PREDICTION OF THE LOWER LIP AND CHIN RESPONSE CONSEQUENT TO SURGICAL ADVANCEMENT OF THE MANDIBLE

N.F. GREEN-THOMPSON

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Nadia Farrah Green-Thompson

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DECLARATION

I, Nadia Farrah Green-Thompson, declare that this research is my own work. It is being submitted for the degree of Master of Dentistry in the branch of Orthodontics at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other university.

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Dr NF Green-Thompson

_____ day of ____________________, 2011

DEDICATION

This research is dedicated to my husband Riyas and my three beautiful children who have stood beside me with patience, love and support without which none of this would have been possible.

ABSTRACT

It has been evident from the literature that the reports of response of the lower lip and soft tissue chin to the surgical advancement of the deficient lower jaw are strongly discrepant. Therefore, the objective of this study was to improve the understanding of the soft tissue response, with particular reference to the role of the preoperative soft tissue thickness. It has become evident from a review of current studies that tissue thickness may not play as significant a role as was previously thought, thus indicating the role of other factors in the prediction of the lower lip and chin response for the individual.

This study assessed the soft tissue changes of the lower lip within a homogenous sample group of 39 patients who had undergone a surgical advancement of the lower jaw. Lateral cephalometric radiographic records at time periods before and after the surgical procedure were used. The radiographs were hand traced and specific landmarks were computer digitized with the Analysis System (Olympus Pty, Ltd) relative to a constructed X-Y axis. The change in the position of these landmarks at the various time periods was calculated according to the mean value of each reading for each landmark.

Multiple regression analyses of the data resulted in poor correlations of the lower lip position with the extent of mandibular advancement surgery when the variables of horizontal overjet and the vertical overbite of the incisors, the lower lip thickness (lower incisor tip to labrale inferius as well as lower lip protrusion ahead of the upper incisor teeth) and the pre-operative soft tissue thickness were included (0.27 in the horizontal dimension; 0.51 in the vertical dimension). The addition of the variables tissue thickness and lower lip thickness within the

multiple regression equation did not result in a notable improvement in coefficients of correlation either (0.77 to 0.78).

Within the stepwise regression equations specific variables have been identified as having an influence on the prediction of the response of the lower lip and chin consequent to the mandibular advancement surgery (R^2=0.93-0.97(horizontal); R^2=0.89-0.96(vertical)). These points include stomion, upper incisor tip, hard and soft tissue pogonion, lower incisor tip, gnathion and menton. The prediction equations were independently cross-validated against each individual within the sample group, achieving high cross-correlation values (0.85-vertical to 0.90- horizontal) between the prediction equation and the observed values.

The findings of this study have identified factors that play a role in the soft tissue response of the lower lip and chin consequent to mandibular advancement surgery, enabling a more accurate prediction for the individual.

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CHAPTER ONE: INTRODUCTION

Class II malocclusion results from an antero-posterior mismatch between the dental, the skeletal or the dento-skeletal components of the maxilla and mandible. Angle (1907), concentrating on the dental relationships, described the anterior position of the maxillary molars relative to the mandibular molars in his classification of Class II malocclusion. However, a Class II malocclusion of skeletal origin is more complex and manifests most commonly in an anterior posterior discrepancy of the bases with the maxilla positioned ahead of a relatively deficient mandible (Bishara, 2006).

Class II malocclusions are prevalent amongst a large proportion of patients undergoing orthodontic treatment. The condition is common in the Caucasian ethnic group than amongst Mongoloids and Negroids (Bishara, 2001). Epidemiological studies by Kelly (1977) on an adolescent population in the United States showed that 15%-20% of a teenage population group presented with an overjet in excess of 6mm.

The salient clinical features of the facial soft tissue features in Class II Division I problems of skeletal origin include an increased convexity of the total facial profile, a strained in-contact lip position, an excessively curled and everted lower lip as well as a deepening of the labiomental fold. Skeletally, the discrepancy between the sizes and / or relative positioning of the jaws results in the relatively prominent maxilla and a retrognathic mandible. The dental relationships are usually described as Angle Class II with an increased overjet and a deep overbite.

The motivation for seeking treatment of this malocclusion, besides correction of functional disorders, often includes a psychosocial component due to the negative effect of the facial and dental aesthetics on self esteem. When the malocclusion is complicated by a relatively deficient mandible, a skeletal problem is imposed that is challenging to treat with orthodontics alone.

Proffit and Ackerman (1994) outlined three primary treatment approaches for the correction of the skeletal retrognathism. In the growing child, a Class II jaw malocclusion (excluding craniofacial abnormalities) treatment maybe by means of dentofacial orthopaedic techniques, taking advantage of any favourable mandibular growth potential. In the non-growing (adult) patient, orthodontic camouflage of the skeletal malrelationship is accomplished by retraction of the upper incisor teeth and proclination of the lower incisors. In some cases, a relatively minor surgical procedure such as a genioplasty can be employed to further enhance facial aesthetics (Proffit, Turvey, Moriarty, 1983). In cases of severe soft tissue and skeletal imbalance, a carefully co-ordinated orthognathic surgical procedure which requires orthodontic preparation, surgical mandibular advancement and orthodontic finishing, produces the optimum aesthetic, stable and functional result (Ackerman, Proffit and Sarver, 1999). Forecasting this final post-operative aesthetic result is dependent on detailed diagnostic and treatment planning procedures. Hence, the reaction of the soft tissue drape of the face to surgical movement of the jaws and teeth needs to be precisely understood.

CHAPTER TWO: LITERATURE REVIEW

Studies of the changes in thickness of the lower lip as the lower jaw is surgically advanced in the treatment of mandibular antero-posterior deficiency have produced widely inconsistent findings. Lines and Steinhauser (1974) were the first to analyse the relationship of the changes between the hard and soft tissues. They studied a composite surgical sample group of 35 patients at a period of three months post-surgery. However, only nine of these patients underwent mandibular advancement procedures. In this group, a simple comparison between the pre and post-operative cephalometric tracings revealed that the lower lip at vermilion (labrale inferius) responded at a ratio of 0.62:1 relative to the total distance that the lower incisor was advanced. The soft tissue chin measured at pogonion reacted at a 1:1 ratio relative to the movement of the underlying hard tissue at gnathion. They explained that the lower lip change is due to the pre-operative curled, everted and protrusive position of the lip which is often described as ‘pseudo-positioning’. These characteristics contribute to the varied response of the lower lip to the surgical advancement of the mandible.

Quast, Biggerstaff and Haley (1983) reported on the change of the lower lip at labrale inferius (Li) following mandibular advancement surgery in a sample of eighteen patients. The cephalometric head films were taken prior to surgery, and at post-surgical periods from 3.7 months and at the longer term at 18 months. The films were traced and the changes in position of the digitized points were analyzed according to a constructed co-ordinate system. An analysis of the horizontal soft tissue changes showed that the lower lip at labrale inferius responded to the advancement of the mandible at the tip of the lower incisor at a ratio of 0.38:1, and soft tissue pogonion relative to the hard tissue chin at a ratio of 0.97:1. This poor response of the lower lip was attributed to the differences in the short to long term data which may be due to remodelling changes of the soft and hard tissues. A simple regression analysis showed that the horizontal spatial change of labrale inferius was very closely correlated with the surgical changes measured at the lower incisal edge (r=0.89). The authors of this study emphasized the importance of long term post-operative data to enable more accurate assessment of the response of the lip, at a time when soft tissue remodelling and adaptation is complete.

Mommaerts and Marxer (1987) analyzed the soft tissue changes within a homogenous sample of 35 patients who underwent mandibular advancement. They found that the response of the soft tissue at labrale inferius to the underlying hard tissue advancement at the inferior incisal edge after one year was at a ratio of 0.55:1, and soft tissue chin at pogonion responded at a 1:1 ratio relative to the corresponding underlying hard tissue point. Simple regression analysis demonstrated that only a moderate correlation existed between labrale inferius and the horizontal change at the inferior incisal edge (r=0.70). According to the investigators, the uncertainty of the patient's lip position on the radiographs used in this study as well as the extent of the surgical correction resulted in an incomplete understanding of the relative changes at labrale inferius.

In 1989, Dermaut and De Smit studied a sample of 31 patients following mandibular osteotomy. The cephalograms were taken with the teeth in occlusion although there was no record as to whether the lips were in repose thereby eliminating any lip strain. The soft tissue changes at labrale inferius were recorded at a simple ratio of 0.26:1 relative to the anterior displacement of the lower incisor teeth as the maxilla was surgically advanced. They speculated that the thickness of the lower lip affected the extent of the post operative changes at labrale inferius. They further described how the soft tissue change included a straightening of the lower lip and a flattening of the labiomental sulcus, attributing the poor response of the lower lip to pre-operative lip strain. Hence, it may be deduced that in this sample of patients the radiographs were probably taken with the lips not being in repose.

Hernandez-Orsini, Jacobson, Sarver and Bartolucci (1989) reported upon a homogenous sample of 31 patients following mandibular advancement. The cephalograms of the patients were taken before the surgery with the teeth in occlusion and the lips in repose. These were repeated at a period of 14 months following surgery. The soft tissue changes at labrale inferius responded in a ratio of 0.43:1 relative to the advancement of the lower incisor. The ratio of movement at soft tissue menton was recorded as 0.97:1 and at soft tissue pogonion as 0.94:1 relative to the corresponding hard tissue points. Hernandez-Orsini et al (1989) proposed that the position of the mandibular incisor teeth contributed to the form and redundancy of the lower lip and that the pre-surgical soft tissue thickness played a significant role in predicting the outcome.

Ewing and Ross (1992) analyzed the soft tissue response of the lower lip within a heterogenous sample group of 31 patients following mandibular advancement, including patients who had undergone advancement genioplasty (eleven), and others whose surgery had included maxillary superior repositioning (six). The findings for the patients who underwent genioplasty were separated from those patients who underwent only mandibular advancement procedures. The study was performed using cephalometric head films taken with the lips in repose, and at two long term post-operative time intervals of approximately 14 and 35 months. Horizontal (S-N) and vertical (N-Pog) reference planes were constructed in order to separate the hard and soft tissue movements in both dimensions.

The lower lip thickness at labrale inferius measured from (Li) to the vertical plane (N-Pog) responded to the horizontal surgical advancement of the lower jaw by thinning at an average amount of 1.4mm. The range of this change, however, varied widely from a 4.3mm reduction to a 2.2mm increase in thickness of the lower lip tissue. The overall ratio of the response between labrale inferius and the advancement of the lower incisor was given at 0.8:1. A marked flattening of the labiomental sulcus was also noted. Regression analysis included the degree of bite opening measured between the upper incisor tip (UIT) and lower incisor tip (LIT), as well as the increase in total facial height (N-Me) during the mandibular advancement procedure. Neither of these variables contributed to the variation in the response of the lower lip tissue.

Thüer, Ingervall and Vuillemin (1994) assessed a more homogenous group of 30 consecutive patients who underwent mandibular advancement only. The cephalometric head films were taken with the lips in repose, were traced and the reference points digitized. A reference axis was constructed at a seven degree angle at sella relative to the sella-nasion line in order to calculate the co-ordinates of each digitized point at each time period. An analysis of the soft tissue changes from the time periods T1 (pre surgery- mean time: one day) to T3 (post-surgery: mean time of thirteen months) resulted in a ratio of 0.66:1 descriptive of the change of the lower lip at labrale inferius in response to the mandibular advancement measured at the lower incisor tip. The change at the soft tissue chin at menton relative to the corresponding underlying hard tissue point resulted in a ratio of 1:1. The labiomental fold flattened following surgery. Regression analyses were not performed.

A larger sample of 61 patients was used to analyse the longer term soft tissue profile changes following mandibular advancement surgery in a study by Mobarak, Espeland, Krogstad and Lyberg (2001). The positions of the soft and hard tissue landmarks were measured in the horizontal and vertical planes. The sample was separated into groups according to mandibular plane angle (high, medium and low angle groups) in an attempt to enable a more specific prediction of the anticipated soft tissue changes after mandibular advancement surgery. When comparing the post-surgical soft tissue profiles, it was noted that the degree of normalization of the facial aesthetics varied between the different facial patterns. The authors found an overall reduction in the thickness of the lower lip, as well as a lengthening and straightening of this tissue resulting in a decrease in the depth of the labiomental fold. These changes were most pronounced in the low angle group indicating the role in the soft tissue response of an alteration of anterior facial height at the time of surgery. The lower lip reacted by unrolling and extending which contributed to the reduction of its anterior displacement. The ratio of this soft: hard tissue change (Li: L1) was at 0.59:1 (low angle group) and 0.60:1 (high and medium angle groups). The influence of the pre-surgical tissue thickness of the lower lip, measured from the tip of the lower incisor tooth to labrale inferius, demonstrated a moderately statistically significant correlation with the net change of that dimension (r=0.72 (high angle), 0.77 (medium angle) and 0.74 (low angle)). As reported in previous studies, the soft tissue chin followed the advancement of the corresponding hard tissue point (Pg'-Pg) at a ratio of 1:1. These results were computed from a long term three year post-operative sample. Included, therefore, were elements of surgical relapse as well as a certain amount of ageing of the soft tissue.

The findings of these past studies draw attention to the complexity involved in predicting the response of the lower lip to mandibular advancement surgery. Veltkamp, Buschang, English, Bates and Schow (2002) reported upon a heterogenous sample of 58 mandibular advancement patients within which 29 patients had also undergone an maxillary surgical procedure. The tracing of the lower lip was divided into thirds to facilitate detailing its response to the mandibular advancement procedure. The majority of the thinning response of the lower lip was noted in the superior third of the lower lip, measured from the lower incisor tip LIT – Li. The ratio of movement of labrale inferius to the advancement of the lower incisor tip (LIT) within this sample was found to be 0.79:1. The development of an algorithm by way of a multivariate regression analysis enabled the authors to relate the combination of numerous factors, and provided a more accurate explanation of the variation in the response of the lower lip area when compared with those described in simple ratios. The soft tissue response was predictable within 2mm of the observed change 80% of the time when the independent variables of horizontal skeletal movement, tissue thickness (B to B'), the protrusion of labrale inferius ahead of the upper incisor and the vertical movement of the hard tissues were included (R^2=0.89(h); 0.91(v)). Clinically, the changes in the lip profile were described as a slight straightening of the lower lip contour (lip unfurling), enhanced projection of the chin, and a reduction of lip pout. The response of the soft tissue chin at pogonion relative to the underlying hard tissue surgical advancement at 0.92:1 was closely in keeping with ratios previously stated, and strongly correlated with the corresponding hard tissue change (R^2=0.96(h); 0.81(v). These authors included patients who required additional procedures such as maxillary impaction and genioplasty .They, unfortunately, did not state whether the additional surgery had any influence on the post-surgical position of the lower lip.

