71	0.40
Y-B	1.85*	0.82	0.88	1.62	0.80
X-IES	2.60	2.45	3.82	3.29	0.18
Y-IES	3.28	2.96	1.84	1.89	0.41
X-IEI	-6.79*	3.10	-6.99*	2.31	0.17
Y-IEI	0.60	3.82	0.98*	1.41	0.30
X-MS	2.30	3.01	3.55*	3.09	0.97
Y-MS	0.38	2.54	-0.57	1.35	1.08
X-MI	-6.54*	3.77	-6.09*	3.08	0.32
Y-MI	-1.53	2.53	-2.37	1.04	0.99
X-PNS	2.48	2.98	3.43*	1.81	0.89
Y-PNS	-1.19*	1.42	-1.16*	1.76	0.04
X-PG	-6.23*	1.93	-7.04*	2.99	0.46
Y-PG	1.76	1.56	0.91	1.82	0.27
X-PN	0.38	0.60	0.31	1.35	0.17
Y-PN	0.58	1.63	-1.14*	1.49	2.63

APPENDIX VIII (continued)

VARIABLE	Male differences T2-T3		Female differences T2-T3		t Value
	MEAN T2-T3	S.D	MEAN T2-T3	S.D	
X-SUN	1.93*	0.65	3.30*	1.46	0.18
Y-SUN	2.65*	1.37	1.43*	1.24	1.00
X-SLS	1.80*	0.69	2.90*	0.88	0.98
Y-SLS	2.45*	1.62	1.01*	1.61	0.44
X-LS	1.38*	0.69	2.20*	1.51	0.86
Y-LS	2.56*	1.72	0.89	1.52	1.00
X-LI	-3.71*	1.72	-4.40*	1.37	0.53
Y-LI	0.98*	1.09	1.03	1.90	1.75
X-ILS	-5.48*	1.72	-6.16*	1.28	0.47
Y-ILS	1.43*	1.08	0.74	1.12	1.58
X-PGS	-6.12*	1.79	-6.46*	1.91	0.19
Y-PGS	1.70*	1.18	0.81	1.82	0.78
ULH	-0.32	0.92	-1.11*	0.75	1.14
LLH	0.76*	1.04	2.75*	2.89	1.36
ULT	1.22*	0.84	2.65*	0.85	1.38
LLT	-0.27*	0.35	-0.19	0.44	0.16

S.D = standard deviation

* indicates mean differences which differed significantly from zero at the 5% level

Angular variables measured in degrees

Linear variables measured in millimetres

- shows increase for angular variables

- shows decrease for linear variables

APPENDIX IX

POST TREATMENT CHANGES

POST-SURGERY6 MONTHS MINUS POST-SURGERY 12 MONTHS (T3-T4)

VARIABLE	Male differences T3-T4		Female differences T3-T4		
	MEAN T3-T4	S.D	MEAN T3-T4	S.D	t Value
SN7ARGO	0.92	2.68	0.52	2.07	0.37
SN7GOME	1.04	1.93	-0.13	0.98	1.34
ARGOGN	0.17	1.98	-0.68	1.75	1.02
SNA	-0.05	0.89	0.90	1.29	1.47
SNB	-1.15*	1.46	-0.22	0.98	1.52
UISN7	-1.70*	1.95	-2.10*	1.54	0.28
LIMP	-0.64	1.38	-1.36*	1.13	0.34
NLA	4.51*	3.63	-0.14	1.03	1.43
LMA	-3.88*	2.41	-0.09	1.01	1.00
NFRA	0.13	3.81	0.44	4.22	0.17
NMA	-2.09	3.97	-1.57	3.01	0.33
X-A	-0.58*	0.62	-1.20*	0.97	1.55
Y-A	-1.75*	1.93	-0.45	0.86	2.60
X-B	1.03*	0.84	0.47*	0.40	2.10
Y-B	-0.10	0.90	-0.82*	1.04	0.74
X-IES	0.43	1.39	-0.43	0.73	1.73
Y-IES	-0.22	0.81	0.36	0.60	1.83
X-IEI	0.74	1.27	-0.22	1.48	1.56
Y-IEI	-0.60	1.67	-0.39	1.31	1.47
X-MS	0.06	1.50	-0.57	0.90	1.15
Y-MS	-0.02	0.89	0.38	1.24	0.82
X-MI	0.49	1.14	-0.47	1.06	1.95
Y-MI	-0.28	0.78	0.32	1.15	1.34
X-PNS	0.40	3.00	-0.69	1.52	1.02
Y-PNS	0.44	1.25	0.43	0.69	0.02
X-PG	1.37*	0.84	0.37*	0.34	2.02
Y-PG	-0.06	0.90	-0.74	1.27	1.47
X-PN	-0.28	0.74	-0.09	0.90	0.50
Y-PN	0.10	1.30	0.26	0.70	1.99

