CHAPTER 1: INTRODUCTION

'The study of orthodontia is indissolubly connected with that of art as related to the human face. The mouth is a most potent factor in making or marring the beauty and character of the face.'

Angle, 1907.

An excessive increase in lower anterior facial height, often called the 'long-face syndrome', was first described by Schendel, Eisenfeld, Bell, Epker and Mishelevich in 1976. The pathognomonic features of this dentofacial deformity include a large interlabial gap, increased exposure of the upper incisor teeth beneath the relaxed upper lip, a 'gummy' smile and strain of the lips on closure. Furthermore, this dentofacial deformity may or may not be associated with an open bite.

The treatment of these patients requires the combined skills of the orthodontist and the maxillofacial surgeon. Other disciplines such as periodontics, prosthodontics, otorhinolaryngology, plastic surgery, psychology and even speech therapy may also be involved. With such multidisciplinary involvement, the goals of excellent function, stability and aesthetics can be achieved.

In the first phase of treatment of this condition the teeth are orthodontically aligned. This is followed by surgical elevation of the maxilla with subsequent anticlockwise rotation of the mandible. Once healing has occurred, post-surgical orthodontics continues to the completion of treatment.

Following any surgical movement of the jaws, there is a concomitant soft-tissue change which does not necessarily correlate directly with the hard-tissue movement. With maxillary advancement surgery the reaction of the soft-tissues to the anteroposterior movement of the maxilla has been well documented (Dann, Fonseca and Bell, 1976; Freihofer, 1976, 1977; Araujo, Schendel, Wolford and Epker, 1978; Teuscher and Sailer, 1982; Carlotti, Aschaffenburg and Schendel, 1986; Stella, Streater, Epker and Sinn, 1989; Hui, Hagg and Tideman, 1994; Dancaster, 1999). The mid-facial soft-tissue changes following superior repositioning of the maxilla have, likewise, been studied by Bell and Dann, 1973; Schendel, Eisenfeld, Bell and Epker, 1976; Radney and Jacobs, 1981; Mansour, Burstone and Legan, 1983; and, Rosen, 1988. Only three of the above reports (Schendel et al, 1976; Radney and Jacobs, 1981; Mansour et al, 1983) however, mention lower lip and soft-tissue chin changes as a consequence of mandibular autorotation following vertical maxillary impaction.

It is essential for the orthodontist and the surgeon to have a complete understanding of the soft-tissue changes resulting from a given surgical procedure in order to accurately forecast the expected post-surgical profile changes.

The purpose of this investigation was to study the soft-tissue changes occurring in the lower lip and chin areas in the sagittal plane following vertical maxillary impaction and the consequent mandibular autorotation. This information may provide relevant data to enhance the treatment planning and forecasting process.

CHAPTER 2: LITERATURE REVIEW

This study is concerned with the dentoskeletal deformity commonly described as 'vertical maxillary excess' or the 'long-face syndrome' which is frequently associated with hyperdivergent or 'high-angle' Class II malocclusions. Vertical maxillary excess or long-face syndrome presents certain pathognomonic features which have been described by numerous authors (Schendel et al, 1976; Fish, Wolford and Epker, 1978; Bell and Proffit, 1980; Wolford and Hilliard, 1981; Schendel and Williamson, 1983). These include:

1) narrow nose with a prominent nasal dorsum and narrow alar bases;
2) depressed nasolabial areas;
3) normal to obtuse nasolabial angle;
4) excessive exposure of maxillary anterior teeth and gingiva with the lips in repose and upon smiling ('gummy' smile);
5) possible presence of a dental anterior open bite;
6) hyperfunction of the mentalis muscle with eversion of the lower lip;
7) lip incompetence;
8) large interlabial distance;
9) retropositioned chin due to clockwise or opening rotation of the mandible; and
10) increased lower anterior facial height.

Patients with these features often have convex facial profiles and leptoprosopic facial morphological patterns.

Goldsmith, Berkman, Rothschild, Shprintzen and Trieger (1980) conducted oral and cephalometric evaluations of patients presenting with this dentofacial deformity. Their intra-oral analyses most often revealed the presence of a Class II malocclusion with a high, constricted palatal vault, upright and crowded anterior teeth, an accentuated curve of occlusion, and cross-bite tendencies, particularly in the open-bite cases. Their cephalometric investigations revealed an increased skeletal- and soft-tissue ratio of lower facial height to middle facial height, increased distance between the root apices and the nasal floor, as well as a steep mandibular plane. Furthermore, the maxilla was usually in a normal anteroposterior position, while the mandible was usually retropositioned.

Solow and Kreiborg (1977) hypothesized that the increased facial height observed in these patients may cause stretching and tightening of the related soft tissues thus exerting greater lip pressures against the incisor teeth. This could result in their assuming more upright positions.

Schudy (1964) and Creekmore (1967) observed a tendency toward continued unfavourable vertical growth in patients with increased anterior facial height. Consequently, following conventional orthodontic treatment, these patients frequently are left with compromised facial aesthetics. However, Schudy and Creekmore predicted that comprehensive orthognathic treatment of Class II and open-bite malocclusions designed to decrease vertical facial height and improve facial proportions could result in not only functional occlusion but also in facial harmony.

Before the 1970's, all severe malocclusions requiring surgical correction were primarily treated with mandibular setback or advancement osteotomy regardless of whether the maxilla or mandible was at fault. Maxillary surgery was considered to be too dangerous due to the possibility of severance of the blood supply to the bone and teeth during the surgical procedure. This posed a significant problem when planning treatment for patients presenting with deformities primarily involving the maxilla as found in the ‘long-face syndrome’.

The down-fracturing technique of the maxillary osteotomy at the Le Fort 1 level was first described and documented by Obwegeser (1969), and then by Bell (1975), although a similar operation had been performed as early as 1867 by Cheever (Moloney and Worthington, 1981). Since the early 1970’s, the maxilla has been routinely surgically advanced, retracted, elevated, narrowed and expanded in the correction of complex dentofacial problems.

The Le Fort 1 osteotomy has been shown by various authors to be a reliable procedure for the correction of vertical maxillary excess, with well-documented long-term stability (Schendel et al, 1976; Bell and Proffit, 1980). With this procedure, superior repositioning of the maxilla reduces the overexposure of the maxillary incisors beneath the relaxed upper lip. In addition, the accompanying autorotation of the mandible leads to relaxation of the musculature of the lips and cheeks (Proffit and Phillips, 1988). Mandibular autorotation alone, however, may not be sufficient to correct the contour-deficient chin which is often associated with these Class II and open-bite malocclusions. For this reason, Bell and Dann (1973) suggested that vertical maxillary impaction should be accompanied by a genioplasty when necessary, which would allow latitude in planning the correction of such dentofacial deformities with post-treatment facial convexity improvement.

The soft-tissue changes of the upper lip that occur with maxillary retraction, advancement and elevation are well documented.

Lines and Steinhauser (1974) assessed the soft-tissue response in maxillary set-back surgery and found that the soft tissue followed the upper incisor in a ratio ranging from 1:2 to 1:3. These authors suggested that the soft tissue of the maxilla was prevented from following the hard tissue in the same 1:1 relationship as occurs in the mandible due to its firm connection to the base of the nose.

The findings of the studies that examined the soft-tissue changes associated with total maxillary advancement (Dann et al, 1976; Freihofer, 1976, 1977; Araujo et al, 1978; Teuscher and Sailer, 1982; Mansour et al, 1983; Carlotti et al, 1986; Stella et al, 1989; Hui et al, 1994; Dancaster, 1999) have varied considerably. For example, Araujo et al (1978) calculated the ratio of the upper lip change to incisor movement as being 0.4:1, while Carlotti et al (1986) found this ratio to be 0.96:1. This inconsistency in findings probably occurred due to combination of vertical and anteroposterior movements, inclusion of cleft lip and palate patients in the group studied as well as small sample sizes. Furthermore, such variability may be due to thin and thick lips responding differently to the horizontal change in upper incisor movement. Dancaster (1999) found that the mean ratio of labrale superius to upper incisor tip advancement was 0.76:1 for thin lips (those less than 15mm thick) as opposed to 0.27:1 for thick lips (those greater than 15mm thick). Such an observation suggests that thin lips advance 2.8 times further than thick lips when measured as a ratio of labrale superius to upper incisor tip in a horizontal direction with maxillary advancement surgery.

The conclusions of the first study evaluating the effects of anterior vertical maxillary osteotomy on the anteroposterior position of the upper lip in 25 adult patients were published by Bell and Dann in 1973. These authors showed that for every millimetre of movement of the upper incisors, the upper lip moved approximately 0.7mm, rotating and translating about a point (centre of rotation) located between subnasale and the anterior nasal spine. This centre of rotation was repositioned both vertically and sagitally at surgery and the resultant soft-tissue changes progressed from this point, becoming more apparent at the vermillion border, as the lip uncurled and rotated posteriorly.

Schendel et al (1976) investigated the soft-tissue changes resulting from maxillary impaction in 24 patients, using a computer morphometric analysis. However, 14 of the 24 patients underwent concomitant mandibular surgery and follow-up radiographs were taken as early as four months postoperatively. Observations of the upper lip response to the vertical movement of the maxilla measured at the upper incisor demonstrated a high correlation.

Mansour et al (1983) studied the ratio of soft-tissue to hard-tissue changes in a group of 14 subjects undergoing maxillary impaction and demonstrated many statistically significant correlations. However, prediction schemes for the soft-tissue changes evaluated presented with a mean error value of approximately 22 percent, thus suggesting that the clinician should always be aware of individual variation. The conclusions of that study pertaining to the upper lip response were that the lower border of the upper lip moves superiorly approximately 40 percent of the vertical maxillary change accompanied by a ten percent decrease in the vertical length at the vermillion border. A superior vertical change occurs in all of the maxillary soft-tissue points, again progressively increasing in magnitude from soft-tissue subnasale to the free end of the upper lip.

Schendel and Williamson (1983) hypothesized that the undesirable effect of upper lip shortening and thinning that is frequently associated with maxillary advancement and vertical maxillary impaction may occur because of change in the length of the facial muscles following their detachment during the surgical procedure. These authors therefore proposed a VY-soft tissue closure technique of the maxillary vestibular incision accompanied by nasolabial muscular reorientation. The technique involves advancing excess facial muscular and lip tissue medially during suturing in order to allow the lip to retain a length and fullness similar to that existing preoperatively. Dancaster (1999) demonstrated how a VY-closure technique would allow the lip to roll out by permitting 25 percent more stomion superius advancement than would otherwise occur. Furthermore, he showed lip shortening between subnasale and stomion superius to decrease from 0.26:1 to 0.1:1 with this technique.

Only three reports are documented (Schendel et al, 1976; Radney and Jacobs, 1981; Mansour et al, 1983) that discuss lower lip and interlabial gap changes as a consequence of mandibular autorotation following vertical maxillary impaction.