Iizuka, Eggensperger and Smolka (2004) studied the horizontal and vertical changes in the lower lip profile within a homogenous sample of 30 patients undergoing mandibular advancement only. Cephalometric observations were made from a constructed X-Y cranial base co-ordinate system. These patients were also divided into three groups according to the magnitude of the mandibular occlusal plane angle, which included high angle (ten patients), medium angle (sixteen patients) and low angle (four patients) groups. The measurements were assessed from the pre-operative (1-2 days) to longer term post-operative time periods (average: 14 months post-surgery). The average response of the lower lip tissue in the sample measured from the tip of the lower incisor (LIT) to labrale inferius (Li), was at a ratio of 0.54:1 relative to the change in position of the bone. The authors suggested that the change in the position of the lower lip was closely correlated with the change in position of the lower incisors, although no regression analyses were undertaken. The response of the soft tissue chin relative to the advancement of the underlying hard tissue was at a ratio of 1:1, in keeping with previous findings. The authors stated that the pre-operative thickness of the lower lip, positional change of the inferior incisors by the post-operative orthodontic treatment and the limitations in securing a relaxed lip position on the cephalometric radiographs were factors that ultimately affected the reliability of the measurement of the response of the lower lip tissue to the surgical advancement procedure. The limitations of this study also included the small number of patients in each subgroup.

Kneafsey, Cunningham, Petrie and Hutton (2008) developed a multiple regression model in order to predict the complex lower lip response to mandibular advancement surgery more accurately. The variables included in the multiple regression equation were, in the horizontal plane: the pre-surgical positions of the mandibular incisor, stomion inferius and labrale inferius, and in the vertical plane, the pre-surgical total facial height. The soft tissue thickness from the lower incisor tip to labrale inferius (LIT to Li), and the post-operative changes at the lower incisor tip were further included. These variables were highly correlated at at R^2=0.96.

The prediction equation for soft tissue pogonion included the horizontal pre-surgical positions of stomion inferius, labrale inferius, inferior labial sulcus, soft tissue pogonion and menton, and the post-operative changes at hard tissue pogonion in both the horizontal and vertical planes. These variables were also highly correlated at $R^2 = 0.99$. The authors performed a statistical procedure in order to cross-validate these predictions on a small sample of five independent patients which resulted in a predictive accuracy ranging from 0.21mm (Li) to 1.03mm (pogonion) which was indicative of the variation of the individual soft tissue response. There was however, no mention of the time intervals at which the pre-operative (T1) and post- operative (end of treatment- T2) films were taken.

Most recently McCollum, Gardner, Evans and Becker (2009) reported on the response of the lower lip and chin to mandibular advancement. Within a sample of 25 patients, seven patients had undergone a concomitant genioplasty. It was shown statistically that the advancement genioplasty had no influence on the soft tissue response of the lower lip after the mandibular advancement surgery. The response of the lower lip at labrale inferius relative to the change at the lower incisor tip was at a ratio of 0.77:1 similar to those results published by Talbott (1975) at 0.85:1, Ewing and Ross (1992) at 0.81:1, and Veltkamp et al (2002) at 0.79:1. In an attempt to predict the final position of the lower lip more accurately, the tissue thickness of the lower lip measured from the lower incisor tip to labrale inferius was included in a multiple regression equation. The resultant coefficient of determination (CoD) was only marginally improved in the horizontal plane from 46.92% to 47.36%. The findings in the vertical plane showed a greater improvement of the coefficient of determination (CoD) from 16.73% to 32.39%, although these values were still low. This indicated that other factors might play a role in the prediction of the lower lip response to the mandibular advancement procedure.

Published reports of the lower lip response to the mandibular advancement procedure have not demonstrated consensus. The broad variation has been attributed to inconsistencies in lip position at the different times of radiographic exposure, different muscular patterns associated with different facial types, the extent of pre-surgical overbite and overjet as well as the pre-surgical soft tissue thickness of the lower lip. More abstract factors such as the ageing of the soft tissues, tone of musculature, facial type as well as the extent of the lower lip eversion prior to surgery have also been implicated. Various shortcomings within previous investigations have not enabled an accurate forecasting of this soft tissue response of the lower lip which is an essential tool in the treatment planning process.

The purpose of this retrospective study is therefore to identify the factors that play a role in the prediction of the soft tissue response of the lower lip and chin subsequent to mandibular advancement surgery within a homogenous sample of surgically treated skeletal Class II malocclusions.

CHAPTER THREE: MATERIALS AND METHOD

3.1 Sample Group

The sample comprised the cephalograms of 39 Caucasian patients who had been treated in a single private orthodontic practice in Johannesburg. The group included 27 female and 12 male patients, all of whom had completed growth. The mean age at the start of treatment within the female group of patients in the sample was 32 years 5 months with a range of 14 years 5 months to 48 years 3 months, and amongst the males in the sample the mean age was 29 years 10 months (range 17 years 7 months to 49 years 6 months). All subjects had been treated by the same orthodontist. The sample was collected according to defined criteria, i.e. patients who required surgical advancement of the mandible only, without any additional maxillary or genioplasty procedures. All patients had undergone comprehensive full fixed edgewise orthodontic appliance therapy prior to the surgery. The teeth in both jaws were orthodontically decompensated and stabilised in the planned pre-surgical positions for at least six weeks prior to the surgery to ensure that no further orthodontic movements occurred and only minimal adjustments would be required during the post-operative healing period. The surgical procedure was carried out by means of a standard bilateral sagittal split osteotomy, retained with screw and rigid (plated) internal fixation of the proximal and distal segments. These procedures were carried out mainly by one surgeon with five other surgeons having performed a small number of the remaining surgical procedures. Ethical approval (R14/49 Green-Thompson) was granted for this study by the Committee for Research on Human Subjects: Protocol Number M08-1028.

The lateral cephalometric radiographs analyzed in this study were taken by one radiographer on one of two machines (General Electric, and Soredex, Istrodent) within the same practice. Consistent source-subject and subject-film distances were used, whilst the orthodontist personally ensured that the lips of the patient were in repose and that the jaws were in centric occlusion (Burstone, 1967). All radiographs displayed sufficient clarity of detail to enable an accurate and confident identification of the soft tissue profile and specific hard tissue landmarks.

The lateral cephalometric head films for each case had been taken at the following time periods:

(i) T1 radiographs- these films were taken at a maximum of six weeks prior to the surgical procedure (39 patients) at the time of completion of active pre-surgical orthodontic treatment when the upper and lower arches had been stabilised with full thickness arch wires.

(ii) T2 radiographs- these post-operative records had been taken at no less than six weeks after the advancement procedure. The post-operative time period at which the films of the 11 female patients were taken was at an average of 7.7 weeks, and at an average of six weeks for the four males in this group.

(iii) T3 radiographs- these films constituted an intermediate sample of post-operative records taken no less than six months after the mandibular advancement procedure (33 patients). The radiographs were taken at an average time period of 7.3 months for the 22 female patients, and at an average time of 8.3 months amongst the 11 male patients.

(iv) T4 radiographs- these films constituted a long term sample of post-operative records taken at least one year after the surgical procedure. There were eleven patients included in this sample- ten females and one male. The post-operative time period at which these radiographs were taken ranged from 12 months to 22.5 months.

(v) T5 radiographs- these films were taken at the longest post-operative period at which records were available, and the sample size was eight patients (six female and two male). The films were taken at time periods ranging from 2 years 3 months to 15 years 7 months after surgery.

Table 3.1 Details of the sample used in the study.

PT Number	M/ F	AGE AT START (YEARS/ MONTHS)	SURGERY -T1 (WEEKS)	SURGERY – T2 (WEEKS)	SURGERY- T3 (MONTHS)	SURGERY – T4 (MONTHS)	SURGERY- T5 (YEARS/ MONTHS)
1	F	48/3	2	-	-	21	-
2	F	25	4	11	6	-	-
3	F	42/6	4	-	8	-	-
4	F	14/10	3	-	6.5	-	-
5	F	48	2	6	6	13	-
6	F	34	4	12	6.3	-	-
7	F	30/2	4	-	6	-	-
8	F	17/9	11	-	8	14.5	-
9	F	38	4	-	6	22.5	-
10	F	31	5	-	7.5	-	-
11	F	14/5	6	7	7.25	-	-
12	F	32/11	1	-	-	-	15/7
13	F	24/2	5	-	8.5	18	-
14	F	17/5	7	6	6	-	3/5
15	F	32/3	2	6	-	12	-
16	F	15/10	4.5	-	11	-	3/7.5
17	F	26	9	7	-	18	2/7
18	F	35	3 days	8	6	-	4/4
19	F	42/2	3.5	-	8.5	-	-
20	F	46/2	2	-	6	-	-
21	F	40	4	6	6	-	-
22	F	33/8	10	-	6	-	-
23	F	33/4	14	8	11	13	-
24	F	31/3	7	-	10	17	-
25	F	50	4	-	9	16	-
26	F	29/2	8	8	-	-	2/3
27	F	42/6	1	-	6	-	-
28	M	29	1	6	6	-	-
29	M	30	4	6	7	-	-
30	M	42/7	4	-	9	-	-
31	M	18	6	-	11.5	-	-
32	M	34/5	10	-	8	-	-
33	M	20	2	-	7	-	3
34	M	49/6	2	6	8	-	-
35	M	20/10	3.5	-	-	12.5	-
36	M	17/7	4 days	-	8	-	5.7
37	M	31/7	3	-	6	-	-
38	M	30/2	1 day	6	10	-	-
39	M	20/7	3	-	11	-	-

3.2 Method

The cephalometric radiographs were traced on 0.05mm D/Matt drafting film (Frank Booth and Associates, Corporate Profile and Product Articles, Braamfontein, Johannesburg, South Africa) using a finely sharpened 5H 2mm lead Faber Castell tracing pencil. Two locating cross hairs were scribed onto each film in the upper and lower corners for the purposes of reorientation of subsequent tracings. These cross hairs were copied directly onto each tracing paper after it had been secured to the film by means of Scotch Tape (Scotch Tape 3M). The anatomic structures that were traced included the inner outline of sella turcica, the midline floor of the anterior cranial fossa, the roof of the orbit, the nasal bone, the mandible, the maxilla (including points prosthion and anterior and posterior nasal spines), and the soft tissue outline from glabella to the junction of the chin with the throat. The upper and lower most anteriorly placed incisor teeth were traced using the standard Unitek tracing template (3M- Unitek Co, Monrovia, California, USA), located over the incisal tip and aligned along the long axis of the tooth. The following cephalometric points were identified, defined as follows (Figure 3.2.1):

Hard tissue points:

1. Sella (S) - The constructed point at the centre of the pituitary fossa (Broadbent, 1931).

2. Nasion (N) - The most anterior point of the frontonasal suture as seen on "norma lateralis" (van der Linden, 1971).

3. Anterior Nasal Spine (ANS)

- "The tip of the median, sharp, bony process of the maxilla at the lower margin of the anterior nares" (McNamara, 1993).

4. Hard Tissue Subspinale- Point A (A)

- "The deepest point on the contour of the alveolar projection between the anterior nasal spine and prosthion" (Van der Linden, 1971).

5. Maxillary/ Upper Incisal Tip (UIT)

- The tip of the maxillary central incisor crown.

6. Mandibular/ Lower Incisor Tip (LIT)

- The tip of the mandibular central incisor crown.

7. Hard Tissue Supramentale- Hard Tissue Point B (B)

- "The most posterior point in the concavity between infradentale and pogonion" (Van der Linden, 1971).

8. Hard Tissue Pogonion (Pog)

- "The most prominent or most anterior point on the bony chin" (Van der Linden, 1971).

9. Hard Tissue Gnathion (Gn)

- "The midpoint between the most anterior and most inferior points on the bony chin" (Van der Linden, 1971).

10. Hard Tissue Menton (Mn)

- "The most inferior midline point on the lower margin of the mandibular symphysis" (Van der Linden, 1971).

11. Hard Tissue Gonion (Gn)

- "The lowest, most posterior and most outward everted point on the angle of the mandible" (Salzmann, 1943). On the lateral cephalogram, it is a constructed point of the bisected angle formed by lines tangent to the lower and posterior borders of the mandible (Rakosi, Jonas, Graber (1993).

Soft tissue points:

12. Soft Tissue Subnasale (Sn)

- "The point at which the nasal septum merges with the upper cutaneous lip" (Worms, Isaacson and Speidel, 1976).

13. Superior Labial Sulcus: Soft tissue Point A (A')

- "The point of greatest concavity in the midline of the upper lip between subnasale and labrale superius" (Burstone, 1958).

14. Labrale Superius (LS)

- "The median point in the upper margin of the upper membranous lip" (Burstone, 1958).

15. Stomion (St)

- "The junction of the upper and lower membranous lips" (Worms, Isaacson and Speidel, 1976).

16. Labrale Inferius (Li)

- "The median point in the lower margin of the membranous lower lip" (Burstone, 1958).

17. Inferior Labial Sulcus: Soft Tissue B Point (B')

- "The point of greatest concavity in the midline of the lower lip between labrale inferius and soft tissue pogonion" (Burstone, 1958).

18. Soft Tissue Pogonion (Pog')

- "The most prominent or anterior point on the soft tissue chin, in the midsagittal plane" (Burstone, 1958).

19. Soft Tissue Gnathion (Gn')

- "The midpoint between soft tissue pogonion and soft tissue menton" (Van der Linden, 1971).

20. Soft Tissue Menton (Mn')

- "The most inferior point on the contour of the soft tissue chin" (Farkas, 1994).