APPENDIX IX (continued)

VARIABLE	Male differences T3-T4		Female differences T3-T4		t Value
	MEAN T3-T4	S.D	MEAN T3-T4	S.D	
X-SUN	-0.34	0.87	-0.65	0.94	0.75
Y-SUN	-0.56	0.94	-0.90*	0.95	2.45
X-SLS	-0.25	0.87	-0.99*	0.94	0.49
Y-SLS	-0.92*	1.04	-0.50	0.97	0.82
X-LS	-0.25	0.84	- 0.91*	0.79	1.98
Y-LS	-0.17	0.90	-0.24	0.86	1.18
X-LI	0.29	0.96	-0.77*	1.06	1.86
Y-LI	-0.18	0.93	-0.20	0.90	0.37
X-ILS	0.85*	0.51	0.27	0.39	2.08
Y-ILS	-0.24	0.93	-0.64	1.06	2.28
X-PGS	1.10	0.68	0.09	0.26	1.58
Y-PGS	-0.15	0.92	-0.54	1.27	0.34
ULH	-0.36	0.93	0.03	0.94	0.80
LLH	-0.38	0.98	-0.88*	0.96	0.48
ULT	-0.24	0.51	-0.55*	0.60	0.77
LLT	0.18	0.98	-0.19	1.32	0.70

S.D = standard deviation

* indicates mean differences which differed significantly from zero at the 5% level

Angular variables measured in degrees

Linear variables measured in millimetres

- shows increase for angular variables

- shows decrease for linear variables

APPENDIX X

POST TREATMENT CHANGES

POST-SURGERY 12 MONTHS MINUS POST-SURGERY 24 MONTHS (T4-T5)

Variable	Male differences T4-T5		Female differences T4-T5		
	MEAN T4-T5	S.D	MEAN T4-T5	S.D	t Value
SN7ARGO	0.89	3.01	-0.64	0.87	1.80
SN7GOME	-0.46	1.07	0.91	1.08	1.43
ARGOGN	-2.23	3.11	0.50	2.40	2.12
SNA	0.46	0.92	-0.15	0.51	1.31
SNB	-0.24	0.82	-0.25	0.81	0.02
UISN7	-0.20	0.91	-1.10	1.20	2.00
LIMP	1.98*	0.95	1.60	0.60	0.85
NLA	-1.05	1.09	0.48	0.98	0.41
LMA	0.54	0.94	-4.69*	1.06	1.28
NFRA	-2.84	5.41	-0.66	5.56	0.63
NMA	-0.64	3.01	-2.17	6.15	0.50
X-A	-0.32	0.88	0.36	0.70	1.36
Y-A	0.18	0.63	0.03	0.18	0.27
X-B	-0.45	0.91	0.74	0.73	0.44
Y-B	0.01	0.19	0.35	0.83	1.28
X-IES	-0.55*	0.18	0.73	0.76	3.65
Y-IES	0.38	0.79	-0.47	0.60	1.93
X-IEI	0.08	1.45	-0.04	0.63	0.17
Y-IEI	0.11	0.68	0.97*	0.67	2.53
X-MS	-0.42	1.71	0.89*	0.49	1.66
Y-MS	0.58	0.84	-0.30	0.76	1.74
X-MI	0.61	2.29	0.97*	0.45	0.34
Y-MI	0.43	1.36	-0.20	0.55	0.96
X-PNS	-0.47	1.40	1.52*	1.06	3.82**
Y-PNS	0.33	1.48	-0.38	0.62	0.99
X-PG	0.38	0.48	0.98	0.82	0.89
Y-PG	0.05	0.13	0.25	0.46	1.81
X-PN	0.14	0.31	0.08	0.48	0.23
Y-PN	0.33	1.29	-0.68	1.15	1.31