In their computer morphometric study investigating soft-tissue changes resulting from maxillary impaction, Schendel et al (1976) observed that the mandible rotates on an arc originating at the condyle resulting in simultaneous changes in mandibular hard and soft tissues. These authors reported that the soft-tissue pogonion follows the skeletal pogonion in a 1:1 relationship but that the lower lip falls somewhat lingual to the arc of mandibular autorotation in a 1:1 ratio with maxillary incisor retraction. This relationship was furthermore reflected in the high correlation coefficients between the maxillary incisor movement in the horizontal and vertical axes and lower lip movement in the horizontal axis. These ratios suggest that the lower lip unfolds from the mental fold in a superior direction as a combined function of mandibular autorotation, maxillary incisor retraction, and improved lip posture and tonicity. However, certain aspects of this investigation need to be critically evaluated. Firstly, 14 of the 24 patients underwent concomitant mandibular surgery. Secondly, the sample ranged in age from 13 to 33 years, and growth may not have yet been completed in the youngest patients. Thirdly, the follow-up radiographs were taken as early as four months postoperatively and therefore the lip profiles may not have attained their eventual configuration. Finally, this study failed to examine whether a particular soft-tissue response is dependent on a multivariable change (i.e. can the movement of a single soft-tissue point be more accurately predicted if more than one variable is taken into consideration).

Radney and Jacobs (1981) evaluated a group of ten non-growing patients who had undergone maxillary osteotomies at the Le Fort 1 level to elevate the maxilla. This surgery was accompanied by concomitant movement of the maxilla in the anteroposterior plane of space. The data were gathered from cephalograms taken at least four weeks prior to surgery and no sooner than six months postoperatively. Simple regression equations were determined for the correlations and these were found to be statistically significant. However, as previously mentioned, it is highly improbable that consistently accurate prediction of soft-tissue change can be accomplished with only simple correlations especially when the surgical correction involves a three-dimensional skeletal change. Radney and Jacobs (1981) found that soft-tissue pogonion and the lower lip responded in a similar fashion to that described by Schendel et al

(1976). Moreover, these authors explained that because the mandibular incisor fell inside the arc of rotation, the lower lip unfolded in a superior direction flattening the inferior labial sulcus and thus increasing the labiomental angle. Furthermore, it became evident that the amount of posterior intrusion of the maxilla and the amount of anteroposterior movement of the maxillary central incisor related most closely to the changes in the lower lip. Posterior maxillary intrusion allows the mandible to autorotate thus bringing the lower lip in approximation to the upper incisor, whose anteroposterior position would concomitantly influence the ultimate horizontal position of the lower lip. These relationships, nevertheless, represented only weakly significant correlations possibly due to inconsistent muscular tone of the lower lip and chin between pre- and post-operative radiographs as well as to errors in measurement and landmark location. In addition, very poor correlation coefficients were obtained in the vertical dimension. It is therefore difficult to predict accurately the changes to the lower lip without taking into account significant horizontal and vertical correlations.

The third study to measure the soft-tissue changes of the lower lip and chin in response to maxillary vertical impaction was conducted by Mansour et al (1983). Difficulties with this study have been reported previously. The documented lower lip and chin soft-tissue changes can be summarised as follows:

1) soft-tissue pogonion and mandibular sulcus follow approximately 90 percent of the underlying skeletal change;
2) soft-tissue menton changes more than hard-tissue menton in the vertical plane possibly due to stretching of the soft-tissue as a result of the autorotation; and

3) lower lip follows only 75 percent of the lower incisor movement in the horizontal plane thus increasing the labiomental angle but there is 93 percent conformity in the vertical plane.

The ratio of 0.93:1 describing the vertical change in the lower lip relative to the vertical change in the lower incisor is extremely significant in planning treatment for patients presenting with long-face syndrome because reduction in the interlabial gap is one of the objectives of maxillary impaction surgery. This ratio indicates that the lower lip does not follow the lower incisor in a 1:1 relationship which has important implications for planning reduction of the interlabial gap in these patients.

The remaining findings of Mansour, Burstone and Legan's investigation were similar to those reported by Schendel et al (1976) and Radney and Jacobs (1981).

It is evident from the three studies describing the lower lip and soft-tissue chin changes that the accuracy of the resultant clinical predictions may be questioned as vertical movements were combined with anteroposterior movements, mean error values were high, mainly simple correlations were developed that were weakly significant and the sample sizes were small.

It is well recognized in the literature that the integumental drape does not necessarily correspond to that of the underlying dental and skeletal structures and that it does not necessarily react in a 1:1 ratio to movement of these hard-tissue structures (Burstone, 1958, 1959, 1967; Subtelny, 1959; Hambleton, 1964; Cox and van der Linden, 1971; Worms, Isaacson and Speidel, 1976; Park and Burstone, 1986; Nanda and Ghosh, 1995). However, one of the principles of orthognathic treatment is to create an aesthetically pleasing and balanced face in harmony with the underlying dental and skeletal structures. Therefore, it is essential for the orthodontist and the oral surgeon to be able to precisely predict the soft-tissue changes which can be expected from a given amount and direction of surgical osseous movement.

The purpose of this study was to assess retrospectively the soft-tissue changes of the lower lip and chin of the autorotated mandible in the sagittal plane following vertical maxillary impaction in order to provide the clinician with relevant quantitative data to assist in treatment planning. The methodology was aimed at satisfying as many as possible of the 23 criteria proposed by Betts and Fonseca (1992) that are essential to any study investigating the soft-tissue changes associated with orthognathic surgery. These were:

1) the study should be prospective;
2) adequate sample size;
3) randomized treatments (if treatments differ within sample);
4) subjects should all be non-growing;
5) no history of previous trauma to osseous structures of face;
6) absence of congenital defects or syndromes;
7) elimination of confounding effects of pre- and post-operative orthodontic tooth movements;
8) constant presence or absence of orthodontic appliances;
9) same cephalostat to be used for all cephalograms with identical source-subject and subject-film distances;
10) soft tissues in repose for all cephalograms;

11) superimposition of cephalograms on the nearest osseous structure not affected by surgery or on a stable reference line;

12) the use of a tracing template to assist in landmark identification;

13) evaluation of both profile and full facial soft tissue change, or 3-D analysis;

14) no concomitant or prior soft-tissue surgery;

15) exclusion of segmental surgical procedures;

16) one vector of movement (or grouped within study);

17) no concomitant osseous surgery on another portion of the facial skeleton;

18) homogeneity of the soft-tissue incisions and closure techniques;

19) no hard-tissue contouring;

20) use of rigid osseous fixation;

21) uniform follow-up intervals;

22) follow-up time of at least six months (one year is preferable); and

23) error analysis of measurement and landmark identification.

CHAPTER 3: MATERIALS AND METHODS

3.1 SAMPLE

Cephalometric radiographs taken of 22 patients with growth having been completed were selected from amongst the files of a private orthodontic practice. Ethical approval had been granted by the Committee for Research on Human Subjects on 27th September 2002, Protocol Number M02-09-24, for the retrospective study of these records. The mean age of the sample at surgery was 26 years and 3 months, with ages ranging from 15 years 1 month to 45 years (Table 3.1.1). The criterion for subject selection was autorotation of the mandible in excess of 2mm as a sequel to correction of increased lower anterior facial height by maxillary impaction. Six of the patients had received additional advancement genioplasty procedures. Patients presenting with any congenital defects or developmental syndromes were excluded from this study. Each patient had undergone full fixed edgewise appliance orthodontic therapy prior to surgery. The incisor teeth had been orthodontically decompensated where necessary and stabilized six weeks prior to surgery so that no further incisor movement would have been required in the post-operative period. Vertical maxillary impaction was accomplished by a maxillary osteotomy at the Le Fort I level with the same maxillofacial and oral surgeon operating on 17 of the 22 cases. Three other surgeons treated the remaining five cases.

All lateral cephalometric radiographs had been taken on the same machine by the same operator using identical source-subject and subject-film distances. The cephalograms were taken with the lips in repose (Burstone, 1967) and the jaws in centric relation; this was supervised by the orthodontist. Each radiograph was sufficiently detailed to enable accurate recording of the soft-tissue profile and identification of pertinent hard-tissue landmarks. The lateral radiographs for each case included those taken (i) on completion of the presurgical orthodontic phase of treatment and after which time no further orthodontic tooth movement had occurred (referred to hereafter as T1 radiographs) and (ii) long-term, between six to 32 months (mean 15 months) post surgery and following removal of appliances (referred to hereafter as T2 radiographs). Freihofer, in 1976, found that in two thirds of patients, lip profiles changed measurably between four and six months following Le Fort 1 osteotomy, whereas after six months the profile attained its definitive configuration. Comparison of the radiographs taken at T1 and T2 therefore would indicate the changes that have taken place as a result of the orthognathic surgical procedures.

For each time interval assessed, the data were divided into two categories:

1) patients who had had surgical maxillary intrusion with subsequent mandibular autorotation (n=16); and

2) patients who had had surgical maxillary intrusion, mandibular autorotation and an additional advancement genioplasty procedure (n=6).

Table 3.1.1 Details of the sample used in this study.

PATIENT NUMBER	AGE YEARS	Mx.† IMPACTION	Mx.† IMPACTION & GENIOPLASTY	SURGERY – T2 MONTHS
1	30	X		26
2	15	X		30
3	45	X		12
4	29	X		20
5	19		X	6
6	30	X		10
7	17		X	8
8	36	X		6
9	22	X		19
10	28	X		22
11	32	X		28
12	15	X		32
13	29	X		6
14	24		X	6
15	17	X		29
16	32	X		6
17	35	X		6
18	32		X	6
19	25	X		11
20	17		X	7
21	18		X	20
22	21	X		11

† Abbreviation. Refer to APPENDIX A, page 63.

3.2 METHOD

Cephalometric radiographs were traced on Ozatex 0.05mm D/Matt drafting film paper (Ozalid SA Pty Ltd, Drawing Office Material, Spartan, Kempton Park, South Africa) using a 6H pencil. Two locating crosses were scribed directly onto the radiographic film and copied onto each tracing paper after it had been secured onto the radiograph. The anatomic structures that were traced included sella turcica, the floor of the anterior cranial fossa, the roof of the orbit, the nasal bone, the mandible, the maxilla (including prosthion, anterior nasal spine and posterior nasal spine), and the soft-tissue outline from glabella to the junction of the chin with the throat. The upper and lower most anteriorly placed incisors were traced using a standard Unitek tracing template (3M – Unitek Co, Monrovia, California, U.S.A.) located accurately over the incisal tip and aligned along the long axis of the tooth. The following cephalometric landmarks were then identified (Figure 3.2.1):

1)	Sella	(S)
2)	Nasion	(N)
3)	Lower Incisor Tip	(LIT)
4)	Lower Incisor Anterius	(LIa)
5)	Infradentale	(In)
6)	Supramentale	(B)
7)	Hard-tissue Pogonion	(Pog)
8)	Hard-tissue Gnathion	(Gn)
9)	Hard-tissue Menton	(Me)
10)	Stomion Superius	(Stm-s)
11)	Stomion Inferius	(Stm-i)

12)	Labrale Inferius	(Li)
13)	Sulcus Inferius	(Si)
14)	Soft-tissue Pogonion	(Pog’)
15)	Soft-tissue Gnathion	(Gn’)
16)	Soft-tissue Menton	(Me’)