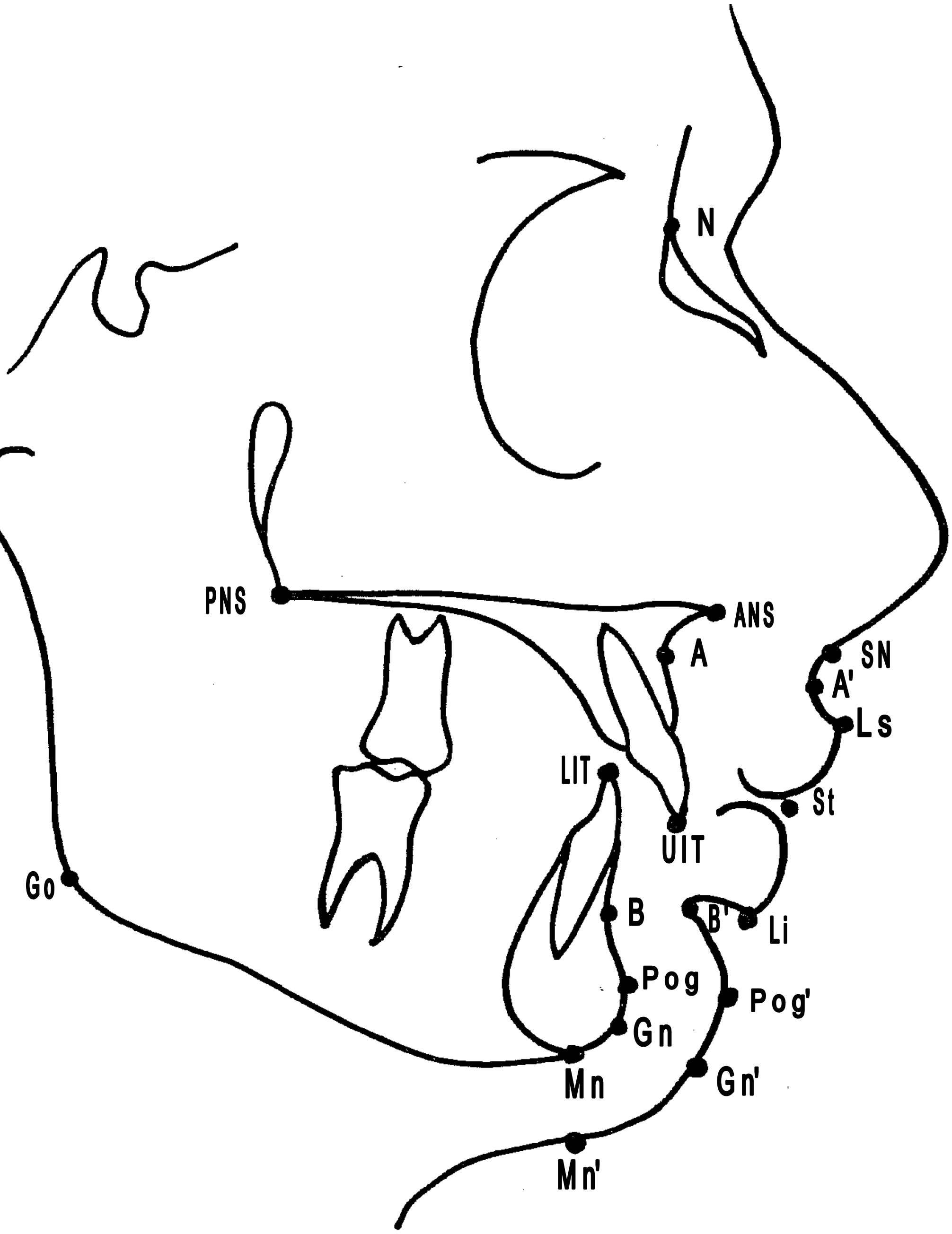


Figure 3.1 Cephalometric landmarks used in this study

A standard reference plane was constructed in order that any changes in the position of the co-ordinates of each landmark at subsequent time periods could be assessed. A baseline plane was drawn through points sella (S) and nasion (N), and used to construct the reference system. The axis "X" was drawn at an angle of 6 degrees from sella below the S-N plane. The "Y" reference axis was constructed at 90 degrees to the "X" axis. This method of reference for measurements was according to that proposed by Phillips, Turvey and McMillian (1989). In this way, a reference co-ordinate system for all measurements was established with the origin at Point S (Figure 3.2).

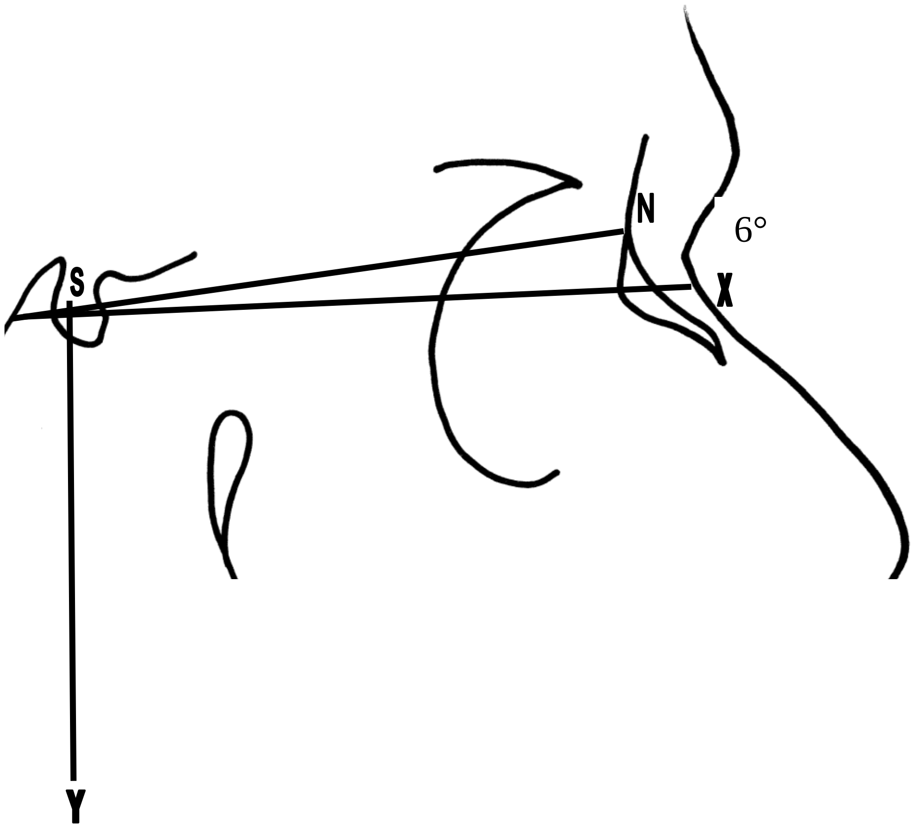


Figure 3.2 Constructed reference plane through Point S.

3.2.1 Method of measurement

In order to determine the intra-examiner repeatability of the accuracy of landmark identification, the T1 radiographs of 16 patients were traced twice under the same conditions. The first tracing was completed as previously described and the reference axis constructed in the cranial base area. At a time interval of no less than 24 hours later, a second tracing of the anatomical structures was completed on a fresh sheet of tracing paper. Now, this second tracing was overlaid on the first tracing ensuring, as accurately as possible, superimposition of the cranial base, as represented by the sphenoid plane and the cribriform plate (De Coster, 1953). Once the superimposition had been established, the reference axes were traced from the first tracing to the second tracing. This ensured standardization of the reference axes on each set of two tracings for each patient.

The reference axes were transferred from the pre-surgical films to the post-surgical films by exactly the same superimposition technique. The cross hairs inscribed onto each film and its tracing were used as an additional method to facilitate reorientation of the tracings upon the films.

The co-ordinates of each landmark relative to the X and Y axes were identified and recorded sequentially using of the Analysis Imaging System (Wirsam Scientific Pty, Ltd). This process required the uploading of the film and its superimposed tracing onto the computer system. This was achieved by laying the film and tracing out on a back-lit screen, and recording an electronic image, captured with an analogue closed circuit television camera (Vitus, Olympus), the data could then be uploaded as required.

3.2.2 Calibration of measurements

In order to ensure that measurements were standardized, a method of calibration was devised for the tracings of the films taken on either the General Electric, or the Soredex cephalometric units. This method is illustrated below in Figures 3.1 to 3.3 and was carried out as follows:

i. A 12mm thick sheet of perspex was cut to dimensions of 238mm x 177mm to be used as a reference plate. The rectangular dimensions corresponded to the average size of a cephalometric film.

ii. Ten circular holes were drilled into the perspex sheet with a 17mm drill secured in a drill press. These holes were made at specific sites on the perspex sheet upon which a cephalogram had been placed, enabling the drilling to be effected approximately over the relevant anatomical images on the cephalometric head film.

iii. Ten carbon steel ball bearings of Grade 1/1000 and Rockwell hardness of +/- 65 (Sampabuita Technology (Pty)), measuring 16mm in diameter were placed within these holes and secured with transparent adhesive glue.

iv. The perspex sheet was mounted vertically onto a perspex base and rigidly secured with two screws enabling the perspex sheet to stand upon the platform of a camera tripod where it was secured by means of another screw protruding from the platform into the centre of the perspex base. A spirit level was used to ensure that the base plate was placed in a level position (Figure 3.3).

v. The camera tripod and perspex plate construction was positioned at a location equidistant from the cephalometric ear-rods. This positioning mimicked the position of the patient's mid sagittal plane to ensure that the magnification most closely resembled that occurring on the previously exposed films of the patients.

vi. The radiograph was exposed at the lowest magnification to ensure the best clarity of the stainless steel balls. This was carried out on both machines (General Electric and Soredex).

vii. Each film was then placed on a radiographic viewing box and an electronic image was captured by the Vitus Camera, positioned at a fixed distance. These data were then uploaded onto the Analysis System.

viii. The film was magnified to 120% by the computer programme in order to increase visual perception of the perimeter of the stainless steel ball bearings. The measurement data of the radiographic images and the precisely known actual size of the ball bearings were used to establish a magnification factor and thereby to calibrate the Analysis Measuring System for the specified cephalometer. This then standardized the subsequent measurements for all films of the patients taken on the relevant machine. The calibration factor so determined was applied by the Analysis programme, which also automatically adjusted to the different degrees of zoom used to view the films in this study.

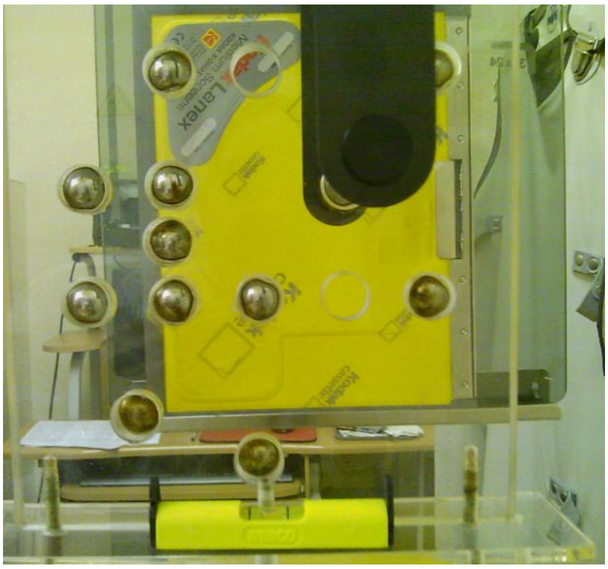


Figure 3.3 The perspex sheet with embedded stainless steel balls, held vertically upon a horizontal support, as confirmed by a spirit level.

Figure 3.4 Perspex sheet upon tripod set midway between the ear rods of the cephalometer

Figure 3.5 Perspex sheet centralized between the ear rods of the cephalometer.

3.2.3 Method of measurement technique

The co-ordinates of each landmark were digitized in perpendicular relation to the X and Y base axes. This entailed the use of the Analysis measurement toolbar set at 'arbitrary line' thus allowing the identification of the landmark with the cursor controlled by the computer mouse. A line was extended from the landmark, perpendicular to the X or Y axes respectively, enabling the digital recording of the horizontal or vertical co-ordinate of the landmark. Each landmark was digitized in this manner and the co-ordinates of data saved to an accuracy of two decimal places.

Three angular measurements were recorded at the following areas of reference:

i. occlusal plane (a line from the bisection of the incisal overbite to the intercuspation of the first molars (Downs, 1948), and

ii mandibular plane (a line extending through points Go- Gn (Steiner, 1952), both with reference to the S-N line, and the

iii. labio-mental fold (the angle formed by Li-B'-Pog').

The landmarks on all the tracings were measured three times and the mean value established. All sets of duplicate tracings for all 16 patients at T1 were completed at a single sitting for each pair thus further reducing operator variability (Houston, 1983).

These data were recorded on the programme spreadsheet and saved, organized and tabulated in Microsoft Excel (2007) in preparation for statistical analysis at the Medical Research Council Biostatistics Unit in Pretoria.

3.3 Statistical Analysis

A series of descriptive, exploratory and comparative statistical analyses were performed. Simple and multiple regression as well as stepwise regression analyses were also undertaken. The stepwise regression equations were independently cross-validated as a predictor of the observed result for all patients within the sample (Appendix B).

3.3.1. Error of the method

This exercise was essential in order to test for the accuracy of the digitizing procedure, as well as to determine the intra and inter-examiner repeatability of landmark identification.

3.3.1.1 Accuracy of digitizing

In order to test the proficiency of the operator in using the Analysis software, one randomly chosen radiograph was redigitised on nine separate occasions at least 24 hours apart.

3.3.1.2 Intra-examiner repeatability of the accuracy of landmark identification

The T1 radiographs of 16 randomly selected patients were traced in duplicate. The measurements of these tracings were used to assess the accuracy of repeatability of the identification of landmarks by the operator. The coefficient of repeatability was calculated for each landmark.

Mitgard, Bjork and Linder-Aronson (1974) have reported that the repeatability of hard tissue landmarks varies depending on the point being identified. A variation of 0.42mm was found for point S, whereas 2.08mm was seen for point orbitale. These authors did however find that the majority of landmarks were reproducible at an accuracy level of 1mm-1.5mm. This figure was confirmed by the findings of Hillesund, Fjeld and Zachrisson (1978), for the accuracy of repeatability of soft tissue landmark identification in the horizontal plane. The required level of repeatability for the identification of landmarks located on definitive landmark areas in this study was set at less than 1.5mm, and at less than 2mm for those landmarks located on curved surfaces.

3.3.1.3 Inter-examiner accuracy of landmark identification

A randomly chosen radiograph was traced by seven orthodontists on separate occasions. Each orthodontist located a series of six common landmarks. These were later digitized and analyzed statistically in order to derive an intraclass correlation coefficient as a measure of agreement between the participants.

The six landmarks chosen were:

i. B’ (soft tissue B point)
ii. Li (labrale inferius)
iii. Pog’ (soft tissue pogonion)
iv. LIT (lower incisor tip)
v. Pog (hard tissue pogonion)
vi. Mn (hard tissue menton)

CHAPTER FOUR: RESULTS

4.1 Error of the method

4.1.1 Intra-examiner accuracy of digitizing

Intra-examiner observations of reliability report on the measuring consistency of one person on different occasions. Table 4.1 represents the coefficients of variation for each landmark as a measure of intra-examiner accuracy for eleven hard and nine soft tissue landmarks digitized and the three angles measured by the author on nine separate occasions each at least 24 hours apart. These coefficients were calculated by dividing the standard deviation (SD) by the mean, and expressed as a percentage i.e. CV% = SD/Mean x 100. A coefficient of variation of less than 5% was deemed to be clinically acceptable (Bland and Altman, 1986).