APPENDIX X (continued)

VARIABLE	Male difference T4-T5		Female difference T4-T5		t Value
	MEAN T4-T5	S.D	MEAN T4-T5	S.D	
X-SUN	-0.32	0.53	0.10	0.52	0.53
Y-SUN	0.20	0.64	0.07	0.25	1.85
X-SLS	-0.08	0.11	0.40	0.60	0.70
Y-SLS	0.45	0.65	0.31	0.96	1.63
X-LS	-0.08	0.11	0.33	0.98	0.16
Y-LS	0.06	0.14	0.07	0.25	0.38
X-LI	-0.07	0.16	0.12	0.24	0.08
Y-LI	0.06	0.19	0.14	0.48	1.63
X-ILS	-0.40	0.74	0.55	0.65	0.18
Y-ILS	0.22	0.56	0.09	0.16	0.45
X-PGS	-0.66	0.88	0.71	0.94	0.06
Y-PGS	0.13	0.39	0.14	0.47	1.60
ULH	0.60	0.83	0.08	0.15	0.80
LLH	-0.49	0.67	-0.11	0.37	1.13
ULT	0.00	0.66	0.47	0.77	0.75
LLT	0.05	0.11	0.19	0.25	0.25

S.D = standard deviation

* indicates mean differences which differed significantly from zero at the 5% level

** indicates significant t value for the stage differences between males and females
($p < 0.05$)

Angular variables measured in degrees

Linear variables measured in millimetres

- shows increase for angular variables

- shows decrease for linear variables

APPENDIX XI

POST TREATMENT CHANGES

POST-SURGERY 24 MONTHS MINUS POST-SURGERY 36 MONTHS (T5-T6)

VARIABLE	Male differences T5-T6		Female differences T5-T6		t Value
	MEAN T5-T6	S.D	MEAN T5-T6	S.D	
SN7ARGO	0.06	1.41	0.70	1.63	0.54
SN7GOME	0.75	1.04	0.13	0.96	0.52
ARGOGN	0.45	1.51	-0.52	0.43	1.07
SNA	-0.62	0.53	0.61	1.33	1.69
SNB	0.21	0.34	0.53	0.78	1.24
UISN7	0.75	1.03	0.45	0.60	0.38
LIMP	-0.82	1.17	-1.24	1.20	0.30
NLA	-2.45	1.63	-0.62	1.97	0.36
LMA	-0.91	1.21	0.74	1.31	0.42
NFRA	-0.19	1.90	0.25	1.92	0.30
NMA	1.06	1.30	-0.07	1.22	1.18
X-A	0.40	0.66	-0.41	0.81	1.42
Y-A	0.40	0.67	-0.57	0.35	1.28
X-B	-0.13	0.54	-0.32	0.51	0.45
Y-B	-0.14	0.84	-0.28	0.86	1.47
X-IES	0.22	0.38	-0.30*	0.21	2.13
Y-IES	0.60	0.97	0.13	0.53	0.76
X-IEI	-0.05	0.39	-0.16	0.48	0.34
Y-IEI	-0.76	0.64	-0.33	0.55	0.98
X-MS	0.03	0.99	-0.71	1.05	0.94
Y-MS	0.63	0.53	0.11	1.18	0.78
X-MI	-0.50	0.90	-0.47	0.61	0.06
Y-MI	-0.46	0.58	-0.07	1.21	0.57
X-PNS	0.66	2.22	-1.49	1.50	1.46
Y-PNS	0.69*	0.20	0.30	0.43	1.60
X-PG	0.23	0.76	-0.27	0.71	0.07
Y-PG	-0.16	0.53	-0.30	0.78	0.79
X-PN	0.39	0.22	0.00	0.83	0.90
Y-PN	1.01	1.10	0.15	0.55	1.24