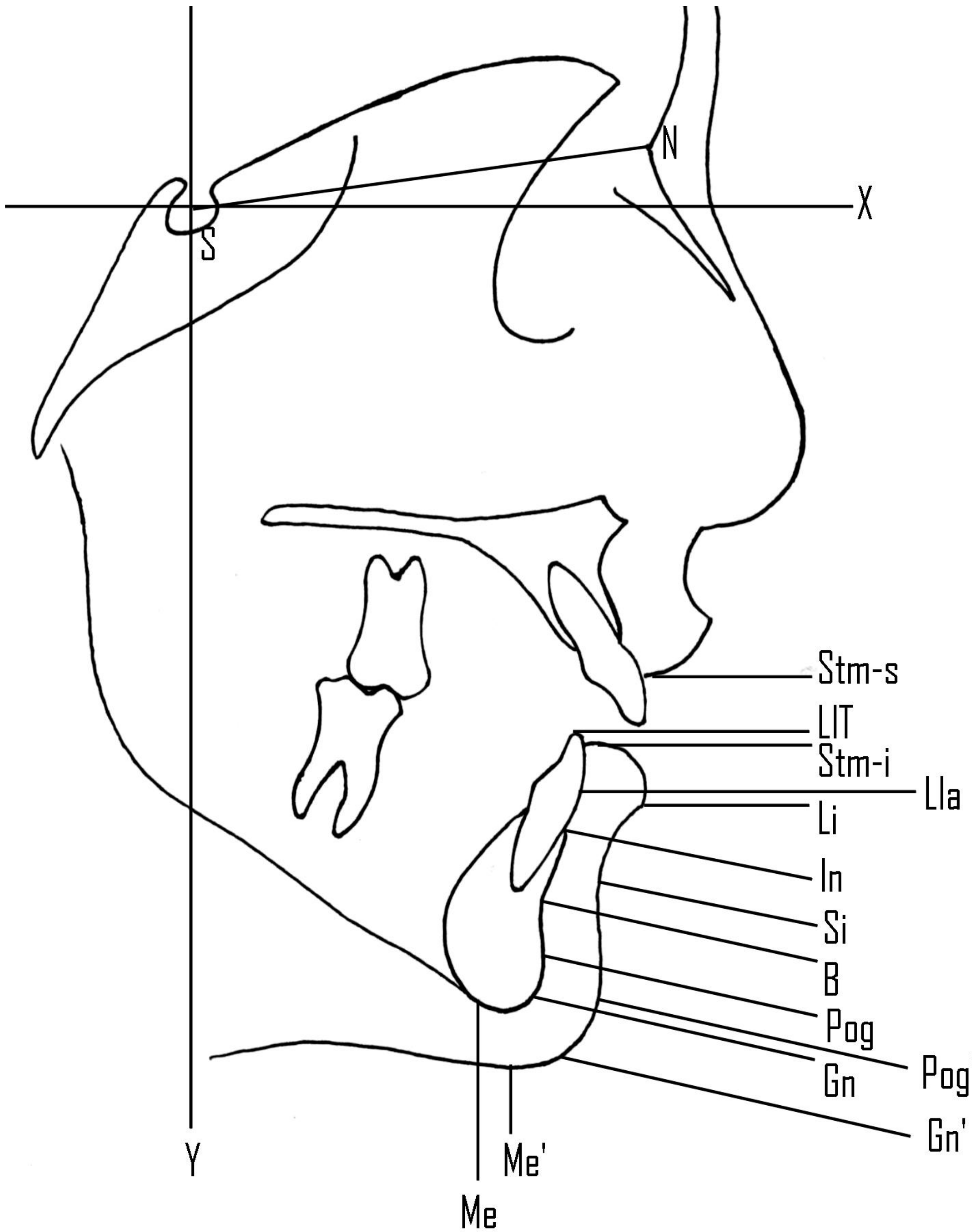


Figure 3.2.1 Cephalometric landmarks and reference planes used in this study.

For the purpose of this study, the above tabulated landmarks were defined as follows:

1) Sella (S) – constructed midpoint in the median plane of the pituitary fossa (Bjork, 1947)

2) Nasion (N) – most anterior point of the frontonasal suture in the median plane (Bjork, 1947)

3) Lower Incisor Tip (LIT)

– midpoint of the incisal edge of the most anterior mandibular central incisor in the sagittal plane (Sollow and Tallgren, 1976)

4) Lower Incisor Anterius (LIa)

– most anterior point on the crown of the lower central incisor outline (Mansour et al, 1983)

5) Infradentale (In)

– point of transition from the crown of the most prominent medial mandibular incisor to the alveolar projection (Bjork, 1947)

6) Supramentale (B)

– most posterior point in the concavity between infradentale and pogonion (Downs, 1948)

7) Hard-tissue Pogonion (Pog)

– most prominent or most anterior point on the bony chin (van der Linden, 1971)

8) Hard-tissue Gnathion (Gn)

– most anterior and inferior point on the midsagittal plane of the contour of the chin (Radney and Jacobs, 1981)

9) Hard-tissue Menton (Me)

– most inferior point on the outline of the mandibular symphysis in the midsagittal plane (Downs, 1948)

10) Stomion Superius (Stm-s)

– constructed point at the most inferior level of the upper membranous lip (Dancaster, 1999)

11) Stomion Inferius (Stm-i)

– constructed point at the most superior level of the lower membranous lip (Dancaster, 1999)

12) Labrale Inferius (Li)

– median point in the lower margin of the lower membranous lip (Burstone, 1958)

13) Sulcus Inferius (Si)

– point of greatest concavity in the midline of the lower lip between labrale inferius and soft-tissue pogonion (van der Linden, 1971)

14) Soft-tissue Pogonion (Pog')

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

15) Soft-tissue Gnathion (Gn')

– most anterior inferior point on the soft-tissue chin outline (Radney and Jacobs, 1981)

16) Soft-tissue Menton (Me')

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

Reference planes (Figure 3.2.2) were constructed following the method of Phillips, Turvey and McMillian (1989):

1) S-N plane - connecting points S and N.

2) X-axis - constructed through point S at 6 degrees to the S-N Plane.
(This line runs approximately parallel to the true horizontal in most patients.)

3) Y-axis - constructed through point S at 90 degrees to the X-axis.

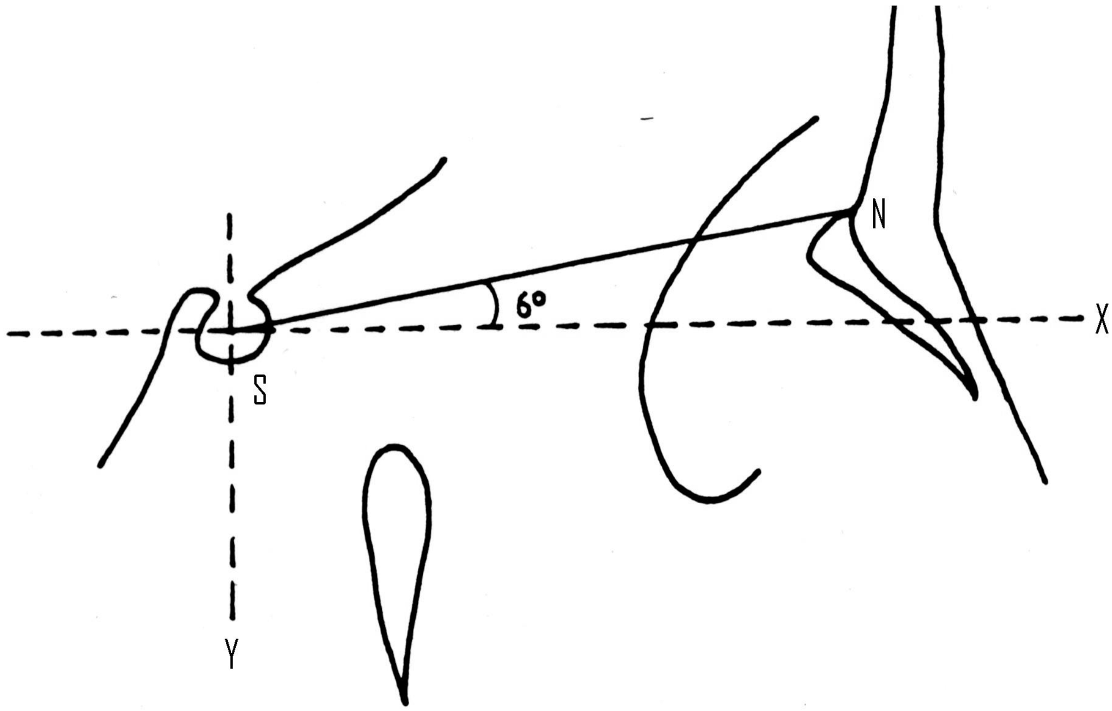


Figure 3.2.2 Construction of reference planes used in this study.

Through the use of these planes, a coordinate reference system with an origin at point S was established.

According to Baumrind and Frantz (1971), the reproducibility of points placed on anatomically formed edges or creases e.g. sella and nasion, rates extremely high; however, those landmarks placed on curves with wide radii show proportionally greater errors of measurement. This was in agreement with an earlier study by Richardson (1966) who demonstrated an increase in deviation when recording points on anatomical curves in the profile e.g. supramentale and pogonion. Therefore, in order to locate a particular landmark defined as ‘most anterior’ or ‘most posterior’ on a curved segment of the tracing, Gardner (1991) proposed dropping a perpendicular from the X-axis to the most anterior or posterior part of the curvature in question and to establish the midpoint of this linear contact area by measuring its distance and then bisecting it (Figure 3.2.3). A similar procedure was followed for landmarks defined as ‘most superior’ or ‘most inferior’ except in this instance the contact area was established by extending a perpendicular line from the Y-axis to the landmark in question. This method of location allows for more accurate and repeatable measurement of cephalometric landmarks along a contact area, in both the horizontal and vertical planes, by the use of simple geometrical principles. Landmarks numbered 4, 6, 7, 8, 9, 10, 11, 13, 14, 15, and 16 in the list above required the use of this method of location.