Table 4.1 Coefficients of variation as a measure of intra-examiner accuracy of digitizing.

HARD TISSUE LANDMARK		COEFFICIENT OF VARIATION (%)	SOFT TISSUE LANDMARK		COEFFICIENT OF VARIATION (%)	ANGLE	COEFFICIENT OF VARIATION (%)
S	h	0.00	Sn	h	0.17	OPL	2.74
	v	0.00		v	0.45		
N	h	0.43	A’	h	0.11	MPL	1.67
	v	1.09		v	0.60		
ANS	h	0.16	Ls	h	0.15	LMF	0.65
	v	0.50		v	0.51		
A	h	0.14	St	h	0.35		
	v	0.48		v	0.42		
UIT	h	0.21	Li	h	0.36		
	v	0.19		v	0.29		
LIT	h	0.20	B’	h	0.25		
	v	0.20		v	0.37		
B	h	0.21	Pog’	h	0.29		
	v	0.51		v	0.44		
Pog	h	0.33	Gn’	h	1.05		
	v	0.37		v	0.34		
Gn	h	0.42	Mn’	h	1.12		
	v	0.12		v	0.17		
Mn	h	0.48					
	v	0.23					
Go	h	2.20					
	v	0.72					
Mean	h	0.48	Mean	h	0.43	Mean	1.69
	v	0.44		v	0.40	Range	0.65-2.74
Range	h	0.20-2.20		h	0.11-1.12		
	v	0.12- 1.09		v	0.17-0.60		

h – horizontal
v - vertical

The average coefficient of variation for all hard tissue landmarks measured in the horizontal dimension was 0.48%, with a range of 0.2% to 2.20%. In the vertical dimension, the average coefficient of variation was 0.44%, with a range of 0.12% to 1.09%. For the soft tissue landmarks measured in the horizontal dimension, the average coefficient of variation was 0.43% with a range of 0.11% to 1.12%, and in the vertical dimension, the coefficient of variation averaged 0.40%, with a range of 0.17% to 0.60%. The angles measured yielded an average coefficient of variation of 1.69% with a range of values from 0.65% to 2.74%. The mean values and range of the coefficients of variation for the hard tissue landmarks measured in both horizontal and vertical dimensions excluded the 0.00% values of the sella co-ordinate, although this point has been included in Table 4.1 for completeness.

The mean values and ranges of the coefficients for all points were therefore well within the limit of 5% suggested as being a clinically acceptable level of accuracy (Bland and Altman, 1986).

4.1.2 Intra-examiner repeatability of landmark identification

Intraclass correlation coefficients (ICC) were used to determine the intra-examiner agreement for each cephalometric landmark identified. The coefficients were derived from the analysis of variance (ANOVA), and assessed examiner reliability by comparing the variability of ratings of the same landmarks at each attempt with the total variation across all ratings and all landmarks (Kish, 1965). This is a measure of the homogeneity of the landmarks identified within the sample and has a maximum value of one (1) when there is complete homogeneity. Table 4.2 represents the intraclass correlation coefficients of the author for the repeatability of the identification of landmarks measured from the first and second tracings of the T1 radiograph for a random group of 16 patients.

Table 4.2 Intraclass correlation coefficients for each landmark traced from a duplicate set of T1 radiographs for a group of 16 patients.

HARD TISSUE L/MARK	ICC	95% CONF. INTERVAL	SOFT TISSUE L/MARK	ICC	95% CONF. INTERVAL	ANGLE (DEGREES)	ICC	95% CONF. INTERVAL
S h	0.000	-	S h	0.000	-	OPL	0.953	0.907-0.999
v	0.000	-	v	0.000	-			
N h	0.976	0.952-0.999	Sn h	0.994	0.988-0.999	MPL	0.87	0.749-0.991
v	0.7352	0.506-0.964	v	0.635	0.338-0.932			
ANS h	0.975	0.95-0.999	A’ h	0.987	0.976-0.999	LMF	0.678	0.409-0.947
v	0.867	0.741-0.991	v	0.983	0.966-0.999			
A h	0.985	0.969-0.999	Ls h	0.996	0.992-0.999			
v	0.966	0.933-0.999	v	0.982	0.966-0.999			
UIT h	0.998	0.996-0.999	St h	0.993	0.985-0.999			
v	0.990	0.981-0.999	v	0.99	0.980-0.999			
LIT h	0.967	0.935-0.999	Li h	0.981	0.962-0.999			
v	0.689	0.427-0.951	v	0.984	0.968-0.999			
B h	0.951	0.9045-0.999	B’ h	0.95	0.901-0.999			
v	0.979	0.958-0.999	v	0.993	0.986-0.999			
Pog h	0.961	0.9227-0.999	Pog’ h	0.962	0.925-0.999			
v	0.959	0.92-0.999	v	0.974	0.947-0.999			
Gn h	0.957	0.914-0.999	Gn’ h	0.961	0.922-0.999			
v	0.983	0.967-0.999	v	0.989	0.977-0.999			
Mn h	0.967	0.965-0.999	Mn’ h	0.97	0.940-1.000			
v	0.241	0.000-0.710	v	0.995	0.99-0.999			
Go h	0.894	0.795-0.994						
v	0.968	0.936-.0.999						

h – horizontal
v - vertical

The intraclass correlation coefficients ranged from 0.894 (hard tissue point gonion) to 0.998 (hard tissue point upper incisor tip) in the horizontal dimension with a range of values in the 95% confidence interval from 0.427 to 0.999. The coefficients for the landmarks measured in the vertical dimension ranged from 0.635 (soft tissue point Subnasale) to 0.996 (hard tissue A point), with a range of values from 0.338 to 0.999 within the 95% confidence interval. These findings indicated a high degree of accuracy of repeatability of landmark identification.

4.1.3 Inter-examiner accuracy of landmark identification

Table 4.3 represents the coefficients of variation for the means of the values obtained by the seven independent orthodontists and the author for the same landmarks identified by each one. Each measurement was repeated three times by all observers in order to minimize the extent of variability (Harris and Smith, 2009).

Table 4.3 Inter-examiner accuracy of landmark identification

LANDMARK		ORTHODONTISTS			RESEARCHER	DIFFERENCE OF MEANS	
		Mean (mm)	SD	CV	Mean (mm)	mm	%
Li	h	67.63	0.98	0.82	67.70	-0.07	0.1
	v	86.94	1.39	1.65	88.68	-1.74	1.96
B'	h	61.02	0.99	0.83	61.03	-0.01	0.02
	v	92.28	0.90	0.68	94.48	-2.20	2.33
Pog'	h	63.80	1.67	2.39	63.76	0.04	0.06
	v	104.95	1.27	1.38	108.77	-3.82	3.51
LIT	h	59.74	0.61	0.32	60.25	-0.51	0.85
	v	71.53	0.64	0.35	72.35	-0.82	1.13
B	h	50.38	0.85	0.62	50.42	-0.04	0.08
	v	89.02	1.40	1.67	90.18	-1.16	1.29
Pog	h	53.11	1.41	1.70	52.77	0.34	0.64
	v	103.22	1.62	2.24	105.89	-2.67	2.52
Mn	h	46.66	0.91	0.70	45.67	0.99	2.17
	v	109.43	5.04	21.80	111.67	-2.20	2.01

h – horizontal
v - vertical

The coefficients of variation for all points in the orthodontist group ranged from 0.35% to 21.8%. Despite this large range, the majority of these values were below 2% with the exception of soft tissue pogonion horizontal (2.39%), hard tissue pogonion vertical (2.24%), and hard tissue menton vertical (21.80%). These higher coefficients were due to more deviant values recorded from landmarks digitized by one specific examiner. This could be due to an individual perception of the location of the point according to the eyesight and handedness of the digitizer. The high standard deviation and coefficient of variation of point Menton in the vertical dimension suggested that this point was not suitable for inclusion in further statistical analysis. Despite these few deviant values, there was an overall high degree of accuracy for the identification of all other landmarks as reflected by the range of the differences in the mean values (0.06% minimum to 3.51% maximum).

Table 4.4 represents the intraclass correlation between the means of the values obtained by seven independent orthodontists and the researcher who each located and digitized seven landmarks.

Table 4.4 Intraclass correlation for assessment of inter-examiner reliability of identification of the co-ordinates of landmarks.

LANDMARK CO-ORDINATE	INTRACLASS CORRELATION (MEAN)	95% CONFIDENCE INTERVAL
HORIZONTAL	0.98181	0.96035-1.00327
VERTICAL	0.97239	0.94004-1.00475
COMBINED	0.99363	0.98845-0.99882

The mean values of the intraclass correlations (ICC) were assessed for the degree of accuracy in the identification of the seven landmarks in both the horizontal and the vertical directions. These values were correlated at 0.98181 for the horizontal co-ordinate of all the landmarks, 0.97239 for the vertical co-ordinate of the landmarks, and at 0.99363 when both horizontal and vertical co-ordinates of the landmarks were identified. These values were all greater than or equal to 0.90, and none of the 95% confidence limits on the ICC had a lower boundary that was less than 0.97. An ICC of 0.75 or above is usually considered to be good and above 0.90 is considered excellent (Harris and Smith, 2009). The landmarks measured in the vertical dimension had a lower ICC, although the ICC for this parameter was nonetheless excellent at 0.97239.

4.2 Exploratory statistics for all landmarks from time periods T1 to T5

The positional changes of each landmark across all time periods were assessed. Not all records at each time period were available for every patient. As a result, the mean results at each time period were calculated for that group of specific patients for whom an observation had been recorded at that particular time period.

Table 4.5 Exploratory statistics for the horizontal co-ordinates of all landmarks for the time periods T1 to T5.

Landmark	T1 (mm)			T2 (mm)			T3 (mm)			T4 (mm)			T5 (mm)		
	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD
<u>Horizontal</u>															
N	39	77.97	7.09	13	74.51	6.72	33	77.31	5.64	9	76.45	5.46	7	72.95	11.48
ANS	39	81.01	7.61	13	78.69	6.93	33	80.99	6.54	8	78.74	6.08	7	73.00	10.85
A	39	76.38	7.78	13	73.80	7.81	33	76.33	6.95	8	73.43	7.25	7	68.50	10.61
UIT	39	78.21	9.04	13	76.45	8.64	33	78.63	7.97	9	76.48	8.26	7	70.03	10.12
LIT	39	70.64	8.24	13	74.08	8.83	33	75.75	7.56	9	72.28	7.88	7	67.05	9.43
B	39	63.90	8.62	13	67.04	9.62	33	68.90	8.85	9	66.59	8.13	7	60.54	9.12
Pog	39	65.51	9.56	13	68.57	10.43	33	70.44	9.78	9	68.28	8.59	7	60.93	9.97
Gn	39	62.53	9.56	13	65.99	10.94	33	67.42	9.77	9	65.16	8.22	7	57.69	9.83
Mn	39	57.41	9.28	13	61.51	10.87	33	62.21	9.55	9	60.15	8.06	7	52.65	9.56
Go	39	11.77	5.43	12	9.22	4.82	30	9.40	5.59	8	11.62	4.84	7	10.79	5.94
Sn	39	93.33	9.33	13	90.00	9.66	33	92.85	8.29	9	90.74	6.98	7	84.91	12.74
A’	39	90.68	9.63	13	87.66	9.69	33	90.46	8.34	9	87.66	7.87	7	81.93	12.46
Ls	39	92.70	9.89	13	89. 61	9.77	33	92.30	8.69	9	89.82	8.94	7	83.57	12.56
St	39	83.81	9.42	13	82.99	10.15	33	84.71	8.65	9	81.59	8.58	7	76.08	11.31
Li	39	85.08	9.03	13	86.82	9.76	33	88.80	8.65	9	85.71	8.24	7	79.00	11.39
B’	39	76.27	8.33	13	79.20	9.61	33	81.37	8.47	9	79.39	7.89	7	71.72	10.09
Pog’	39	78.98	9.64	13	81.00	11.13	33	83.60	9.56	9	81.56	8.67	7	73.41	11.67
Gn’	39	70.43	10.06	13	73.14	11.68	33	75.54	9.90	8	75.74	6.23	7	64.98	10.69
Mn’	39	59.09	8.94	12	63.15	10.94	31	63.65	9.34	8	62.85	6.23	7	54.14	9.90

Table 4.6 Exploratory statistics for the vertical co-ordinates of all landmarks and angles for the time periods T1 to T5.

Landmark	T1 (mm; degrees (angles) N	Mean	SD	T2 (mm; degrees (angles) N	Mean	SD	T3 (mm; degrees (angles) N	Mean	SD	T4 (mm; degrees (angles) N	Mean	SD	T5 (mm; degrees (angles) N	Mean	SD
Vertical															
N	39	8.20	1.16	13	8.24	1.89	33	9.00	5.26	9	8.02	0.73	7	7.46	1.27
ANS	39	49.67	5.39	13	47.86	5.66	33	49.32	5.31	8	48.18	6.21	7	47.44	7.40
A	39	57.27	4.69	13	55.80	4.26	33	57.44	4.50	8	56.62	4.98	7	55.23	8.09
UIT	39	81.52	6.71	13	78.35	5.31	33	80.64	4.73	9	79.59	5.24	7	77.05	11.24
LIT	39	77.67	7.64	13	77.33	5.36	33	78.81	4.73	9	77.38	4.96	7	74.00	10.16
B	39	96.45	8.18	13	96.97	7.26	33	98.42	6.00	9	96.50	6.77	7	91.61	13.41
Pog	39	111.92	9.83	13	111.74	9.38	33	113.17	7.32	9	110.50	7.91	7	107.43	17.29
Gn	39	117.88	10.18	13	117.48	9.18	33	118.96	7.64	9	116.56	8.20	7	112.44	17.23
Mn	39	116.59	19.93	13	118.68	8.84	33	120.15	7.83	9	117.56	7.78	7	113.11	17.01
Go	39	86.37	8.99	13	77.13	23.98	32	81.56	16.97	9	83.56	8.20	7	75.53	12.68
Sn	39	55.26	6.81	13	52.36	5.62	33	53.90	4.37	9	54.41	5.48	7	52.50	8.90
A’	39	62.17	5.87	13	59.92	5.37	33	61.85	4.58	9	61.63	4.42	7	59.01	9.75
Ls	39	68.94	11.96	13	67.57	5.93	33	70.21	5.25	9	70.37	3.77	7	65.87	10.46
St	39	79.50	7.27	13	75.91	6.14	33	78.35	5.17	9	78.01	5.01	7	74.03	11.49
Li	39	91.72	8.57	13	87.06	6.95	33	89.14	6.02	9	87.95	6.89	7	85.51	12.96
B’	39	95.80	8.73	13	95.47	8.45	33	97.13	6.38	9	94.12	6.13	7	91.18	13.72
Pog’	39	112.19	10.28	13	110.79	9.91	33	112.90	7.76	9	111.47	7.16	7	106.54	16.30
Gn’	39	123.55	10.57	13	122.20	9.52	33	124.69	7.78	9	122.56	8.14	7	117.52	17.66
Mn’	39	127.37	10.87	13	125.80	9.05	33	128.51	7.97	9	125.64	8.01	7	120.69	18.19
Angles															
OPL	39	15.07	4.12	13	14.55	4.24	33	14.15	3.69	9	12.67	2.31	7	17.16	4.91
MPL	39	28.75	6.44	13	31.75	5.99	33	30.98	6.27	9	29.05	3.04	7	32.00	9.17
LMF	39	252.96	15.65	13	229.48	10.23	33	231.42	10.69	9	230.42	9.85	7	225.18	37.97

4.3 Results from the time periods T1 to T3

4.3.1 Comparative statistics

4.3.1.1 Paired Student's t tests

Paired Student's t tests were used to compare the positional changes in the horizontal and vertical co-ordinates of the various landmarks for the 33 patients where T1 and T3 records were available. These changes were indicative of associated changes in the specific areas of the soft tissue profile.