APPENDIX XI (continued)

VARIABLE	Male differences T5-T6		Female differences T5-T6		t Value
	MEAN T5-T6	S.D	MEAN T5-T6	S.D	
X-SUN	0.29	0.32	-0.35	0.76	0.70
Y-SUN	0.10	0.50	-0.32	0.69	1.71
X-SLS	0.14	0.63	-0.22	0.27	1.44
Y-SLS	0.05	0.16	-0.21	0.94	0.13
X-LS	0.18	0.56	-0.43	0.39	0.92
Y-LS	0.15	0.51	-0.38	0.53	1.13
X-LI	0.27	0.56	-0.55	0.48	0.71
Y-LI	0.05	0.26	-0.05	0.14	0.70
X-ILS	0.14	0.65	-0.42	0.48	0.65
Y-ILS	-0.06	0.23	-0.05	0.27	0.60
X-PGS	0.21	0.78	-0.16	0.21	0.25
Y-PGS	-0.09	0.31	-0.30	0.64	0.52
ULH	0.51	0.60	-0.69	0.76	1.19
LLH	0.13	0.64	0.37	0.53	0.20
ULT	-0.04	0.20	-0.36	0.89	0.72
LLT	-0.02	0.17	0.14	0.31	0.38

S.D = standard deviation

* indicates mean differences which differed significantly from zero at the 5% level

Angular variables measured in degrees

Linear variables measured in millimetres

- shows increase for angular variables

- shows decrease for linear variables

APPENDIX XII

DEFINITIONS

A. LANDMARKS

1. **Sella turcica(S)**: the centre of the pituitary fossa of the sphenoid bone.

2. **X ALIGN(X):** Any point on the S-N 7 line except Sella.

3. **Glabella (G)**: the most prominent point in the midsagittal plane of the forehead. (Legan and Burstone 1980).

4. **Soft tissue nasion(NAS)**: the point of greatest concavity in the midline between forehead and nose (Krogman and Sassouni 1957).

5. **Rhinion(R):** junction of bony and cartilaginous dorsums. It approximates the maximal prominence of a bony-cartilaginous dorsal convexity (hump) when present (Powells and Humphreys 1984).

6. **Pronasale(PN):** the most prominent point on the contour of the nose (De Laat 1974).

7. **Columella point(CM):** the most anterior point on the columella of the nose (Legan and Burstone 1980).

8. **Subnasale(SUN):** the point at which the nasal septum merges with the upper cutaneous lip in the mid sagittal plane (Legan and Burstone 1980).

9. **Superior labial sulcus(SLS):** the point of greatest concavity in the midline of the upper lip beteen subnasale and labrale superius (Holdaway 1983).

10. **Labrale superius(LS):** a point indicating the mucocutaneous border of the upper lip (Legan and Burstone 1980).

11. **Stomion superius(STMS):** the lowermost point of the vermilion border of the upper lip (Legan and Burstone 1980).

12. **Stomion inferius(STMI):** the uppermost point of the vermilion of the lower lip (Legan and Burstone 1980).

13. **Labrale inferius(LI)**: a point indicating the mucocutaneous border of the lower lip (Legan and Burstone 1980).

14. **Inferior labial sulcus(ILS):** the point of greatest concavity in the midline between the lower lip and chin (Legan and Burstone 1980).

15. **Soft tissue pogonion(PGS)**: the most anterior point on the soft tissue chin (Legan and Burstone 1980).