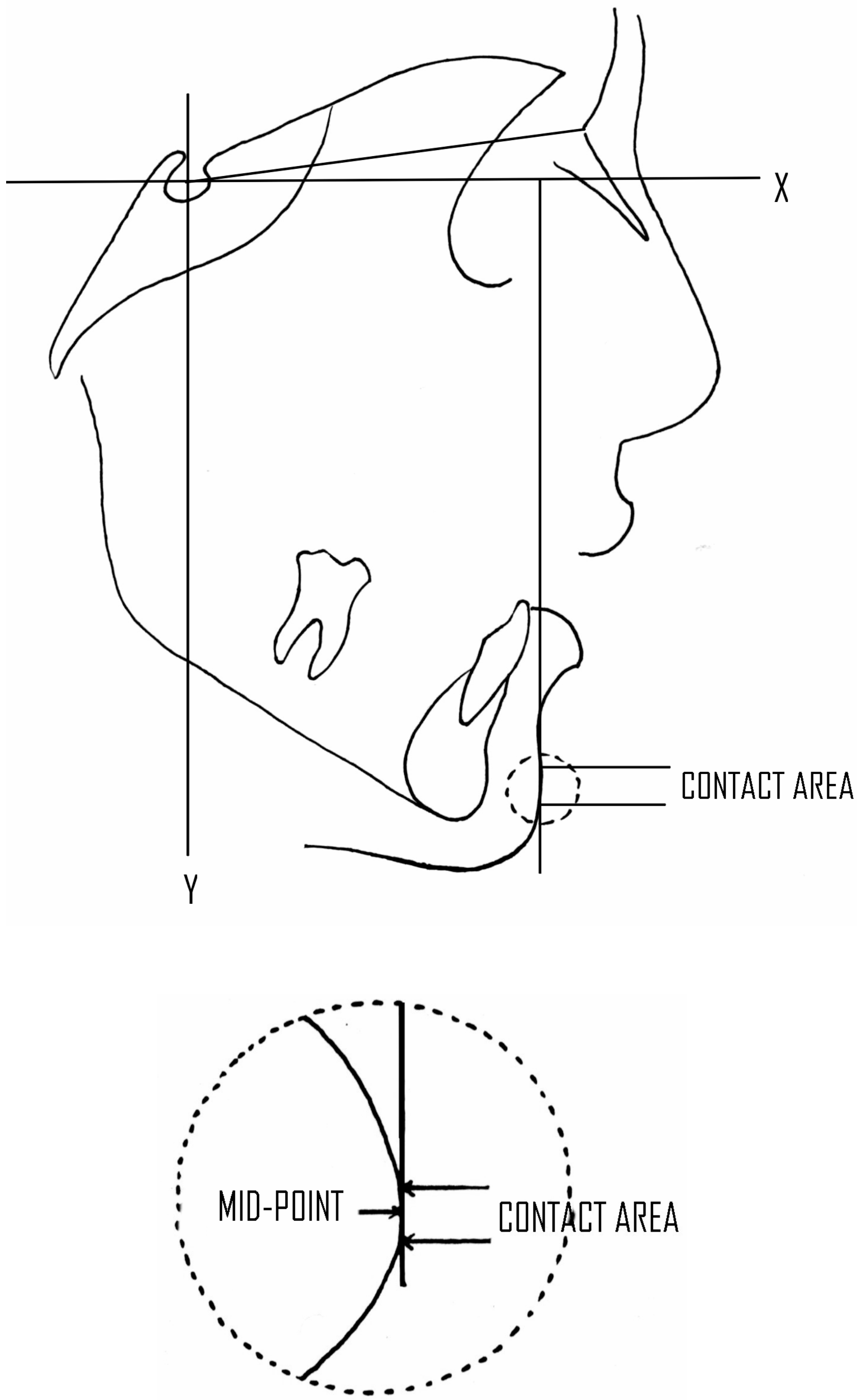


Figure 3.2.3 Definition of a point on a curved segment.

3.2.1 The Cephalometric Measuring Sequence

The T1 radiographs of 15 patients were traced twice and the reference axes were transferred from the first to the second presurgical tracing after superimposing the two tracings over the locating crosses that had been traced directly from the film. This standardized the reference system for each set of tracings for each patient.

The reference axes constructed for each subject on the presurgical tracings were then transferred to each of the post-surgical tracings after superimposing over the cranial base areas. This was achieved by finding the closest correspondence between the tracings using sella turcica, DeCoster's line (line representing the sphenoid plane and the cribriform plate – DeCoster, 1953; Quast, Biggerstaff and Haley, 1983), roof of the orbit, orbit and the frontonasal area as reference structures (Steuer, 1972).

The coordinates of every landmark on each tracing were sequentially computed using a digitizing programme on a Kontron MOP – Videoplan computer (Kontron Messgerate GMBH, Image-analysis-systems 8057 Eching/Munchen, Breslauer Street 2, Germany) (Figure 3.2.1.1). This entailed orientating the tracings on the computer tracing board so that the reference axes superimposed upon the 'X' and 'Y' coordinate axes set by the computer on the digitizing tablet. The 'X' coordinates represented the horizontal distance from the vertical axis, and the 'Y' coordinates the vertical distance from the horizontal axis measured in millimetres to an accuracy of three decimal places. A positive value was assigned to posterior or superior displacements, while a negative value was assigned to anterior or inferior changes.

The parameters on all the radiographs were measured thrice and a mean value was established thereby decreasing variability (Houston, 1983). The variability was further minimized by completing both sets of tracings for an individual patient at the same session (Houston, 1983).

The data recorded on the Kontron computer were organized and tabulated using Statistix version 4.1 software. These data were then statistically analyzed in the Medical Research Council Biostatistics Unit, Pretoria.

Figure 3.2.1.1 The Kontron Videoplan Digitizing System.

3.3 STATISTICS

A series of statistical analyses was performed including descriptive and correlative procedures. A summary flowchart of these can be found in APPENDIX B.

3.3.1 Error of Method

This included testing for the accuracy of the digitizing procedure, as well as for intra- and inter-examiner repeatability of landmark identification.

3.3.1.1 Accuracy of Digitizing

The proficiency of the operator in using the Kontron Videoplan Digitizing System was tested by redigitizing one randomly chosen tracing on ten separate occasions, each at least 24 hours apart. The coefficient of variation between the ten measurements of each landmark was used to assess the accuracy of digitizing. A clinically acceptable level of accuracy existed when the coefficient of variation was 5% or less.

3.3.1.2 Intra-Examiner Repeatability of Accuracy of Landmark Identification

The duplicate set of data from 15 presurgical tracings was used to assess the accuracy of repeatability of landmark identification. A coefficient of repeatability, as utilized by the British Standards Institution (Bland and Altman, 1986) was calculated for each landmark.

Mitgard, Bjork and Linder-Aronson (1974) reported the accuracy of repeatability of hard-tissue landmarks to vary from 0.42mm for point S to 2.08mm for orbitale; however, they found that the majority of landmarks were reproducible at an accuracy level of between 1.0 and 1.5mm. Hillesund, Fjeld and Zachrisson (1978) reported the accuracy of repeatability of most soft-tissue landmarks in the horizontal plane to range from 1.0 to 1.5mm. Furthermore, Wisth and Boe (1975) found no significant difference between the reliability of location of hard- and soft-tissue landmarks. An acceptable level of repeatability for this study was chosen to be less than 1.5mm for landmarks located on flat surfaces and less than 2mm for those located on curved surfaces.

3.3.1.3 Inter-Examiner Accuracy of Landmark Location

A randomly chosen radiograph was traced on separate occasions by ten different orthodontists. Each, using the described method, located the following six landmarks: Stm-s; Li; Pog'; LIT; LIa; and Pog. Each landmark on each tracing was then digitized and the data subjected to a statistical analysis to derive a coefficient of variation.

3.3.2 Statistics for the Change from T1 to T2 Time Interval

The Mann-Whitney U-test was applied to determine whether the maxillary impaction sample with autorotated mandibles differed significantly from the sample of patients with additional advancement genioplasty procedures with respect to the proportional changes between various hard- and soft-tissue landmarks. If no significant differences were found to exist between these two surgical groups, the two groups could then be pooled to increase the sample size for the study. The detection of significant differences between the two groups would necessitate that the two groups be evaluated separately for the relevant hard- to soft-tissue changes. Testing was carried out at the 0.05 level of significance.

Descriptive and comparative statistics were prepared for the data from the T1 to the T2 time interval. A paired Hotelling's T2-test and a Student's t-test were used to evaluate the significance of the means of the differences between T1 and T2 values for each landmark as measured in millimetres along both the horizontal and vertical reference planes. Testing was carried out at the 0.05 level of significance. The significant changes were then further evaluated for their clinical relevance. A clinically relevant change was chosen to represent any change of greater than 1.5mm (Baumrind and Frantz, 1971; Mitgard et al, 1974; Hillesund et al, 1978).

Those hard- and soft-tissue landmarks for which statistically significant and clinically relevant changes were recorded were further analyzed to assess the relationships between those changes. Correlation and regression analyses were used in this statistical evaluation following the methodology of Radney and Jacobs (1981) (refer to APPENDIX B for a summary flowchart of the statistics used).

Simple correlation analyses involved a 1:1 comparison of changes in soft-tissue ratios to changes in hard-tissue ratios. The Pearson correlation coefficients (R) thus obtained allowed further calculation of the coefficients of determination (*c of d*) expressed as a percentage for each set of landmarks using the formula, $c \text{ of } d = R^2 \times 100$. The coefficient of determination assesses the degree of variation in the soft-tissue change that may be explained by the degree of variation in the hard-tissue change expressed as a percentage. A 60 percent coefficient of determination for a specific hard- to soft-tissue change would imply that 60 percent of the change occurring at the soft-tissue landmark can be explained by the change occurring at the hard-tissue landmark. A coefficient of determination of greater than 50 percent indicates a good correlation i.e. $R>0.7$.

The following simple correlation and regression analyses were performed to evaluate the strength of the relationship of the changes between the corresponding hard- and soft-tissue landmarks in both the horizontal and vertical dimensions:

1) LIT and Stm-i
2) LIT and Li
3) LIa and Stm-i
4) LIa and Li
5) B and Si
6) Pog and Pog'
7) Gn and Gn'
8) Me and Me'

Multiple regression equations were developed and coefficients of determination *(c of d=* R^2 *x 100)* were calculated and adjusted for sample size when the correlations were statistically significant. A multiple regression analysis assesses the relationship of the hard- and soft-tissue changes together with an additional factor, the presurgical tissue thickness, which can vary depending on the type of soft tissue present. Burstone (1959), Subtelny (1959), Freihofer (1976) and Nanda and Ghosh (1995) discussed the variability of the thickness of the soft tissue covering the dentition and bone and drew attention to the possible importance of evaluating this factor during the treatment planning process. The standard and the adjusted coefficients of determination therefore indicate whether the inclusion of presurgical tissue thickness data enhances the strength of the relationship of the changes at corresponding hard- and soft-tissue points. However, because the sample size was small, the adjusted coefficients of determination are more accurately representative of the actual degree of this influence.

The results of all the above mentioned calculations were then used to develop tables of predicted movement of soft-tissue landmarks in response to hard-tissue changes.

CHAPTER 4: RESULTS

4.1 ERROR OF METHOD

4.1.1 Accuracy of Digitizing

Table 4.1.1.1 presents the coefficients of variation for each landmark digitized on ten separate occasions at least 24 hours apart. These coefficients of variation are expressed as a percentage of the standard deviation divided by the mean (i.e. C.V.=S.D./mean x 100).

For the 16 individual landmarks measured, the coefficient of variation ranged from 0.000% to 0.205% in the horizontal dimension and 0.000% to 0.846% in the vertical dimension. This was well within the 5% variation level of accuracy chosen for this study.

Table 4.1.1.1 Coefficients of variation for landmark location on ten separate occasions.

HARD-TISSUE LANDMARK		C.V.[†] %	SOFT-TISSUE LANDMARK		C.V.[†] %
S	h	0.000	Stm-s	h	0.105
	v	0.000		v	0.223
N	h	0.075	Stm-i	h	0.099
	v	0.846		v	0.192
LIT	h	0.175	Li	h	0.146
	v	0.176		v	0.174
LIa	h	0.176	Si	h	0.077
	v	0.183		v	0.102
In	h	0.201	Pog'	h	0.113
	v	0.163		v	0.104
B	h	0.205	Gn'	h	0.148
	v	0.107		v	0.162
Pog	h	0.126	Me'	h	0.107
	v	0.109		v	0.180
Gn	h	0.105			
	v	0.149			
Me	h	0.125			
	v	0.072			

[†] Abbreviation. Refer to APPENDIX A, page 63.

4.1.2 Intra-Examiner Repeatability of Accuracy of Landmark Identification

Table 4.1.2.1 presents the coefficients of repeatability for presurgical hard- and soft-tissue landmarks measured off two T1 tracings traced 24 hours apart for a group of 15 patients. These coefficients of repeatability were obtained by doubling the standard deviation for the difference between the two measurements of each coordinate of every variable.