Table 4.7 Analysis of horizontal positional changes of all landmarks between time periods T1 and T3 using the Student's t test.

Parameter	T1-mm (N=33)			T3 -mm (N=33)			p value	95% confidence change T1 to T3
	Mean	SD	SEM	Mean	SD	SEM		
Horizontal								
N	78.08	7.29	1.27	77.31	5.64	0.98	0.3006	(-)0.73 -2.27
ANS	81.46	7.81	1.36	80.99	6.54	1.14	0.5303	(-)1.04 -1.97
A	76.97	8.08	1.41	76.33	6.95	1.21	0.3773	(-)0.81 -2.08
UIT	79.21	9.35	1.63	78.63	7.97	1.40	0.4434	(-)0.93 -2.08
LIT	71.66	8.42	1.47	75.75	7.56	1.32	0.000 *	(-)5.42 – (-)2.76
B	65.03	8.84	1.54	68.90	8.85	1.54	0.000 *	(-)5.16 – (-)2.59
Pog	66.93	9.53	1.66	70.44	9.78	1.70	0.000 *	(-)4.92 – (-)2.09
Gn	63.96	9.45	1.64	67.42	9.77	1.70	0.000 *	(-)4.81 - (-)2.06
Mn	58.85	9.16	1.59	62.21	9.55	1.66	0.000 *	(-)4.69 – (-)2.04
Go (N=30)	11.40	5.27	0.96	9.4	5.59	1.02	0.0052	0.65 – 3.35
Sn	93.87	9.8	1.71	92.85	8.29	1.44	0.2608	(-) 0.80 – 2.85
A'	91.37	10.12	1.76	90.46	8.34	1.45	0.2959	(-)0.84 – 2.69
Ls	93.46	10.45	1.82	92.30	8.70	1.51	0.2173	(-)0.72 – 3.04
St	84.75	9.79	1.70	84.71	8.65	1.51	0.9613	(-)1.53 – 1.60
Li	86.05	9.40	1.63	88.80	8.65	1.51	0.0018 *	(-)4.38 – (-)1.10
B'	77.35	8.54	1.49	81.37	8.47	1.48	0.000 *	(-)5.37 – (-)2.67
Pog'	80.34	9.65	1.68	83.60	9.56	1.66	0.0002 *	(-)4.81 – (-)1.71
Gn'	71.83	9.99	1.74	75.54	9.90	1.72	0.000 *	(-)5.05 – (-)2.37
Mn'(N=30)	60.71	8.35	1.52	64.19	8.98	1.64	0.000 *	(-)4.85 – (-)2.11

*Change (T1-T3) significant at $p<0.05$

Table 4.8 Analysis of vertical positional changes of all landmarks between time periods T1 and T3 using the Student's t test.

Parameter	T1-mm/ degrees(angles) (N=33)			T3 -mm/ degrees(angles) (N=33)			p value	95% confidence change T1 to T3
	Mean	SD	SEM	Mean	SD	SEM		
<u>Vertical</u>								
N	8.25	1.24	0.22	9.00	5.26	0.92	0.4120	(-)2.6 – 1.09
ANS	49.37	5.62	0.98	49.32	5.31	0.92	0.9329	(-)1.28 – 1.39
A	57.10	4.56	0.79	57.44	4.50	0.78	0.5942	(-)1.64 – 0.95
UIT	81.22	6.71	1.17	80.64	4.73	0.82	0.4991	(-)1.15 – 2.30
LIT	77.59	7.85	1.37	78.81	6.01	1.05	0.2533	(-)3.35 – 0.91
B	96.31	8.27	1.44	98.42	5.99	1.04	0.0425*	(-)4.15 – (-)0.08
Pog	111.71	9.77	1.70	113.17	7.32	1.27	0.2116	(-)3.80 – 0.87
Gn	117.73	10.12	1.76	118.96	7.63	1.33	0.3227	(-)3.70 – 1.26
Mn	116.02	21.21	3.69	120.15	7.83	1.36	0.2341	(-)11.06 – 2.80
Go (N=32)	86.50	9.35	1.65	81.56	16.97	2.99	0.0401*	0.24- 9.64
Sn	55.17	6.80	1.18	53.90	4.37	0.76	0.1392	(-)0.44 – 2.98
A'	62.03	5.80	1.01	61.85	4.58	0.80	0.7840	(-)1.12 – 1.47
Ls	68.42	12.72	2.21	70.21	5.25	0.91	0.4042	(-)6.13 – 2.53
St	79.30	7.41	1.29	78.35	5.17	0.90	0.3074	(-)0.92 – 2.83
Li	91.46	8.63	1.50	89.14	6.02	1.04	0.0493*	0.01 – 4.63
B'	95.63	8.65	1.51	97.13	6.38	1.11	0.1910	(-)3.79 – 0.79
Pog'	112.04	10.37	1.80	112.90	7.76	1.35	0.4973	(-)3.44 – 1.70
Gn'	123.47	10.77	1.87	124.69	7.78	1.35	0.3426	(-)3.81 – 1.36
Mn' (N=30)	127.35	11.10	1.93	128.51	7.97	1.39	0.3711	(-)3.75 – 1.44
<u>Angles</u>								
OPL	14.42	3.58	0.62	14.15	3.69	0.64	0.4191	(-)0.42 – 0.98
MPL	28.26	6.47	1.13	30.98	6.27	1.09	0.000 *	(-)3.80 – (-)1.66
LMF	253.32	14.52	2.53	231.42	10.69	1.86	0.000 *	18.39 – 25.40

*Change (T1-T3) significant at $p<0.05$

Statistically significant differences were noted within the T1 to T3 time periods at the following points in the horizontal dimension: lower incisor tip, hard tissue B point, pogonion, gnathion, menton, gonion, and soft tissue, labrale inferius, B point, pogonion, gnathion, menton. In the vertical dimension, statistically significant differences were noted at hard tissue B point and gonion and at soft tissue point labrale inferius. The angles that showed statistically significant changes included both the mandibular plane angle and the labiomental fold.

4.3.1.2 Simple ratios

Table 4.9 represents the relationships of the changes in corresponding soft and hard tissue points expressed as simple ratios. These ratios are displayed for those points that exhibited statistically significant differences within Tables 4.5 and 4.6.

Table 4.9 Simple ratios for the changes occurring in corresponding soft and hard tissue points that exhibited statistically significant differences between T1 and T3.

Parameter	Difference between mean measurements T3 to T1	Simple ratio
Horizontal		
Li :LIT	2.75: 4.09	0.67: 1
B’: B	4.02: 3.87	1.04: 1
Pog’: Pog	3.26: 3.51	0.93: 1
Gn’: Gn	3.46: 3.71	1.07: 1
Mn’: Mn	3.48: 3.36	1.03: 1

The simple soft: hard tissue ratio for the relationship for the response of the lower lip consequent to surgical advancement of the mandible was 0.67:1. The ratios for the soft tissue changes of the chin relative to the changes in the corresponding hard tissue points were 1.04:1 at B point, 0.93:1 at pogonion, 1.07:1 at gnathion and 1.03:1 at menton.

4.4 Regression analyses for results from time periods T1 to T3

4.4.1 Static variables

Multiple regression equations were developed relating the positions of all landmarks at T1 in both horizontal and vertical dimensions. The equation included the pre-surgical (T1) predictor variables such as overjet (O/J), overbite (O/B), lower lip substance (measured from Li to UIT and LIT) and tissue thickness measured at the base of the lower lip (B to B') (Tables 4.10 and 4.11).

In assessing the morphology of the lower lip, a method was devised which reflects the bulk of the lower lip as opposed to limiting the evaluation to the thickness only. The method incorporated two measurements which are combined to express more comprehensively the morphology of the lower lip. Thus, the substance rather than the thickness of the lower lip was assessed by calculating the lengths of two canted lines, firstly by joining UIT and Li and then from LIT to Li (Figure 4.2). On each line, a right angled triangle was constructed by extending the horizontal and vertical axes. The lengths of these adjacent sides of the triangle were computed by reference to their co-ordinates. The length of the canted line was calculated in a Pythagorean manner as it formed the hypotenuse of a right angled triangle. In this way, a single measurement reflected by the hypotenuse of the triangle was obtained using both horizontal and vertical components of each landmark. This was later subjected to statistical analysis for evaluation.

The lower lip substance (Li-UIT/LIT) was measured as the hypotenuse of a right angled triangle constructed from the horizontal and vertical distances from labrale inferius (Li) and the upper/lower incisor tips (UIT/LIT). The measurement of tissue thickness at the base of the lower lip (B to B') was also obtained from the construction of an hypotenuse of a right angled triangle, the adjacent sides of which were formed by the horizontal and vertical distances from soft tissue and hard tissue B point (B' to B). These measurements are illustrated in (Figures 4.1, 4.2 and 4.3).

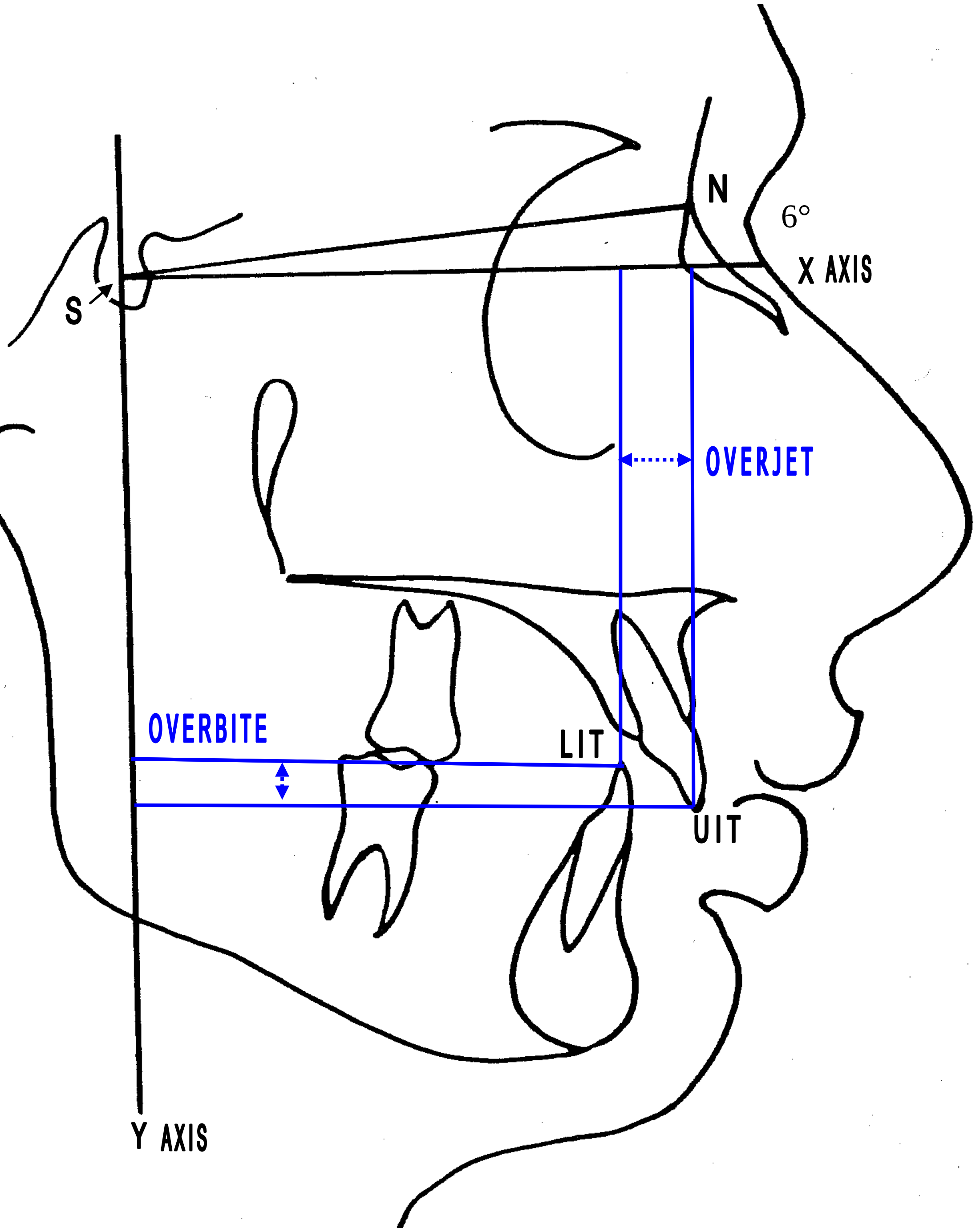


Figure 4.1 Measurement of pre-operative predictor variables of overjet (O/J) and overbite (O/B).