16. **Soft tissue gnathion(GNS)**: the constructed midpoint between soft tissue pogonion and soft tissue menton; can be located at the intersection of the subnasale to soft tissue pogonion line and the line from cervical point to soft tissue menton (Legan and Burstone 1980).

17. **Soft tissue menton(MES):** the lowest point on the contour of the soft tissue chin; found by dropping a perpendicular from the horizontal reference plane through menton (Legan and Burstone 1980).

18. **Nasion(N)**: the junction of the frontonasal suture at the most posterior point on the curve at the bridge of the nose (Riolo, Moyers, McNamara and Hunter 1974).

19. **Anterior Nasal Spine(ANS)**: the tip of the median, sharp bony process of the maxilla at the lower margin of the anterior nasal opening (Riolo, Moyers, McNamara and Hunter 1974).

20. **A point(A)**: the most posterior point on the curve of the maxilla between the anterior nasal spine and supradentale (Riolo, Moyers, McNamara and Hunter 1974).

21. **Supradentale(PR)**: the most anterior inferior point on the maxilla at its labial contact with the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

22. **Upper incisor incisal edge(IES)**: the incisal tip of the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

23. **Lower incisor incisal edge(IEI)**: the incisal tip of the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

24. **Infradentale(PRI)**: the anterior superior point on the mandible at its labial contact with the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

25. **B point(B)**: the point most posterior to a line from Infradentale to pogonion on the anterior surface of the symphyseal outline of the mandible. B point should lie within the apical third of the incisor roots (Riolo, Moyers, McNamara and Hunter 1974).

26. **Pogonion(PG)**: the most anterior point on the contour of the bony chin. Determined by a tangent through nasion (Riolo, Moyers, McNamara and Hunter 1974).

27. **Gnathion(GN)**: the most anterior-inferior point on the contour of the bony chin symphysis. Determined by bisecting the angle formed by the mandibular plane and a line through pogonion and nasion (Riolo, Moyers, McNamara and Hunter 1974).

28. **Menton(ME)**: the most inferior point on the symphyseal outline (Riolo, Moyers, McNamara and Hunter 1974).

29. **Lower incisor apex(RI)**: the root tip of the mandibular central incisor (Riolo, Moyers, McNamara and Hunter 1974).

30. **Upper incisor apex(RS)**: the root tip of the maxillary central incisor (Riolo, Moyers, McNamara and Hunter 1974).

31. **Orbitale(OR)**: the lowest point on the average of the right and left borders of the bony orbit (Riolo, Moyers, McNamara and Hunter 1974).

32. **Upper molar mesial contact(MS)**: the mesial contact (height of contour) of the maxillary first molar relative to the functional occlusal plane (Riolo, Moyers, McNamara and Hunter 1974).

33. **Upper molar mesial cusp tip(MTU)**: the anterior cusp tip of the maxillary first molar (Riolo, Moyers, McNamara and Hunter 1974).

34. **Lower molar mesial cusp tip(MTL)**: the anterior cusp tip of the mandibular first molar (Riolo, Moyers, McNamara and Hunter 1974).

35. **Lower molar mesial contact(MI)**: the mesial contact (height of contour) of the mandibular first molar relative to the functional occlusal plane (Riolo, Moyers, McNamara and Hunter 1974).

36. **Posterior nasal spine(PNS)**: the most posterior point at the sagittal plane on the bony hard palate (Riolo, Moyers, McNamara and Hunter 1974).

37. **Pterygo-maxillary fissure, inferior(PTM):** the most inferior point on the average of the right and left outlines of the pterygo-maxillary fissure (Riolo, Moyers, McNamara and Hunter 1974).

38. **Gonion(GO):** the midpoint of the angle of the mandible. Found by bisecting the angle formed by the mandibular plane and a plane through articulare posterior and along the portion of the mandibular ramus inferior to it (Riolo, Moyers, McNamara and Hunter 1974).