The coefficient of repeatability ranged from 0.608 to 1.693mm for landmarks measured in the horizontal dimension, and 0.306 to 1.805mm for landmarks measured in the vertical dimension. The coefficients of repeatability that were greater than the 1.5mm recommended as acceptable by Baumrind and Frantz (1971), Mitgard et al (1974) and Hillesund et al (1978) included: point B in the vertical dimension, sulcus inferior in the vertical dimension and soft-tissue menton in the horizontal dimension. In fact, Hillesund et al (1978) noted that reproducibility of points situated on curves with wide radii was poor, particularly in the vertical plane, and hence, a 2mm level of repeatability was chosen as acceptable for such points in this study. Therefore, all measurements were considered reliable points for further analysis.

Table 4.1.2.1 Coefficients of repeatability for each landmark measured from two T1 tracings traced 24 hours apart for a group of 15 patients.

HARD-TISSUE LANDMARK		C.R.† mm	SOFT-TISSUE LANDMARK		C.R.† mm
S	h	0.000	Stm-s	h	0.782
	v	0.000		v	0.813
N	h	0.608	Stm-i	h	0.862
	v	0.306		v	0.643
LIT	h	0.833	Li	h	0.819
	v	0.629		v	0.922
LIa	h	0.878	Si	h	0.943
	v	1.104		v	1.622
In	h	0.844	Pog’	h	1.010
	v	0.681		v	1.260
B	h	1.006	Gn’	h	1.077
	v	1.805		v	1.281
Pog	h	1.055	Me’	h	1.693
	v	0.949		v	1.365
Gn	h	1.114			
	v	0.589			
Me	h	1.029			
	v	0.603			

† Abbreviation. Refer to APPENDIX A, page 63.

4.1.3 Inter-Examiner Accuracy of Landmark Location

Table 4.1.3.1 presents the coefficients of variation for the means of the values obtained by ten orthodontists and compares these means with the researcher's mean measurements of the same six landmarks.

The coefficients of variation obtained by the ten orthodontists ranged from 0.109% to 0.894% in the horizontal dimension and 0.207% to 1.188% in the vertical dimension. This indicates a high degree of accuracy for the method of landmark location employed in this study.

Bland and Altman's limits of agreement (1986) indicate a bias of 0.122mm in the researcher's mean measurement compared with that of the orthodontists. The upper and lower limits of agreement show that the researcher's measurements lay within 0.879mm and -1.122mm of the orthodontists' mean (this being ±1.96 standard deviations from the researcher's mean). These figures are within the accepted 1.5mm accuracy for cephalometrics (Hillesund et al, 1978).

Table 4.1.3.1 Inter-examiner accuracy of landmark location. (Means, standard deviations and coefficients of variation for each parameter recorded by ten orthodontists and compared with means recorded by the author.)

LANDMARK		ORTHODONTISTS			RESEARCHER	DIFFERENCE
		Mean	S.D.†	C.V.†	Mean	IN MEANS
Stm-s	h	70.284	0.448	0.637	71.113	-0.82
	v	71.194	0.148	0.207	71.09	0.10
Li	h	70.512	0.631	0.894	70.983	-0.47
	v	82.922	0.668	0.806	82.495	0.42
Pog’	h	67.696	0.074	0.109	68.01	-0.31
	v	102.840	0.927	0.902	102.193	0.64
LIT	h	60.922	0.321	0.527	60.464	0.45
	v	71.115	0.267	0.376	70.926	0.18
LIa	h	61.392	0.138	0.224	61.705	-0.31
	v	75.510	0.897	1.188	74.53	0.98
Pog	h	57.991	0.196	0.338	58.21	-0.21
	v	109.51	0.610	0.557	108.706	0.80

† Abbreviation. Refer to APPENDIX A, page 63.

4.2 RESULTS FROM THE PERIOD T1 TO T2

4.2.1 Descriptive and Comparative Analyses

Through the application of the Mann-Whitney U-test, it was determined that the maxillary impaction patients differed significantly post surgery from those that underwent additional advancement genioplasty procedures with respect to the proportional changes in the hard- and soft-tissue landmarks located in the chin area (Table 4.2.1.1). However, no significant differences ($p>0.05$) were found between the mean changes of the landmarks located in the lower lip area in the two groups. Therefore, for the study of the lower lip changes, the two groups can be pooled, thereby increasing the sample size to 22 (Table 4.2.1.2). However, soft-tissue chin changes can only be evaluated from the 16 patients who had not undergone an additional genioplasty procedure (Table 4.2.1.3). Testing was carried out at the 0.05 level of significance.

Negative values are indicative of either anterior movement in the horizontal direction or inferior movement in the vertical direction. Positive values are indicative of either posterior movement in the horizontal direction or superior movement in the vertical direction.

The mean autorotation of the mandible as expressed by the vertical change in the position of hard-tissue menton in the maxillary elevation group (GR1) during the time interval T1 to T2 was 3.25mm superiorly, with a range of 2.23mm to 4.28mm (Table 4.2.1.3). The autorotation of the mandible likewise resulted in a horizontal change in hard-tissue menton which ranged from 1.75mm to 5.49mm in the anterior direction, with a mean of 3.62mm. The mean change in the position of hard-tissue menton in the maxillary elevation plus advancement genioplasty surgery group (GR2) was 5.51mm in the superior direction and 9.41mm in the anterior direction (Table 4.2.1.1). These changes are all within the limits stipulated as criteria for patient selection for inclusion in this study.

Table 4.2.1.1 Levels of significance (* = p≤0.05) for changes in lower lip and chin landmarks during the time interval T1 to T2 between the two surgical groups.

LAND MARK		MEANΔ† GR1†	MEANΔ† GR2†	DIFF† IN MEANS	P-VALUE	MEANΔ† POOLED
LIT	h	-1.306	-3.643	2.337	0.051	-1.944
	v	4.781	5.362	-0.581	0.543	4.94
LIa	h	-1.561	-3.768	2.207	0.056	-2.163
	v	3.864	5.145	-1.281	0.207	4.213
In	h	-1.200	-3.040	1.840	0.284	-1.702
	v	2.691	4.038	-1.347	0.457	3.059
B	h	-2.905	-5.186	2.281	0.119	-3.527
	v	5.040	7.346	-2.306	0.230	5.668
Pog	h	-3.877	-9.153	5.276	0.004*	
	v	2.703	1.598	1.105	0.449	2.402
Gn	h	-3.831	-9.377	5.546	0.003*	
	v	3.078	5.281	-2.203	0.036*	
Me	h	-3.620	-9.406	5.786	0.003*	
	v	3.253	5.508	-2.255	0.036*	
Stm-i	h	-1.608	-1.330	-0.278	0.827	-1.532
	v	4.851	6.933	-2.081	0.301	5.419
Li	h	-1.673	-3.278	1.605	0.163	-2.110
	v	5.521	8.222	-2.701	0.276	6.257
Si	h	-2.502	-5.729	3.227	0.013*	
	v	4.291	6.686	-2.394	0.259	4.944
Pog’	h	-3.430	-7.886	4.456	0.006*	
	v	1.305	0.374	0.931	0.508	1.051
Gn’	h	-3.622	-9.313	5.691	0.001*	
	v	2.713	4.339	-1.627	0.227	3.156
Me’	h	-3.864	-10.712	6.848	0.002*	
	v	3.288	5.827	-2.539	0.031*	

† Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.1.2 Descriptive statistics for hard- and soft-tissue changes in the lower lip area in the pooled sample (n=22) during the time interval T1 to T2.

LANDMARK		MEAN Δ† GR1†	S.D.†	S.E.M.†	RANGE	
					Min†	Max†
LIT	h	-1.944	2.525	0.538	-0.824	-3.063
	v	4.940	1.931	0.412	4.083	5.796
LIa	h	-2.163	2.435	0.519	-1.084	-3.243
	v	4.213	2.086	0.445	3.288	5.138
In	h	-1.702	3.507	0.748	-0.147	-3.257
	v	3.059	3.669	0.782	1.432	4.685
Stm-i	h	-1.532	2.566	0.547	-0.395	-2.670
	v	5.419	4.109	0.876	3.597	7.241
Li	h	-2.110	2.373	0.506	-1.058	-3.163
	v	6.257	5.065	1.080	4.012	8.503

† Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.1.3 Descriptive statistics for hard- and soft-tissue changes in the chin area in the maxillary elevation group (GR1) consisting of 16 patients during the time interval T1 to T2.

LANDMARK		MEAN Δ† GR1†	S.D.†	S.E.M.†	RANGE	
					Min†	Max†
B	h	-2.905	2.565	0.641	-1.538	-4.271
	v	5.040	3.682	0.921	3.077	7.002
Pog	h	-3.877	3.195	0.799	-2.174	-5.580
	v	2.703	1.982	0.496	1.647	3.759
Gn	h	-3.831	3.329	0.832	-2.057	-5.605
	v	3.078	1.931	0.483	2.049	4.107
Me	h	-3.620	3.509	0.877	-1.750	-5.490
	v	3.253	1.927	0.482	2.226	4.279
Si	h	-2.502	2.567	0.642	-1.134	-3.870
	v	4.291	3.487	0.872	2.433	6.150
Pog’	h	-3.430	2.821	0.705	-1.927	-4.933
	v	1.305	2.841	0.710	-0.209	2.819
Gn’	h	-3.622	3.001	0.750	-2.023	-5.222
	v	2.713	2.417	0.604	1.424	4.001
Me’	h	-3.864	4.014	1.004	-1.725	-6.004
	v	3.288	1.956	0.489	2.246	4.330

† Abbreviation. Refer to APPENDIX A, page 63.

Descriptive statistics were carried out to evaluate whether any significant changes in soft-tissue thickness had occurred between the two time intervals as a result of the mandible autorotating post surgery. Lip thickness was assessed in the pooled sample (n=22) and was represented by a measurement from labrale inferius (Li) to three different hard-tissue landmarks: lower incisor tip (LIT); lower incisor anterius (LIa) and incision (In) (Table 4.2.1.4). Chin thickness was assessed in the maxillary elevation group without an additional genioplasty procedure (n=16) and was measured in three different areas on the contour of the chin: from hard-tissue pogonion (Pog) to soft-tissue pogonion (Pog'); from hard-tissue gnathion (Gn) to soft-tissue gnathion (Gn'); and from hard-tissue menton (Me) to soft-tissue menton (Me') (Table 4.2.1.5).

Table 4.2.1.4 Descriptive statistics for changes in the thickness of the lower lip in the pooled sample (n=22) during the time interval T1 to T2.

LIP THICKNESS	T1 MEAN	T2 MEAN	DIFF† IN MEANS	T1 S.D. †	T2 S.D. †	T1 RANGE Min†	Max†	T2 RANGE Min†	Max†
Li↔LIT	-12.50	-12.66	0.16	2.02	2.19	-8.51	-15.78	-9.14	-16.11
Li↔LIa	-11.93	-11.87	0.05	1.95	2.13	-7.99	-15.10	-8.51	-15.36
Li↔In	17.48	17.89	0.40	3.12	3.07	13.14	26.82	12.43	23.92

† Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.1.5 Descriptive statistics for changes in the thickness of the chin in the maxillary elevation sample (n=16) during the time interval T1 to T2.