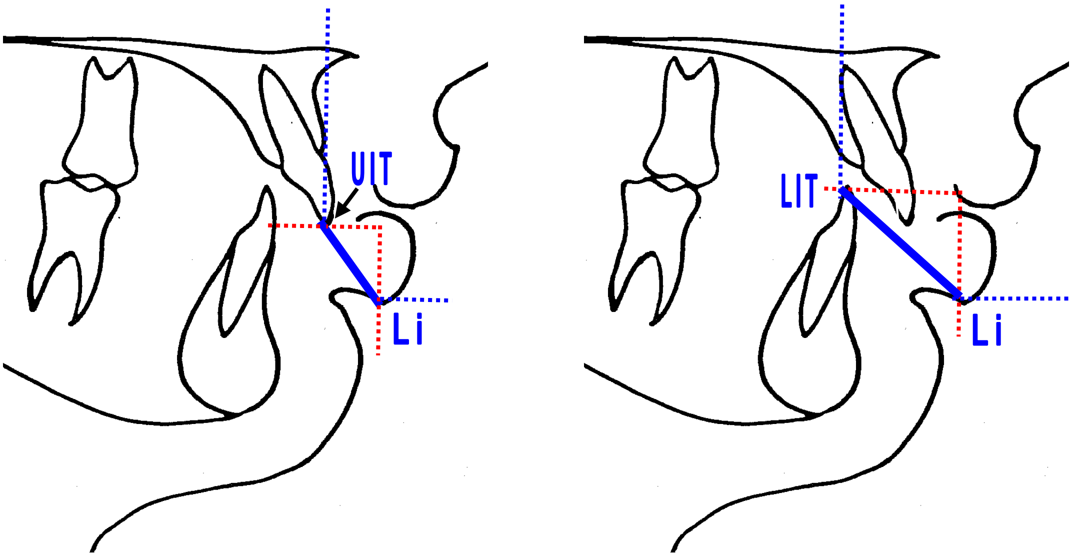


Figure 4.2 Measurements of lower lip substance (right angled triangles) determined by the horizontal and vertical co-ordinates of labrale inferius and the upper and lower incisor tips.

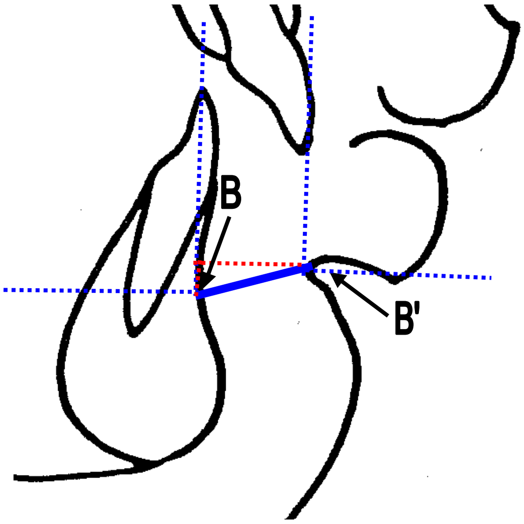


Figure 4.3 Measurement of tissue thickness measured at the base of lower lip also expressed as the hypotenuse of the triangle formed by the horizontal and vertical co-ordinates of hard to soft tissue B points.

Table 4.10 Multiple regression analyses for the changes in horizontal positions of all landmarks and angles at time period T1.

DEPENDENT VARIABLE (D)	CONSTANT	PREDICTOR VARIABLES CORRELATION COEFFICIENTS					CC R^2
		1st (D^1H)	2nd (O/J)	3rd (O/B)	4th (Li-UIT)	5th (B to B')	
N	-28.02	0.34	0.15	0.33	0.01	0.68	0.41
ANS	-26.77	0.28	0.11	0.35	0.04	0.27	0.32
A	-21.26	0.23	0.20	-0.04	0.06	0.18	0.28
UIT	-23.19	0.18	0.56	-0.08	0.07	0.40	0.39
LIT *	-23.82	0.21	-0.20	-0.11	0.14	0.39	0.28
B *	-13.73	0.11	0.05	-0.12	-0.03	0.27	0.08
Pog *	-12.81	0.11	0.00	-0.14	-0.18	0.38	0.06
Gn *	-12.13	0.10	-0.05	-0.13	-0.15	0.39	0.06
Mn *	-8.-13	0.10	-0.05	-0.15	-0.28	0.29	0.06
Go	-6.14	0.15	0.32	0.17	0.08	0.19	0.14
Sn	-28.84	0.19	0.61	-0.01	0.10	0.50	0.36
A'	-29.54	0.23	0.43	-0.04	0.63	0.47	0.40
Ls	-31.83	0.21	0.42	-0.03	0.24	0.57	0.4
St	-27.84	0.25	0.19	-0.15	-0.29	0.78	0.34
Li *	-28.79	0.21	0.18	-0.16	-0.20	0.75	0.27
B' *	-17.90	0.13	0.20	-0.13	-0.24	0.45	0.13
Pog' *	-16.45	0.14	0.05	-0.13	-0.14	0.32	0.09
Gn' *	-11.41	0.09	0.15	-0.16	-0.1	0.15	0.08
Mn' *	-4.41	0.10	0.15	-0.19	-0.02	0.01	0.05
OPL	-4.27	0.22	0.24	0.04	0.33	-0.38	0.32
MPL	-7.72	0.13	-0.11	0.12	0.04	0.09	0.16
LMF	-86.65	0.39	0.51	0.11	0.72	-0.38	0.5

* - statistically significant changes from T1-T3 ($p<0.05$) derived from Student's t tests
[1] - presurgery time period T1
CC - correlation coefficients (R^2)
D - dependent variable
O/J - overjet = ($UIT^1H – LIT^1H$) (Figure 4.1)
O/B - overbite = ($UIT^1V – LIT^1V$) (Figure 4.1)
Li-UIT -lower lip substance calculated by : $\sqrt{(Li^1H – UIT^1H)^2 + (Li^1V – UIT^1V)^2}$ (Figure 4.2)
B to B' - tissue thickness at the base of the lower lip calculated by: $\sqrt{(B'^1H – B^1H)^2 + (B'^1V – B^1V)^2}$ (Figure 4.3).

Table 4.11 Multiple regression analyses for the changes in vertical positions of all landmarks at time period T1.

DEPENDENT VARIABLE (D)	CONSTANT	PREDICTOR VARIABLE CORRELATION COEFFICIENTS 1ST (D^1V)	2nd (O/J)	3RD (O/B)	4th (Li-UIT)	5th (B to B')	R^2
N	(-)6.09	0.35	(-)0.27	(-)0.12	0.15	0.24	0.04
ANS	(-)17.94	0.17	0.27	0.08	0.37	0.18	0.27
A	(-)18.24	0.18	0.38	0.08	0.41	(-)0.06	0.29
UIT	(-)39.38	0.5	0.39	0.09	0.08	(-)0.38	0.56
LIT *	(-)38.25	0.5	0.51	(-)0.42	0.53	(-)0.37	0.71
B *	(-)48.45	0.5	0.48	0.08	(-)0.02	(-)0.42	0.53
Pog *	(-)50.84	0.48	0.46	0.13	(-)0.03	(-)0.63	0.5
Gn *	(-)53.82	0.47	0.58	0.17	(-)0.07	(-)0.57	0.5
Mn *	(-)85.64	0.93	0.15	0.15	(-)1.03	(-)1.15	0.9
Go	22.6	(-)0.38	0.77	0.32	0.82	(-)0.16	0.04
Sn	(-)16.92	0.41	0.25	(-)0.45	(-)0.03	(-)0.35	0.69
A'	(-)23.60	0.35	0.29	0.17	0.08	(-)0.12	0.45
Ls	(-)49.28	0.92	(-)0.24	0.19	(-)0.18	(-)0.98	0.87
St	(-)37.84	0.47	0.49	0.17	0.1	(-)0.29	0.58
Li *	(-)42.46	0.48	0.55	0.14	0.3	(-)0.58	0.58
B' *	(-)49.19	0.49	0.44	0.14	0.09	(-)0.32	0.5
Pog' *	(-)52.51	0.46	0.56	0.18	(-)0.04	(-)0.32	0.49
Gn' *	(-)57.77	0.48	0.43	0.14	(-)0.04	(-)0.48	0.52
Mn' *	(-)57.98	0.43	0.48	0.1	0.45	(-)0.24	0.51

* - statistically significant changes from T1-T3 ($p<0.05$) derived from Student's t tests
1 - presurgery time period T1
CC - correlation coefficients (R^2)
D - dependent variable
O/J - overjet = ($UIT^1H - LIT^1H$) (Figure 4.1)
O/B - overbite = ($UIT^1V - LIT^1V$) (Figure 4.1)
Li-UIT -lower lip substance calculated by: $\sqrt{(Li^1H - UIT^1H)^2 + (Li^1V - UIT^1V)^2}$ (Figure 4.2)
B to B' - tissue thickness at the base of the lower lip calculated by : $\sqrt{(B'^1H - B^1H)^2 + (B'^1V - B^1V)^2}$ (Figure 4.3).

The landmarks which recorded statistically significant changes in the Student's t tests (Tables 4.7 and 4.8) had very poor correlation values (R^2 values) when the multiple regression equations included the predictor variables of overjet, overbite, horizontal lip length and tissue thickness. This indicated that these predictors were not necessarily related to the dependent variables.

4.4.2 Dynamic variables

4.4.2.1 Simple regression analysis

A simple regression analysis (Table 4.12) was conducted to assess the strength of the relationships of the statistically significant ($p<0.05$) and clinically relevant landmarks of the lower lip and soft tissue chin in the horizontal and vertical planes as identified in the Student's t tests (Tables 4.7 and 4.8). These landmarks included labrale inferius, vertical and horizontal, and pogonion, horizontal.

Table 4.12 Simple regression analyses for the soft tissue points labrale inferius and pogonion.

DEPENDENT VARIABLE	CONSTANT (K)	PREDICTOR VARIABLES COEFFICIENTS	CC R^2
$\Delta Pog'H^{(1-3)}$	0.45	1.06 ($\Delta PogH^{1-3}$)	0.94
$\Delta LiH^{(3-1)}$	-1.63	1.07 (Δ $LITH^{3-1}$)	0.76
$\Delta LiV^{(3-1)}$	-3.22	0.74 (Δ $LITV^{3-1}$)	0.47

Δ - change in position from time periods T1 to T3
H - horizontal
V - vertical
^{1} - pre-surgical time period T1
^{3} - six months post-surgical time period T3
CC - correlation coefficients (R^2)

In the horizontal plane there was a very strong correlation between hard and soft tissue pogonion as reflected by the high R^2 value of 0.94. The relationship between the lower incisor tip and labrale inferius at R^2 = 0.76 was not nearly as strong as that of soft and hard tissue pogonion. In the vertical plane, there was a poor relationship between the vertical change in position of the lower incisor tip (LIT) and labrale inferius (Li) at only R^2 =0.47.

4.4.2.2 Multiple regression analysis

To further improve the predictability of the lower lip measured at labrale inferius (Li) in both horizontal and vertical planes, a multiple regression analysis was developed. The predictor variables included the changes in the lower incisor tip, hard tissue to soft tissue B point (B to B'), the protrusion of the lower lip ahead of the upper incisor (Li- UIT), and the thickness of the lower lip measured from Li to LIT (Table 4.13).

Table 4.13 Regression analyses for the soft tissue point labrale inferius.

DEPENDENT VARIABLE	CONSTANT (K)	PREDICTOR VARIABLES COEFFICIENTS			CC R^2
		1^{ST}	2^{nd} (B to B')	3^{rd} (Li-LIT)	
$\Delta LiH^{(3-1)}$	2.08	1.04 (Δ LIT-H^{3-1})	-0.29		0.77
$\Delta LiH^{(3-1)}$	1.85	1.06 (Δ LIT-H^{3-1})		-0.166	0.77
$\Delta LiH^{(3-1)}$	4.97	1.03 (Δ LIT-H^{3-1})	-0.26	-0.15	0.78
$\Delta LiV^{(1-3)}$	7.56	0.77 (Δ LIT-V^{1-3})	-0.34		0.48
$\Delta LiV^{(3-1)}$	15.03	0.65 (Δ LIT-V^{3-1})		-0.88	0.61
$\Delta LiV^{(3-1)}$	10.13	0.68 (Δ LIT-V^{3-1})	-0.89	0.89	0.62

Δ - change in position from time periods T1 to T3
H - horizontal
V - vertical
^{1} - pre-surgical time period T1
^{3} - six months post-surgical time period T3
CC - correlation coefficients (R^2)
Li-LIT - lower lip substance calculated by: $\sqrt{(Li^1H - LIT^1H)^2 + (Li^1V - LIT^1V)^2}$
B to B' - tissue thickness measured at the base of the lower lip calculated by:
$\sqrt{(B'^1H - B^1H)^2 + (B'^1V - B^1V)^2}$

The change in the lower lip at labrale inferius (Li) was reasonably closely correlated to the change in position of the lower incisor tip (ΔLIT) at a value of R^2 =0.76 (Table 4.12). When the variables of B to B', and Li-LIT were added to the regression analysis, the improvement of the correlation was minimal in the horizontal dimension (R^2=0.76 changed to 0.78) (Table 4.13). The correlation improved slightly more in the vertical dimension, although the final correlations were still inadequate (R^2=0.47 changed to 0.62).

These regression analyses indicated that the change in position of the underlying hard tissue structures is more relevant to prediction of the corresponding post-surgical position of the soft tissue than is the pre-surgical thickness of the soft tissue (B to B') and the lower lip (Li-LIT). Hence, there was a need to identify other factors that may more definitively have contributed to the prediction of the soft tissue changes of the lower lip.

4.5 Stepwise regression analyses

Further investigations using stepwise regression analysis, were subsequently undertaken to determine precisely which variables played an influential role in the prediction of the horizontal and vertical soft tissue changes of the lower lip and chin associated with the surgical advancement of the mandible. The paired Student's t tests (Tables 4.7 and 4.8) identified the statistically significant and clinically relevant hard and soft tissue changes in the horizontal and vertical planes. The significance of the p values was now broadened so as to allow a more liberal entry of independent variables into the initial pool of predictor variables than only those that initially exhibited statistical significance at $p<0.05$ (Tables 4.7 and 4.8). The variables resulting from this more liberal interpretation are listed below:

i) Stomion (ΔSt)- pre-post-operative difference

ii) Stomion (St^1H)- horizontal (pre-surgical)

iii) Stomion (St^1V) - vertical (pre-surgical)

iv) Upper incisor tip (UIT^1H)- horizontal (pre-surgical)

v) Lower incisor tip (ΔLITH)- horizontal; pre to post-operative difference

vi) Hard tissue B point (ΔBH)- horizontal; pre to post-operative difference

vii) Hard tissue Pogonion (ΔPogH)- horizontal; pre to post-operative difference

viii) Hard tissue Gnathion (ΔGnH)- horizontal; pre to post-operative difference

ix) Hard tissue Menton (ΔMnH)- horizontal; pre to post-operative difference

x) Upper incisor tip (UIT^{1}V) - vertical; pre-surgical

xi) Lower incisor tip (ΔLITV)- vertical; pre to post-operative difference

xii) Hard tissue B point-(ΔBV) vertical; pre to post-operative difference

xiii) Hard tissue Pogonion (ΔPogV)- vertical; pre to post-operative difference

xiv) Hard tissue Gnathion (ΔGnV)- vertical; pre to post-operative difference

xv) Hard tissue Menton (ΔMnV)- vertical; pre to post-operative difference.