39. **Condylion(CO):** the most posterior superior point on the curvature of the average of the right and left outlines of the condylar head. Determined as the point of tangency to a perpendicular construction line to the anterior and posterior borders of the condylar head (Riolo, Moyers, McNamara and Hunter 1974).

40. **Basion(BA):** the most inferior, posterior point on the anterior margin of foramen magnum (Riolo, Moyers, McNamara and Hunter 1974).

41. **Articulare(AR):** the point of intersection of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles (Riolo, Moyers, McNamara and Hunter 1974).

42. **Cervical point(C):** the innermost point between the submental area and the neck located at the intersection of lines drawn tangent to the neck and submental areas (Legan and Burstone 1980).

All points were located on the mid-sagittal plane except gonion, articulare, condylion and pterygomaxillare so that the magnification factor was constant.

B. ANGULAR VARIABLES

1. **Ramal angle (SN7 AR GO):** The angle formed between SN7 line and the line AR-GO.

2. **Mandibular plane angle (SN7 GO ME):** the angle formed between SN7 and the mandibular line.

3. **Gonial angle (AR GO GN):** the angle formed by a line tangent to the mandibular ramus and the mandibular line.

4. **SNA:** the angle formed between sella-nasion line and a line drawn through nasion and Down's A point.

5. SNB: the angle formed between sella-nasion line and line drawn through nasion and Down's B point.

6. Upper incisor angle (UI-SN7): the angle between SN7 and a line drawn through IES and RS.

7. Lower incisor angle (LI-MP): the angle between the mandibular line and the line IEI and RI.

8. Nasolabial angle (NLA): the angle formed by the points CM-SUN-LS.

9. Labiomental angle (LMA): the angle formed by the points LI-ILS-PGS.

10. Nasofrontal angle (NFRA): the angle between points G, NAS and R (Powell).

11. Nasomental angle (NMA): described by the angle formed by nasal dorsal line and the nasomental line i.e. between lines NAS-R and PN-PGS.

C. LINEAR VARIABLES

(N.B. X refers to X-axis and Y refers to Y-axis)

12. A point horizontal (X-A)

13. A point vertical (Y-A)

14. B point horizontal (X-B)

15. B point vertical (Y-B):

16. Upper incisor incisal edge horizontal (X-IES)

17. Upper incisor incisal edge vertical (Y-IES)

18. Lower incisor incisal edge horizontal (X-IEI)

19. Lower incisor incisal edge vertical (Y-IEI)

20. Upper molar mesial contact horizontal (X-MS)

21. Upper molar mesial contact vertical (Y-MS)

22. Lower molar mesial contact horizontal (X-MI)

23. Lower molar mesial contact vertical (Y-MI)

24. Posterior nasal spine horizontal (X-PNS)

25. Posterior nasal spine vertical (Y-PNS)

26. Pogonion horizontal (X-PG)

27. Pogonion vertical (Y-PG)

28. Pronasale horizontal (X-PN)

29. Pronasale vertical (Y-PN)

30. Subnasale horizontal (X-SUN)

31. Subnasale vertical (Y-SUN)

32. Superior labial sulcus horizontal (X-SLS)

33. Superior labial sulcus vertical (Y-SLS)

34. Labrale superius horizontal (X-LS)

35. Labrale superius vertical (Y-LS)

36. Labrale inferius horizontal (X-LI)

37. Labrale inferius vertical (Y-LI)

38. Inferior labial sulcus horizontal (X-ILS)

39. Inferior labial sulcus vertical (Y-ILS)

40. Soft tissue pogonion horizontal (X-PGS)

41. Soft tissue pogonion vertical (Y-PGS)

42. ULH - Upper lip height (SUN-STOMS):

Y coordinate STOMS - Y coordinate SUN

43. LLH - Lower lip height (MES-STOMI):

Y coordinate MES - Y coordinate STOMI

44. ULT - Upper lip thickness (A-SUN):

X coordinate SUN - X coordinate A

45. LLT - Lower lip thickness (B-ILS):

X coordinate ILS - X coordinate B

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