CHIN THICKNESS	T1 MEAN	T2 MEAN	DIFF† IN MEANS	T1 S.D. †	T2 S.D. †	T1 RANGE Min†	Max†	T2 RANGE Min†	Max†
Pog'↔Pog	13.78	13.34	0.44	1.47	1.73	11.17	16.73	9.80	16.01
Gn'↔Gn	9.83	9.62	0.20	1.03	1.64	8.43	11.83	7.02	12.13
Me'↔Me	-0.24	0.00	0.24	2.95	2.19	-5.38	5.48	-4.44	4.14

† Abbreviation. Refer to APPENDIX A, page 63.

The findings of the above descriptive statistics indicate that the changes in the soft-tissue thickness in the lower lip and chin area as a result of the mandibular autorotation following maxillary elevation ranged from 0.05mm to 0.44mm. These changes were statistically and clinically insignificant ($p>0.05$).

Likewise, descriptive statistics were performed to evaluate whether any significant changes in lower lip length, measured from soft-tissue menton (Me') to stomion inferius (Stm-i), had occurred between the two time intervals as a result of the mandibular autorotation. Lip length was assessed in the 16 patients who had not undergone an additional genioplasty procedure (n=16) (Table 4.2.1.6).

Table 4.2.1.6 Descriptive statistics for change in the length of the lower lip in the maxillary elevation sample (n=16) during the time interval T1 to T2. (-) is not indicative of direction of movement, rather it shows that the post-surgical lip length was greater than the presurgical lip length.

LIP LENGTH	T1 MEAN	T2 MEAN	DIFF† IN MEANS	T1 S.D. †	T2 S.D. †	T1 RANGE Min†	Max†	T2 RANGE Min†	Max†
Stm-i↔me'	49.67	51.24	(-)1.56	5.68	5.06	43.04	63.22	45.69	62.77

† Abbreviation. Refer to APPENDIX A, page 63.

The above findings indicate that the lower lip lengthened by 1.56mm following mandibular autorotation occurring as a result of maxillary elevation.

4.2.2 Simple Correlation Analyses.

Simple correlation analyses, performed to evaluate the strength of the relationship of the changes between various corresponding soft- and hard-tissue landmarks, revealed several statistically and clinically significant responses. In the evaluation of lower lip changes in the pooled sample (n=22), these responses are represented by the following correlations at a 0.05 level of significance (Table 4.2.2.1):

1) ΔStm-i to ΔLIT in the horizontal and vertical direction;

2) ΔStm-i to ΔLIa in the horizontal and vertical direction;

3) ΔStm-i to ΔIn in the vertical direction;

4) ΔLi to ΔLIT in the horizontal and vertical direction;

5) ΔLi to ΔLIa in the horizontal and vertical direction; and

6) ΔLi to ΔIn in the horizontal and vertical direction.

In the evaluation of chin changes in the sample of 16 patients with mandibular autorotation as a consequence of maxillary elevation without an accompanying genioplasty procedure, these responses are represented by the following correlations at a 0.05 level of significance (Table 4.2.2.2):

1) ΔSi to ΔB in the horizontal and vertical direction;

2) ΔPog' to ΔPog in the horizontal and vertical direction;

3) ΔGn' to ΔGn in the horizontal and vertical direction; and

4) ΔMe' to ΔMe in the horizontal and vertical direction.

No statistically significant correlations at a p-value of less than or equal to 0.05 existed between soft-tissue changes in the horizontal direction and hard-tissue changes in the vertical direction.

Table 4.2.2.1 Pearson correlation coefficients and coefficients of determination for changes at a 0.05 level of significance (* = $p \leq 0.05$ and c of d $\geq$ 50%) between corresponding hard- and soft-tissue landmarks in the lower lip area for the time period T1 to T2 within the pooled sample (n=22). A coefficient of determination of greater than 50% indicates a good correlation i.e. $R > 0.7$.

S.T.† TO H.T.† RELATION	DIRECTION	MEAN RATIO	PEARSON (R) CORRELATION	C OF D† R^2 x 100
ΔStm-i/ΔLIT	Horizontal	0.788	0.4897	23.98
ΔStm-i/ΔLIa	Horizontal	0.708	0.4992	24.92
ΔLi/ΔLIT	Horizontal	1.086	0.8419*	70.88*
ΔLi/ΔLIa	Horizontal	0.976	0.8386*	70.32*
ΔLi/ΔIn	Horizontal	1.240	0.6655	44.29
ΔStm-i/ΔLIT	Vertical	1.097	0.7008	49.11
ΔStm-i/ΔLIa	Vertical	1.286	0.7365*	54.24*
ΔStm-i/ΔIn	Vertical	1.772	0.6134	37.63
ΔLi/ΔLIT	Vertical	1.267	0.6986	48.80
ΔLi/ΔLIa	Vertical	1.485	0.7449*	55.49*
ΔLi/ΔIn	Vertical	2.046	0.5214	27.19

† Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.2.2 Pearson correlation coefficients and coefficients of determination for changes at a 0.05 level of significance (* = $p \leq 0.05$ and c of d ≥ 50%) between corresponding hard- and soft-tissue landmarks in the chin area for the time period T1 to T2 within the maxillary elevation surgical group (n=16). A coefficient of determination of greater than 50% indicates a good correlation i.e. $R>0.7$.

S.T.† TO H.T.† RELATION	DIRECTION	MEAN RATIO	PEARSON (R) CORRELATION	C OF D† $R^2 \times 100$
ΔSi/ΔB	Horizontal	0.861	0.9089*	82.61*
ΔPog'/ΔPog	Horizontal	0.885	0.9382*	88.02*
ΔGn'/ΔGn	Horizontal	0.946	0.9680*	93.70*
ΔMe'/ΔMe	Horizontal	1.067	0.6962	48.47
ΔSi/ΔB	Vertical	0.852	0.6706	44.97
ΔPog'/ΔPog	Vertical	0.483	0.4034	16.27
ΔGn'/ΔGn	Vertical	0.881	0.8383*	70.27*
ΔMe'/ΔMe	Vertical	1.011	0.9450*	89.30*

† Abbreviation. Refer to APPENDIX A, page 63.

4.2.3 Multiple Regression Analyses

Multiple regression equations and standard coefficients of determination, as well as coefficients of determination adjusted for the size of the sample, were developed for horizontal and vertical changes in lip position (Table 4.2.3.1) and chin position (Table 4.2.3.2) utilizing statistically significant ($p \leq 0.05$) and clinically relevant changes in corresponding soft- and hard-tissue landmarks. The adjusted coefficients of determination, similarly to standard coefficients of determination, represent the degree of influence the corresponding soft- and hard-tissue variables exert upon the change in lip and chin position; in addition they take into account the size of the sample. Therefore, as with standard coefficients of determination, adjusted coefficients of determination of greater than 50% likewise indicate a good correlation i.e. $R > 0.7$.

Table 4.2.3.1 Multiple regression equations, coefficients of determination and adjusted coefficients of determination for horizontal and vertical changes in lip position. (* = $p \leq 0.05$)

MULTIPLE REGRESSION EQUATIONS	C OF D† $R^2 \times 100$	ADJUSTED C OF D†
ΔLi-h = -1.762 + 0.018 x Li-h + 0.795 x ΔLIa-h	70.71*	67.63*
ΔLi-h = -2.354 + 0.023 x Li-h + 0.765 x ΔLit-h	71.44*	68.44*
ΔLi-h = -6.181 + 0.063 x Li-h + 0.421 x ΔIn-h	49.51	44.20
ΔStm-i-h = -3.541 + 0.043 x Stm-i-h + 0.490 x ΔLIa-h	26.65	18.93
ΔStm-i-h = -3.940 + 0.046 x Stm-i-h + 0.463 x ΔLit-h	26.01	18.23
ΔStm-i-h = -5.524 + 0.062 x Stm-i-h + 0.279 x ΔIn-h	20.62	12.27
ΔLi-v = -16.530 + 0.186 x Li-v + 1.289 x ΔLIa-v	61.30*	57.22*
ΔLi-v = -21.743 + 0.236 x Li-v + 1.218 x ΔLit-v	59.99*	55.78*
ΔLi-v = -24.661 + 0.322 x Li-v + 0.287 x ΔIn-v	48.46	43.04
ΔStm-i-v = -12.277 + 0.161 x Stm-i-v + 1.091 x ΔLIa-v	58.11*	53.70*
ΔStm-i-v = -16.661 + 0.209 x Stm-i-v + 1.040 x ΔLit-v	56.66*	52.10*
ΔStm-i-v = -16.625 + 0.257 x Stm-i-v + 0.377 x ΔIn-v	48.29	42.85

† Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.3.2 Multiple regression equations, coefficients of determination and adjusted coefficients of determination for horizontal and vertical changes in chin position. (* = $p \leq 0.05$)

MULTIPLE REGRESSION EQUATIONS	C OF D† R^2 x 100	ADJUSTED C OF D†
ΔSi-h = -3.974 + 0.057 x Si-h + 0.840 x ΔB-h	85.18*	82.90*
ΔPog'-h = -5.170 + 0.068 x Pog'-h + 0.771 x ΔPog-h	91.33*	89.99*
ΔGn'-h = -2.258 + 0.030 x Gn'-h + 0.846 x ΔGn-h	94.16*	93.26*
ΔMe'-h = -5.221 + 0.079 x Me'-h + 0.712 x ΔMe-h	49.74	42.01
ΔSi-v = -9.939 + 0.119 x Si-v + 0.443 x ΔB-v	50.80*	43.23
ΔPog'-v = -4.214 + 0.038 x Pog'-v + 0.526 x ΔPog-v	17.72	5.06
ΔGn'-v = 3.493 - 0.033 x Gn'-v + 1.098 x ΔGn-v	72.07*	67.77*
ΔMe'-v = -0.178 + 0.003 x Me'-v + 0.956 x ΔMe-v	89.32*	87.68*

† Abbreviation. Refer to APPENDIX A, page 63.

The above multiple regression equations were repeated to assess whether the presurgical soft-tissue thickness influenced the coefficients of determination and the adjusted coefficients of determination of the lip response (Table 4.2.3.3) and of the soft-tissue chin response (Table 4.2.3.4) to the corresponding hard-tissue movement.

Table 4.2.3.3 Multiple regression equations, coefficients of determination and adjusted coefficients of determination for horizontal and vertical changes in lip position when lip thickness was taken into account. (* = $p \leq 0.05$)

MULTIPLE REGRESSION EQUATIONS	C OF D[†] R2 x 100	ADJUSTED C OF D[†]
ΔLi-h = -2.148 - 0.020 x Li-h + 0.785 x ΔLIa-h - 0.276 x LIa-Li-h	73.70*	69.32*
ΔLi-h = -2.737 - 0.011 x Li-h + 0.753 x ΔLit-h – 0.248 x LIa-Li-h	73.86*	69.50*
ΔLi-h = -6.488 + 0.036 x Li-h + 0.408 x ΔIn-h – 0.197 x LIa-Li-h	51.01*	42.85
ΔStm-i-h = -4.415 - 0.033 x Stm-i-h + 0.445 x ΔLIa-h – 0.520 x LIa-Li-h	35.74	25.03
ΔStm-i-h = -4.808 - 0.028 x Stm-i-h + 0.415 x ΔLit-h – 0.510 x LIa-Li-h	34.71	23.83
ΔStm-i-h = -6.304 - 0.013 x Stm-i-h + 0.237 x ΔIn-h – 0.512 x LIa-Li-h	29.29	17.50
ΔLi-v = -18.091 + 0.182 x Li-v + 1.326 x ΔLIa-v – 0.145 x LIa-Li-h	61.59*	55.19*
ΔLi-v = -21.213 + 0.235 x Li-v + 1.217 x ΔLit-v + 0.040 x LIa-Li-h	60.01*	53.35*
ΔLi-v = -25.300 + 0.320 x Li-v + 0.298 x ΔIn-v – 0.064 x LIa-Li-h	48.52	39.94
ΔStm-i-v = -11.866 +0.165 x Stm-i-v +1.073 x ΔLIa-v +0.053 x LIa-Li-h	58.17*	51.19*
ΔStm-i-v = -14.287 +0.212 x Stm-i-v +1.019 x ΔLit-v +0.214 x LIa-Li-h	57.68*	50.63*
ΔStm-i-v = -16.087 +0.265 x Stm-i-v +0.354 x ΔIn-v +0.094 x LIa-Li-h	48.46	39.87

[†] Abbreviation. Refer to APPENDIX A, page 63.