Four parameters were selected as dependent variables having been identified as those most closely related to the areas of interest, i.e. stomion (St), labrale inferius (Li), soft tissue B point (B') and soft tissue pogonion (Pog').

A stepwise regression analysis was then performed to determine the effect of the independent variables on the predictability of the soft tissue response as measured by the dependent variables in the lower lip and chin areas (Tables 4.14 and 4.15).

Table 4.14 Stepwise regression analyses of the various predictor (independent) variables for the soft tissue dependent variables.

Dependent variables	R^2	Constant (K)	PREDICTOR VARIABLES (COEFFICIENTS) 1st	2nd	3rd	4th	5th	6th	
Δ Horizontal									
Stomion	0.89	5.75	-0.07 (St^1H)	0.31(St^1V)	-0.34(UIT^1V)	0.14(ΔPogV)	0.13(ΔBH)	0.12(ΔLITV)	
Li	0.94	1.52	-0.36 (Li^1H)	0.36(ΔBV)	0.36(UIT^1H)	0.29(ΔGnH)	0.60(ΔBH)		
B’	0.94	0.43	0.32 (ΔBH)	0.22(ΔBV)	0.55(ΔMnH)				
Pogonion’	0.97	-1.13	0.11 (ΔBV)	0.53(ΔMnH)	0.62(ΔBH)				
Δ Vertical									
Stomion	0.94	1.5	-0.26(St^1H)	-0.46(St^1V)	0.23(UIT^1H)	0.38(ΔBV)	0.49(UIT^1V)	0.5(ΔPogV)	0.4(ΔMnV)
Li	0.90	-8.61	0.65(UIT^1V)	-0.53(Li^1V)	0.62(ΔBV)	0.35(ΔPogV)			
B’	0.95	-4.52	0.34(UIT^1V)	-0.25(B'^1V)	-0.53(ΔMnH)	0.44(ΔPogV)	0.6(ΔBH)	0.47(ΔBV)	
Pogonion’	0.97	-5.41	0.76(ΔBV)	-0.14(Pog'^1V)	1.6(ΔPogV)	-0.19(ΔLITV)	0.24(ΔBH)	–1.05(ΔGnV)	0.22(UIT^1V)

$p_{e\ (entry)} < 0.1$; $p_{r(remove)} < 0.15$
Δ - change in position of landmark between time periods T3 to T1
^{1} - pre-surgical time period T1
^{3} - six months post-surgical time period T3
H - horizontal measurement of landmark
V - vertical measurement of landmark

The stepwise regression analysis for these four points yielded up to a maximum of seven predictor variables with high correlation coefficients (R^2 values) ranging from 0.89 (stomion) to 0.97 (pogonion) in the horizontal dimension, and from 0.90 (labrale inferius) to 0.97 (pogonion) in the vertical dimension. In order to reduce the complexity of these equations, only thos variables which had recorded a p value between 0.05 and 0.1, i.e. $p_{e(entry)} < 0.05$; $p_{r(remove)} < 0.1$. Effectively, this meant that only those variables that contributed most significantly to the resultant correlations with the soft tissue variables were included in the equation.

Table 4.15 Stepwise multiple regression analyses of the predictor variables for the soft tissue dependent variables with "tightened" p values ($p_{e\ (entry)} < 0.05$; $p_{r\ (remove)} < 0.1$).

			PREDICTOR VARIABLES (COEFFICIENTS)				
Dependent variables	R^2	Constant (K)	1st	2nd	3rd	4th	5th
Horizontal							
Stomion	0.87	2.4	-0.07(St^1H)	0.83(ΔBH)	0.21(ΔPogV)		
Li	0.93	1.43	-0.39(Li^1H)	0.32(ΔBV)	0.40(UIT^1H)	0.91(ΔBH)	
Pogonion'	0.97	-1.13	0.11(ΔBV)	0.53(ΔMnH)	0.62(ΔBH)		
Vertical							
Stomion	0.92	0.34	-0.34(ΔPogV)	-0.55(St^1V)	0.56(UIT^1V)	0.47(ΔBV)	
Li	0.89	-8.86	0.66(UIT^1V)	-0.54(Li^1V)	1.01(ΔBV)		
Pogonion'	0.96	-2.5	0.74(ΔBV)	-1.3(ΔGnV)	1.8(ΔPogV)	-0.2(ΔLITV)	0.24(ΔBH)

$p_{e\ (entry)} < 0.05$; $p_{r\ (remove)} < 0.1$
Δ - change in position of landmark between time periods T3 to T1
^{1} - pre-surgical time period T1
^{3} - six months post-surgical time period T3
H - horizontal measurement of landmark
V - vertical measurement of landmark

This "tightening" of the p values allowed fewer variables into each equation with a minimal reduction in correlation coefficient. The R^2 values ranged from 0.87 (stomion) to 0.97 (pogonion) in the horizontal dimension, and from 0.89 (labrale inferius) to 0.96 (pogonion) in the vertical dimension. This allowed for a more concise equation disregarding extraneous variables which did not offer any significant contribution to the prediction of the post-operative position of the dependent variable.

The final equations including the four variables identified for the prediction of soft tissue points of labrale inferius and pogonion, in both the horizontal and vertical dimensions, was established as follows:

Li (H): R^2 (0.93) = (K) 1.43 + -0.39(Li^1H) + 0.32(ΔBV) + 0.40(UIT^1H) + 0.91(ΔBH)

Li (V): R^2 (0.89) = (K) -8.86 + -0.66(UIT^1H) -0.54(Li^1V) + 1.01(ΔBV)

Pog (H): R^2 (0.97) = (K) -1.13 + 0.11(ΔBV) + 0.53(ΔMnH) + 0.62(ΔBH)

Pog (V): R^2 (0.96) = (K) -2.5 + 0.74(ΔBV) – 1.3(ΔGnV)+1.8($\Delta PogV$)- 0.2($\Delta LITV$) +0.24(ΔBH).

4.6 Cross validation of regression equations

A cross-validation analysis of the stepwise regression equation for the change in position of labrale inferius in both horizontal and vertical dimensions was performed in order to assess the validity of the equation on an independent member of the sample (Table 4.16).

Table 4.16 Cross validation included in the stepwise regression equation for point labrale inferius in the horizontal and vertical dimensions ($p_e < 0.05$; $p_r < 0.1$).

PREDICTOR VARIABLES							
Dependent variable	R^2	Constant	1st	2nd	3rd	4th	Cross validation R^2
ΔHorizontal							
Li	0.93	1.43	-0.39(Li^1-H)	0.32(ΔB-V)	0.40(UIT^1-H)	0.91(ΔB-H)	0.90
ΔVertical							
Li	0.89	-8.86	0.66(UIT^1-V)	-0.54(Li^1-V)	1.01(ΔB-V)		0.85

$p_e < 0.05$; $p_r < 0.1$
Δ - change in position of the landmark from between time periods T1 to T3
^{1} - pre-surgical time period T1
^{3} - six months post-surgical time period T3
H - horizontal measurement of landmark
V - vertical measurement of landmark

The R^2 values for the cross validation indicated a high correlation between the predicted and the observed values within the sample. Cross validation was effected by removing from the overall data set those values recorded for a particular patient, and using the remaining group of data to devise a prediction equation. This was then applied to forecast the values which may have been expected for the patient whose data had been omitted. This procedure was followed sequentially for all patients in the sample. The predicted values could now be compared with the actual values. This procedure resulted in a proven accuracy of R^2=0.93 in the horizontal dimension and R^2=0.89 in the vertical dimension.

CHAPTER FIVE: DISCUSSION

Successful treatment of a non-growing patient presenting with a Class II Division 1 malocclusion due to mandibular deficiency requires a precise diagnosis, a detailed treatment planning process and a well synchronized orthognathic treatment procedure. An important step in this meticulous process is the prediction of the reaction of the soft tissue drape following mandibular advancement surgery.

In this retrospective study, 39 patients who required mandibular advancement surgery were selected on the basis of there being no surgical procedures in addition to the mandibular advancement. This total was reduced to a final sample of 33 patients due to some radiographs having being taken outside the required time period. All the patients in this group were treated with the same orthodontic fixed appliances prior to the surgery which were still present at the time period T3 when the soft tissues were analysed post operatively. Hence any influence exerted by the presence of the brackets would have been consistent pre- and post surgery. The cephalometric records were obtained by the same operator with standardized radiographic methods. The method followed in this study was aimed at satisfying as many of the twenty- three criteria as defined by Betts and Fonseca (1992).

The changes of the face in this study included increases in lower facial height and the mandibular plane angle, associated with the clockwise rotation of the mandible which occurred when, at surgery, the lower incisor teeth were optimally positioned relative to the upper incisors by the surgeon. The soft tissue of the lower lip responded by thinning and lengthening with subsequent reduction of the labiomental fold (Tables 4.5 and 4.6).

A paired Student's t test compared the positional changes of each landmark for the time period T1 to T3 in horizontal and vertical dimensions, and identified those landmarks that exhibited statistically significant changes. These landmarks were the subject of further statistical analysis.

The means of the differences of the changes of clinically relevant corresponding landmarks were expressed in terms of simple ratios. The lower lip responded at a ratio of 0.67:1 in relation to the movement of the lower incisor tip, which is less than previously reported by Talbot- 0.85:1 (1975), Ewing and Ross-0.80:1 (1992), Veltkamp et al-0.79:1 (2002), and McCollum et al-0.77:1 (2009). In most cases in this study, the mandible was advanced in a downward and forward direction in order to reduce the deep overbite, whilst in the studies by McCollum et al (2009), and Veltkamp et al (2002), the cases had more horizontal movement and less vertical change. In the studies by Ewing and Ross' (1992) and Veltkamp et al (2002), many of the cases were associated with maxillary surgical impaction. In such cases, the mandible auto-rotates in an anti-clockwise direction and is then surgically advanced to reduce the overjet. This surgical movement of the mandible was mostly horizontal in the cases reported. Hence, the higher ratios of 0.85:1 and 0.79:1 respectively.

In this study, the chin at soft tissue pogonion reacted at a ratio of 0.94:1 relative to the underlying hard tissue pogonion (Table 4.9). This value was closely in keeping with past reported ratios as noted by Quast and Biggerstaff (1983) and Mommaerts and Marxer (1987) who both reported ratios of 0.97:1, Hernandez-Orsini et al (1993) at 0.93:1, Veltkamp et al (2002) at 0.92:1 and McCollum et al (2009) at 1:1.

The static horizontal and vertical dependent landmarks were regressed with static predictor variables which included the overjet, the overbite, tissue thickness measured at the base of the lower lip (B to B'), and soft tissue measurements of lower lip substance (Li-UIT). The application of Pythagorean analysis in the estimation of the lower lip substance enabled accurate calculation of the length of the inclined lines.

Very poor correlations for the soft tissue lip and chin landmarks were obtained (R^2 =0.05 to 0.58), which indicated that the analysis of the pre-operative static variables had little role to play in the prediction of the soft tissue change (Tables 4.10 and 4.11).

A simple regression analysis (Table 4.12) involving the changes of the statistically significant ($p<0.05$) and clinically relevant corresponding hard and soft tissue points in the horizontal and vertical dimensions (Tables 4.10.and 4.11) was undertaken. The results indicated a strong correlation of R^2 =0.94 for soft tissue pogonion, and a moderate correlation of R^2 =0.74 for the lower lip (Li-LIT) soft tissue relationship. These values were in agreement with Mommaerts and Marxer (1987), Mobarak et al (2001), Veltkamp et al (2002), and McCollum et al (2009). However, Quast and Biggerstaff (1983) reported a stronger correlation at R^2=0.89.

To further improve the prediction of the lower lip and soft tissue chin response to mandibular advancement, a multiple regression analysis was undertaken. The selections for inclusion of static and dynamic variables were derived from previous studies by Lines and Steinhauser, 1974; Quast and Biggerstaff, 1983; Mommaerts and Marxer, 1987; Mobarak et al, 2001; Veltkamp et al, 2002; McCollum et al, 2009). The static variables included the horizontal thickness of the lower lip (Li- LIT), the thickness at the base of the lower lip (B to B') and the protrusion of the lower lip ahead of the upper incisor tip (Li-UIT). The dynamic changes included the change in the position of the lower incisor tip (ΔLIT^{3-1}). The findings revealed only a minimal improvement in the correlation from R^2=0.76 to R^2=0.78. These observations were similar to the reports of Kneafsey et al (2008) and McCollum et al (2009).

Therefore, it might be assumed that other unidentified factors play a role in the accurate prediction or calculation of the lower lip response for the individual patient. A stepwise regression analysis (Table 4.14) was applied to the paired Student's t tests which compared the positional changes of the various landmarks (Tables 4.10 and 4.11). The significance of the p values was first broadened ($p_{e\ (entry)} < 0.1$; $p_{r\ (remove)} < 0.15$) which allowed fifteen independent variables to be incorporated into the stepwise regression analysis. In order to reduce the complexity of the number of predictors involved in each equation, the significance of the p values was then "tightened" such that only those variables with the greatest contribution to the correlation remained ($p_{e\ (entry)}<0.05$;$p_{r\ (remove)}<0.1$). This series of analyses identified the predictor variables that played a highly significant role in the prediction of the change in labrale inferius in the horizontal dimension (R^2=0.93). These were the pre-surgical position of labrale inferius ($Li\text{-}H^1$), the change in B vertical (ΔB-V), the horizontal pre-surgical position of the upper incisor tip (UIT^1-H), the change in gnathion horizontal (ΔGn-H), and the change in B point horizontal (ΔB-H). In the vertical dimension, the post-operative position of labrale inferius was predicted by the vertical positions of the upper incisor tip (UIT^1-V), labrale inferius (Li^1-V), the change in position of B point (ΔB-V) and pogonion (ΔPog-V) (R^2=0.89: Table 4.15). All the other dependent variables, i.e. stomion (St), soft tissue B point (B') and pogonion (Pog) had very high correlation coefficients in both horizontal and vertical planes (Table 4.15).

This study has identified the position of the upper incisor tip (UIT) as a significant factor in predicting both the horizontal and vertical response of the soft tissue of the lower lip. A pertinent implication of this observation is that it substantiates the philosophy of relying on the upper incisor position as the focal point of the visual treatment objective (McCollum, 2001)The change in position of B point in either the horizontal and vertical positions featured as a major contributory variable (Tables 4.14 and 4.15). This observation was also reported by Veltkamp et al (2002). Both changes result in a favourable response of the lower lip.