Table 4.2.3.4 Multiple regression equations, coefficients of determination and adjusted coefficients of determination values for horizontal and vertical changes in chin position when soft-tissue chin thickness was taken into account. (* = $p \leq 0.05$)

MULTIPLE REGRESSION EQUATIONS	C OF D† R^2 x 100	ADJUSTED C OF D†
ΔSi-h = -8.462 + 0.050 x Si-h + 0.821 x ΔB-h + 0.504 x Gn'-Gn-h	89.12*	86.40*
ΔPog'-h = -3.862 +0.068 x Pog'-h +0.783 x ΔPog-h-0.134 x Gn'-Gn-h	91.55*	89.43*
ΔGn'-h = 0.993 + 0.031 x Gn'-h + 0.874 x ΔGn-h – 0.330 x Gn'-Gn-h	95.32*	94.15*
ΔMe'-h = -9.690 +0.079 x Me'-h +0.680 x ΔMe-h +0.443 x Gn'-Gn-h	50.95*	38.68
ΔSi-v = -2.475 + 0.153 x Si-v + 0.216 x ΔB-v – 1.000 x Gn'-Gn-h	55.73*	44.66
ΔPog'-v = 6.027 + 0.038 x Pog'-v + 0.204 x ΔPog-v – 0.963 x Gn'-Gn-h	24.83	6.03
ΔGn'-v = 4.981 - 0.033 x Gn'-v + 1.053 x ΔGn-v – 0.139 x Gn'-Gn-h	72.29*	65.36*
ΔMe'-v = 1.106 + 0.002 x Me'-v + 0.924 x ΔMe-v – 0.114 x Gn'-Gn-h	89.57*	86.97*

† Abbreviation. Refer to APPENDIX A, page 63.

The observations in Table 4.2.3.3 and Table 4.2.3.4 indicate that presurgical soft-tissue thickness only marginally and insignificantly increased or decreased the prediction of the lip and soft-tissue chin response to corresponding hard-tissue movement in both the horizontal and the vertical directions. It may therefore be concluded that presurgical soft-tissue thickness did not influence the relationship of the lip and soft-tissue chin response to the hard-tissue movement.

CHAPTER 5: DISCUSSION

Vertical maxillary excess or 'long-face' syndrome is frequently corrected in the non-growing patient by surgically impacting the maxilla utilizing an osteotomy at the Le Fort 1 level. As a result of this maxillary elevation, the mandible rotates anticlockwise on an arc originating at the condyle. Thus, not only the mid-facial but also the lower facial soft-tissue profile can be altered significantly. The mid-facial soft-tissue changes following superior repositioning of the maxilla have been well documented in the literature (Bell and Dann, 1973; Schendel et al, 1976; Radney and Jacobs, 1981; Mansour et al, 1983; Rosen, 1988). However, only three of the above reports (Schendel et al, 1976; Radney and Jacobs, 1981; Mansour et al, 1983) have mentioned lower lip and soft-tissue chin changes as a consequence of the mandibular autorotation that accompanies vertical maxillary impaction. The chief criticisms of these three reports include the fact that vertical and anteroposterior skeletal movements were combined during surgery, the sample sizes were small, post-operative radiographs were obtained sooner than six months after surgery, mean error values were high and only simple correlations were developed and these were weakly significant. Such lack of scientific data describing the soft-tissue response to a given surgical procedure compels the clinicians to use artistry in the treatment-planning and forecasting process as well as during surgery.

The methodology of the present study was aimed at satisfying as many of the 23 criteria advocated by Betts and Fonseca (1992) as possible, in order to improve the accuracy and consistency of prediction of the ratios of soft- to hard-tissue changes that occur in response to surgical maxillary impaction with consequent mandibular autorotation. Fixed appliances would appear to play no significant role in the posture of the lips as was found by Lin (1983). Cephalometric variability was minimized by exclusively utilizing records that had been taken on the same machine by the same operator using well-established radiographic techniques. The coefficient of variation determining the accuracy of digitizing was less than 1%, well within the 5% level chosen for this study. Furthermore, acceptable limits of intra- and inter-observer accuracy were achieved for landmark identification with the coefficients of repeatability measuring less than 1.5mm for points located on flat surfaces (Baumrind and Frantz, 1971; Mitgard et al, 1974; Hillesund et al, 1978) and less than 2mm for points located on curves with wide radii (Hillesund et al, 1978).

Significant differences were observed post-surgically with respect to the proportional changes in the hard- and soft-tissue landmarks located in the chin area between the patients who underwent maxillary impaction procedures alone and those who had additional advancement genioplasty procedures (Table 4.2.1.1). However, no significant differences ($p>0.05$) were found between the mean changes of the landmarks located in the lower lip area in the two groups. Therefore, genioplasty procedures were not shown to influence the position of the lower lip and thus, for the study of the lower lip changes, the two groups were pooled thereby increasing the sample size to 22. Soft-tissue chin changes, however, were evaluated from the 16 patients who had not undergone an additional genioplasty procedure.

The findings of the present study provide significant information regarding the soft-tissue contours of the lower face response to mandibular autorotation.

No statistically significant change in the lower lip and chin soft-tissue thickness occurred following mandibular autorotation as a result of vertical maxillary impaction (Table 4.2.1.4 and Table 4.2.1.5). The thinning of the upper lip described in the literature in response to vertical maxillary impaction (Bell and Dann, 1973; Schendel et al, 1976) probably results from changes in the length of the facial muscles following their detachment (Schendel and Williamson, 1983). This response did not occur in the lower lip contrary to that reported by Schendel et al (1976), Radney and Jacobs (1981) and Mansour et al (1983) who observed that the lower lip falls somewhat lingual to the arc of mandibular autorotation.

The lower lip lengthened by 1.56mm following mandibular autorotation (measured from stomion inferius (Stm-i) to soft-tissue menton (Me')), probably as a result of relaxation of the musculature in the lip, chin and cheek areas associated with a decrease in the vertical dimension of the lower face (Proffit and Phillips, 1988). This was in agreement with the findings of Schendel et al (1976), Radney and Jacobs (1981) and Mansour et al (1983) who observed that the lower lip unfolds from the labiomental fold superiorly. Furthermore, genial support from the autorotation with greater forward movement of pogonion compared to the incisor tips as well as improved lip competency could play a role in this observation.

Stomion inferius (Stm-i) was found to be an unreliable soft-tissue landmark for predicting lower lip changes in the horizontal direction because its coefficient of determination relative to lower incisor tip (LIT) and lower incisor anterius (LIa) movement was very low at approximately 25% (Table 4.2.2.1). In contrast, labrale inferius (Li) was a significantly more predictable soft-tissue point to measure from, and was found to follow both lower incisor tip (LIT) and lower incisor anterius (LIa) at a ratio of 1:1 with a coefficient of determination of

70% in the horizontal plane of space. This difference in the ratios describing horizontal lip movement as measured at stomion inferius (Stm-i) and labrale inferius (Li) (Table 4.2.2.1) can be explained by the fact that stomion inferius (Stm-i) is located on a curved surface and therefore its identification is more challenging.

In the vertical plane of space, stomion inferius (Stm-i) followed lower incisor tip (LIT) at a ratio of 1:1 and lower incisor anterius (LIa) at a ratio of 1.3:1, with a coefficient of determination of approximately 50% (Table 4.2.2.1). Similarly, labrale inferius (Li) followed lower incisor tip (LIT) at a ratio of 1.3:1 with an approximately 50% coefficient of determination and lower incisor anterius (LIa) at a ratio of almost 1.5:1 with a 55% coefficient of determination. The explanation for the minor difference in the ratios describing the vertical response of the lower lip to the vertical movement of lower incisor tip (LIT) and lower incisor anterius (LIa) is probably based on the effect exerted by anticlockwise rotation of the mandible upon the location of these hard-tissue landmarks in the vertical plane of space.

The lower lip changes, therefore, when measured at labrale inferius (Li), can be described as occurring in an almost 1:1 relationship in response to horizontal movement of lower incisor tip (LIT) and lower incisor anterius (LIa) and in an approximately 1.3:1 and 1.5:1 relationship in response to their respective vertical movement. The horizontal ratio is noticeably greater than that of 0.75:1 described by Mansour et al (1983). Furthermore, it disagrees with the findings of Schendel et al (1976) and Radney and Jacobs (1981) who observed that the lower lip falls inside the arc of mandibular rotation thus resulting in a reduction in its thickness.

Soft-tissue chin changes were examined in both the horizontal and vertical directions at sulcus inferior (Si), soft-tissue pogonion (Pog'), soft-tissue gnathion (Gn') and soft-tissue menton (Me'), relative to their corresponding hard-tissue landmarks (Table 4.2.2.2). In agreement with the finding of previous studies, all soft-tissue points in the chin area responded in an almost 0.9:1 relationship to corresponding hard-tissue movements in both the horizontal and vertical planes of space. Hard-tissue gnathion (Gn) was the most reliable predictor of the soft-tissue chin response in the horizontal plane of space with a coefficient of determination of 94%, while hard-tissue menton (Me') was the most reliable predictor of the soft-tissue chin response in the vertical plane of space with a coefficient of determination of approximately 90%.

No statistically significant correlations could be demonstrated between soft-tissue changes in the horizontal direction and hard-tissue changes in the vertical direction.

Presurgical tissue thickness appears to exert no influence on the response of the lower lip and soft-tissue chin to autorotation of the mandible following vertical maxillary impaction (Tables 4.2.3.1, 4.2.3.2, 4.2.3.3 and 4.2.3.4). This passive soft-tissue response may be explained by the fact that no muscular detachment had been effected in the lower lip and soft-tissue chin region during the maxillary surgery.

The reasons for the difference in results obtained in this study as compared with those of the previous investigations could include the following:

1) In this study, all cephalograms were taken with the lips in repose i.e. muscular tone was consistent between pre- and post-operative radiographs (Burstone, 1967).

2) All cephalograms were taken on the same cephalostat with consistent source-subject and subject-film distances as proposed by Betts and Fonseca (1992).

3) T2 cephalograms were taken at least six months following surgery to accord with Freihofer's (1976) observation that in two thirds of patients, lip profiles changed measurably between four and six months following Le Fort 1 osteotomy, whereas after six months, the profiles attained their definitive configuration. In fact, the T2 radiographs were taken between six and 32 months (mean 15 months) post surgery and it is thus hoped that the long-term soft-tissue effect of autorotation is more accurately described.

4) The sample size comprised 22 patients for the study of the lower lip response and 16 patients for the study of the soft-tissue chin response. In previous studies, the maximum number of patients undergoing vertical maxillary impaction was 14.