A cross validation analysis of the prediction equations for labrale inferius was performed to assess the accuracy of these equations. The results showed that the equations were highly reliable with R^2 values of 0.90 and 0.85 in the horizontal and vertical planes respectively. Kneafsey et al (2008) reported similar high cross validation correlations even though their cross validation sample included only five subjects.

This study has identified the variables that are essential in predicting the position of the lower lip and chin consequent to the surgical advancement of the mandible within a Caucasian population where a deficient mandible and associated Class II malocclusion is most common. This study has refined and improved the understanding of the soft tissue response of the lower lip consequent to the surgical advancement of the mandible. Some studies where the post-surgical time interval was especially long reported a poorer response of the lower lip (Quast and Biggerstaff, 1983 (0.38:1); Mommaerts and Marxer, 1987 (0.55:1); Dermaut and De Smit, 1989 (0.26:1); Mobarak et al, 2001 (0.60:1) which may be related to surgical relapse of the mandible, but also perhaps due to the advancement of the mandible having a strong vertical component in order to correct the deep overbite.

It may be in the combination of the horizontal and the vertical changes that an explanation of the response of the lower lip may be found. Statistically significant changes were recorded in the horizontal dimension for hard tissue points lower incisor tip (LIT), B point (B), pogonion (Pog), gnathion (Gn) and menton (Mn), but for only hard tissue B point (B) in the vertical dimension. In general, horizontal changes approximated four millimeters (4mm), whilst vertical changes were less at about two millimeters (2mm). The lower lip therefore benefitted from greater antero-posterior support from the lower incisor, whilst the admittedly smaller vertical changes contributed to a relative lengthening of this lip. These effects result in a thinning of the tissues and a reduction of the labiomental fold (Tables 4.7 and 4.8). Had pogonion advanced more than hard tissue B point, further vertical support may have been offered to the lower lip. However, this data indicates that an average horizontal relationship between these points remained relatively constant. Hence it may be assumed that even small vertical changes are an important contribution to the improvement in the contour of the lower lip consequent to the surgical advancement of the mandible.

This study found that the thickness of the soft tissue alone was insufficient in explaining the prediction of the lower lip response, confirming the findings of McCollum et al (2009). In contrast, Kneafsey et al (2008), using a multivariate regression analysis, found strong predictability (Li-H: adjusted R^2=0.96) when the post operative positions of stomion and labrale inferius and the horizontal soft tissue thickness (LIT-Li) were included in the equations.

Variables such as tissue tonicity and habits have not been accounted for in the calculation of the predicted position of the lower lip and chin as they are difficult to quantify. This study has shown that it is nevertheless possible to predict very accurately the final position of the lower lip and chin consequent to the surgical advancement of the mandible. Despite the complexity of these equations, they may be of great benefit within the technological advancements in the computer software programmes used in treatment planning.

CHAPTER SIX: CONCLUSIONS

This retrospective study of the soft tissue changes of the lower lip and chin consequent to the surgical advancement of the mandible showed that:

i) The factors that played a most significant role in predicting the horizontal and vertical post-surgical positions of the lower lip included the pre-surgical position of the lower lip itself, the upper incisor tip, and the pre-to post-surgical change in position of B point.

ii) The factors that played a most significant role in predicting the horizontal and vertical post-surgical positions of the chin include the pre-to post- surgical positions of B point, menton, gnathion, pogonion and the lower incisor tip.

iii) Prediction equations for the post-surgical positions of the lower lip and chin were formulated to enable a precise forecast of the soft tissue changes.

iv) The pre-surgical position of the upper incisor tip and the pre- to post-surgical positions of hard tissue B point featured as prominent variables in the prediction equations, emphasizing the effect of any orthodontic and surgical alterations in this area on the soft tissues of the lower lip and chin.

v) The complexity of these prediction equations render them appropriate for a computer software programme.

APPENDICES

APPENDIX A: Index of abbreviations used in text and tables

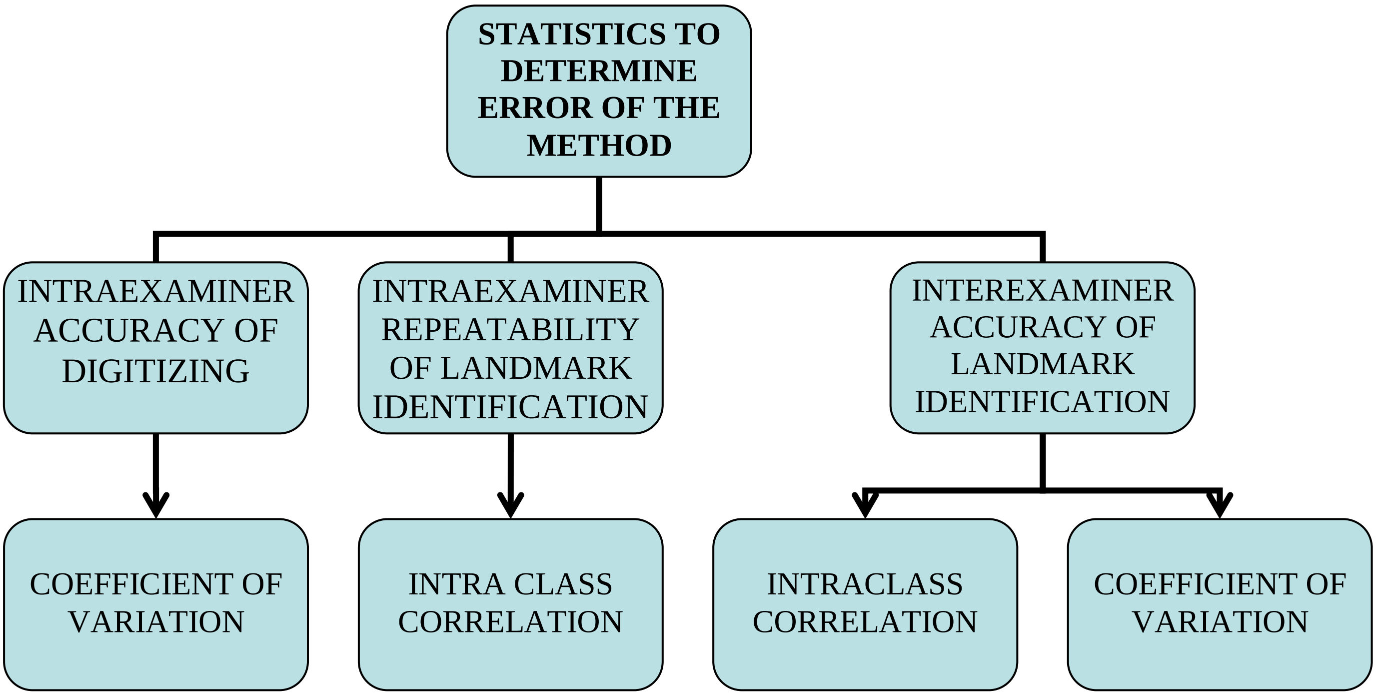
Δ	change
<	less than
>	greater than
*	statistically significant
√	square root
^{1}	presurgery (T1)
^{3}	six months post treatment (T3)
A	hard tissue A point
A’	soft tissue A point
ANS	anterior nasal spine
ANOVA	analysis of variance
B	hard tissue B point
B’	soft tissue B point
CoD	coefficient of determination
CONF	confidence
CV	coefficient of variation
D	dependent variable
D^1H	preoperative position of the dependent variable in the horizontal dimension
D^1V	preoperative position of the dependent variable in the vertical dimension
F	female
ICC	intraclass correlation coefficient
Gn	hard tissue gnathion

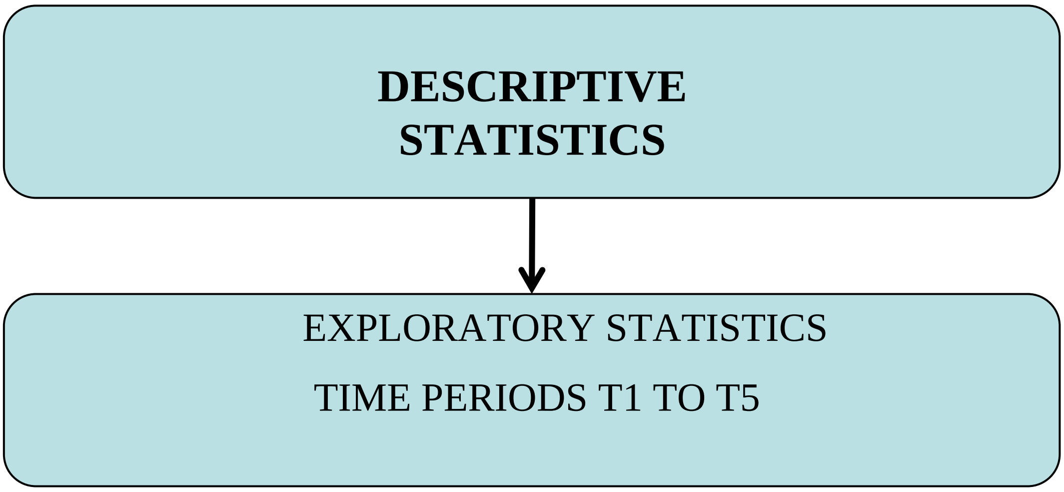
Gn’	soft tissue gnathion
Go	gonion
Go-Gn	gonion- gnathion line
H/h	horizontal
i.e.	that is
Li	labrale inferius
LIT	lower incisor tip
L/MARK	landmark
Ls	labrale superius
M	male
Me	hard tissue menton
Me’	soft tissue menton
n	number of patients in the sample
N	nasion
N-Me	nasion-menton
N-Pog	nasion-pogonion line
O/J	overjet
O/B	overbite
p	p value
$p_{e\ (entry)}$	entry values of p
$p_{r\ (remove)}$	exit values of p
Pog	hard tissue pogonion
Pog’	soft tissue pogonion
PT	patient
r	Pearson correlation coefficient

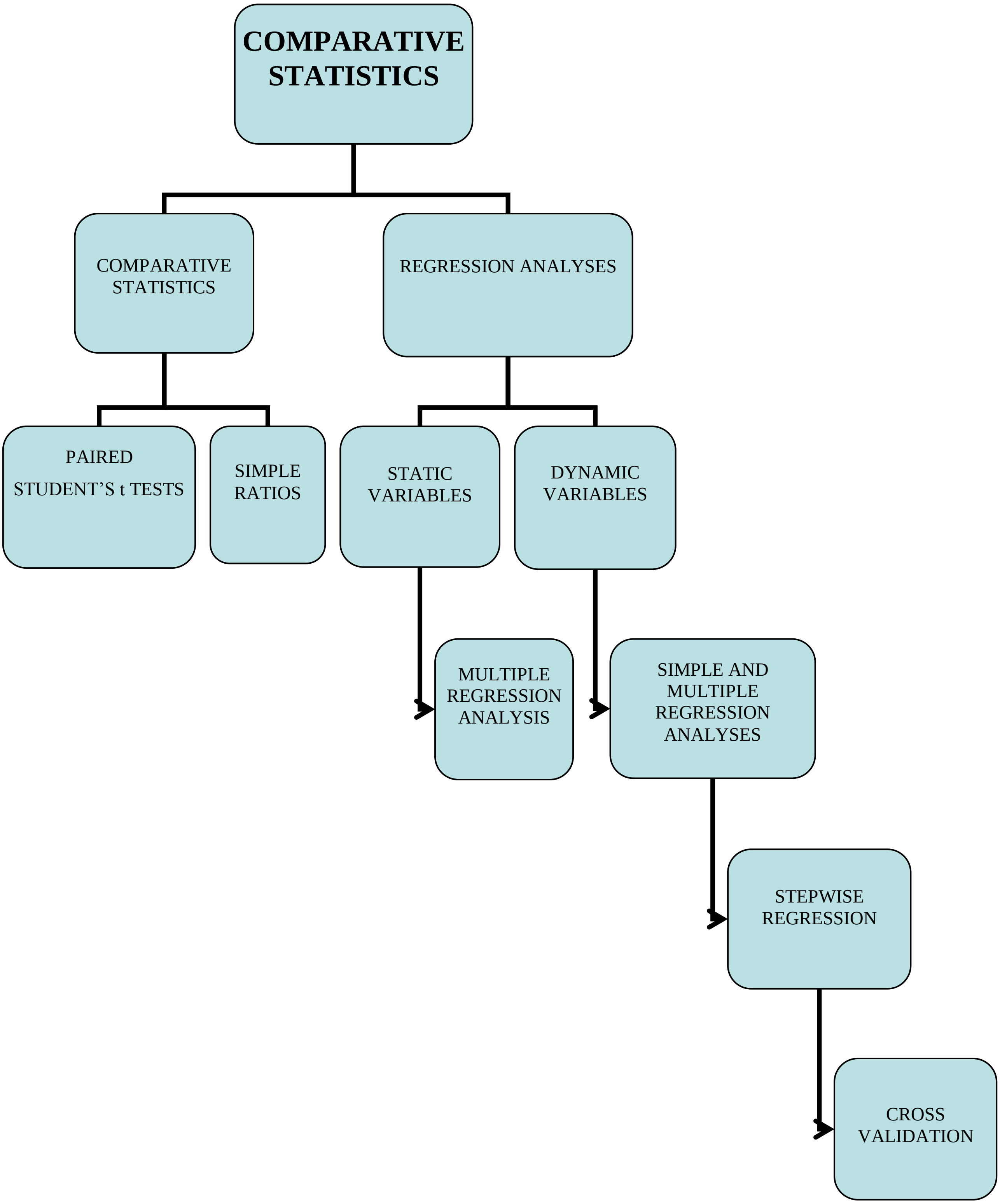
r_i	intraclass correlation coefficient
R^2	correlation coefficient
Sn	Subnasale
St	stomion
S	sella
Sn	soft tissue subnasale
S-N	sella-nasion plane
SD	standard deviation
SEE	standard error of the estimate
SEM	standard error of the mean
TEM	technical measurement error
TT	tissue thickness
T1	pre-operative time period
T2	six weeks post-operative time period
T3	six months post-operative time period
T4	one year post-operative time period
T5	longest post-operative time period
UIT	upper incisor tip
V/v	vertical
X	X reference axis
Y	Y reference axis
X-Y	X-Y co-ordinate axis

B/ APPENDIX

SUMMARY OF STATISTICS






COMPARATIVE STATISTICS
COMPARATIVE STATISTICS
REGRESSION ANALYSES
PAIRED
STUDENT'S t TESTS
SIMPLE RATIOS
STATIC VARIABLES
DYNAMIC VARIABLES
MULTIPLE REGRESSION ANALYSIS
SIMPLE AND MULTIPLE REGRESSION ANALYSES
STEPWISE REGRESSION
CROSS VALIDATION

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