5) Only one vector of skeletal movement was performed at surgery i.e. the only movement of the maxilla was in the vertical direction (Betts and Fonseca, 1992).

6) The only concomitant mandibular surgery performed on six of the 22 cases was an advancement genioplasty procedure.

7) No growing subjects were included in the sample.

8) Multiple regression analyses were performed.

9) Error analysis of landmark identification and measurement were well within acceptable limits.

CHAPTER 6: CONCLUSION

Soft-tissue profile prediction methods in relation to vertical maxillary impaction have been refined in recent years with uncertainty still persisting regarding the long-term response of the lower lip and soft-tissue chin to the accompanying mandibular autorotation. The findings of this study have demonstrated that when preparing a forecast tracing for a patient undergoing maxillary elevation with subsequent anticlockwise rotation of the mandible, it must be realized that the soft-tissues of the lower lip and chin will follow the autorotated mandible in an almost 1:1 ratio. However, some subtle but important changes to the lips and chin in the longer term need to be emphasized particularly since the success of the treatment result is closely related to the accuracy of the prediction method.

The long-term changes (mean of 15 months post surgery) to the lower lip and chin following vertical maxillary impaction can be summarized as follows:

1) The lower lip elevates in a ratio of 1.3:1 relative to the vertical change in lower incisor tip and 1.5:1 relative to the vertical change in lower incisor anterius. These ratios are highly significant when forecasting the reduction in the interlabial gap.
2) The soft-tissue chin responds in an almost 1:1 relationship to corresponding hard-tissue movement in both the horizontal and the vertical planes of space.
3) Additional surgery in the chin area exerts no influence on the response of the lower lip to autorotation of the mandible. However, it is recognized that with an inappropriate

surgical technique the complication of lower lip ptosis may occur. This was not observed in the sample employed in this study.

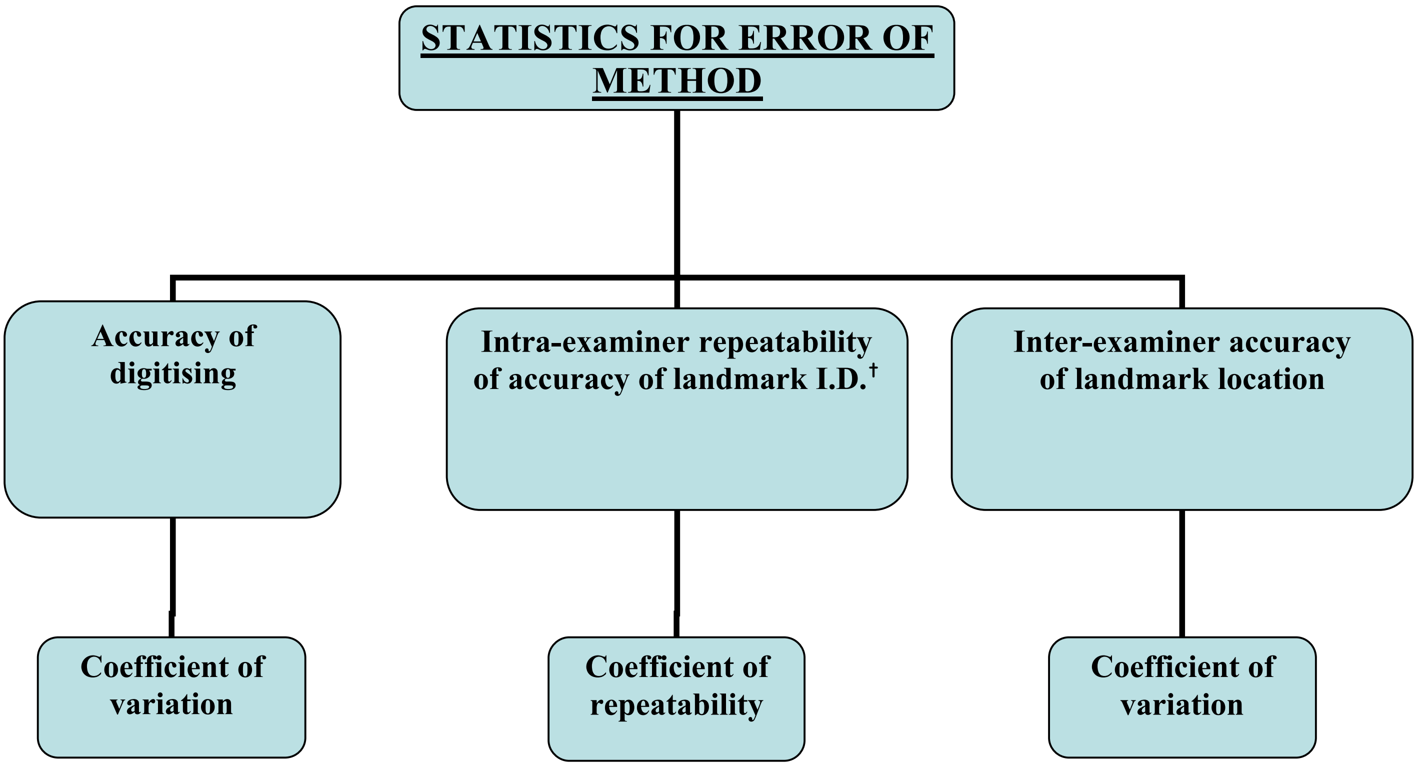
4) Presurgical soft-tissue thickness exerts almost no influence on the response of the lower lip and soft-tissue chin to autorotation of the mandible.

5) The soft-tissue responses of the lower lip and chin to corresponding hard-tissue movement are highly predictable in both the horizontal and the vertical plane of space.

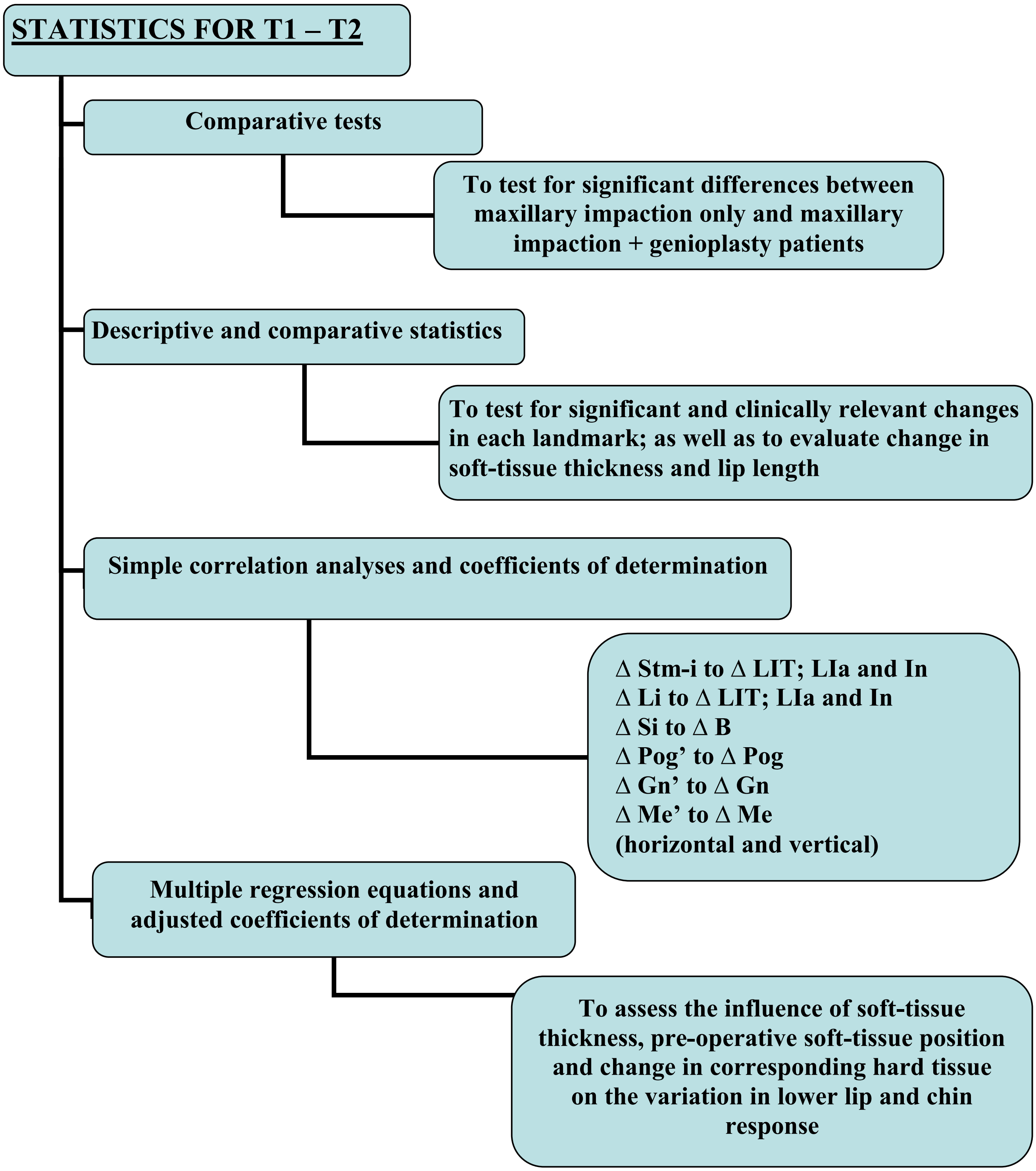
APPENDIX A: Index of abbreviations used in text and tables

Δ	change
≤	less-than or equal to
>	greater than
*	statistically significant, i.e. $p \leq 0.05$
B	supramentale
C OF D	Coefficient of Determination
C.R.	Coefficient of Repeatability
C.V.	Coefficient of Variation
DIFF	differences
e.g.	for example
Gn	hard-tissue gnathion
Gn’	soft-tissue gnathion
GR.	group
h	horizontal
H.T.	hard tissue
i.e.	that is
I.D.	identification
In	infradentale
Li	labrale inferius

LIa	lower incisor anterius
LIT	lower incisor tip
mm	millimetres
Max	maximum
Me	hard-tissue menton
Me’	soft-tissue menton
Min	minimum
Mx.	maxillary
n	number of patients in sample
N	nasion
Pog	hard-tissue pogonion
Pog’	soft-tissue pogonion
R	Pearson Correlation Coefficient
Si	sulcus inferius
Stm-i	stomion inferius
Stm-s	stomion superius
S	sella
S.D.	Standard Deviation
S.E.M.	Standard Error of Mean
S.T.	soft tissue
v	vertical



† Abbreviation. Refer to APPENDIX A, page 63.


STATISTICS FOR T1 – T2
Comparative tests
To test for significant differences between maxillary impaction only and maxillary impaction + genioplasty patients
Descriptive and comparative statistics
To test for significant and clinically relevant changes in each landmark; as well as to evaluate change in soft-tissue thickness and lip length
Simple correlation analyses and coefficients of determination
Δ Stm-i to Δ LIT; LIa and In
Δ Li to Δ LIT; LIa and In
Δ Si to Δ B
Δ Pog' to Δ Pog
Δ Gn' to Δ Gn
Δ Me' to Δ Me
(horizontal and vertical)
Multiple regression equations and adjusted coefficients of determination
To assess the influence of soft-tissue thickness, pre-operative soft-tissue position and change in corresponding hard tissue on the variation in lower lip and chin response

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