

**EVALUATION OF FACIAL SOFT TISSUE CHANGES AND SURGICAL
OUTCOME OF ORTHOGNATHIC SURGERY**

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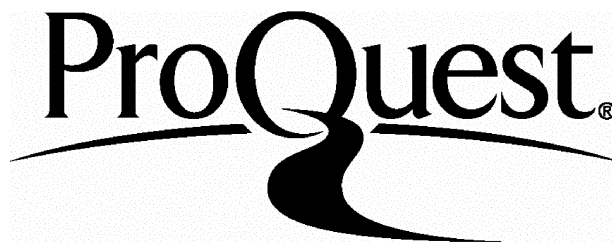
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ABSTRACT

The prediction of soft tissue changes and surgical outcome are main concerns in orthognathic surgery carried out to resolve functional and aesthetic problems. This study programme validated and used the optical surface scanner for assessment of facial appearance for orthognathic surgery treatment planning and postoperative review. The reproducibility of head position for the scans was tested using a headrest, a spirit level and a vertical beam of laser light. The results were analysed using thin-plate splines, a novel morphometric analysis and a useful tool for clinical research. The error due to variation in head position was insignificant. This study found the optical surface scanner an accurate, non-invasive, and user-friendly tool. It was comparable to cephalography with additional advantages of a 3D system.

The presentation of Caucasoid facial patterns in the media determines people's notions of beauty. In line with the homogenisation of culture throughout the world, the panel in this study, although formed of racially different individuals, shared a common base for the assessment and judgement of beauty. Caucasian facial features were perceived more familiar, standard, and beautiful. The best-ranked Afro-Caribbean and Oriental subjects in this study had facial features similar to Caucasians. Facial symmetry, alar base and vermilion border were strong markers for facial beauty according to this study. The chin was coincident and the mid-face was anterior to the facial plane in the most beautiful faces. Other features for a beautiful face indicated by this study included shorter lips, upper incisor exposure of 4-5 mm, equal facial thirds in the vertical height, equal alar base width and intercanthal distance, and equal interlimbus distance and commissural width.

The ratios of the soft tissue changes after correction of Class II and Class III skeletal deformities were quantified and analysed (n=102) using the optical surface scanner and thin-plate splines morphometric analysis for accurate surgical planning. The ratio of soft to hard tissue movement decreased further lateral to the facial midline and on suspended tissues like the lips compared to tissues firmly attached to the underlying structures like subnasale and

pogonion. The soft to hard tissue change ratio was 1:1 on the pogonion but decreased gradually on the labiomental groove (90%) and subcomissural regions (50%). The subnasale projected 80% of the skeletal movement, but the effect on subalar and supracomissural tissues on the upper lip decreased down to 35%. The nasal tip was least affected by 30% despite an 80% change on paranasal regions. The interaction of one lip with the other, and with the incisors affected the lips as well as the skeletal movement. The upper lip vermilion projected up to 75% of the surgical change and the upper vermilion width increased from 7.2 ± 2.3 mm to 8.7 ± 2.1 mm which was statistically significant ($p < 0.05$), but the mean lower lip vermilion width increased from 9.9 ± 2.4 mm to 10.4 ± 2.2 mm which was not significant ($p > 0.05$). The prediction of soft tissue changes after orthognathic surgery can be difficult because these changes depend on various factors including; muscle attachments, proximity of the soft tissues to the underlying bone, the geometrical shape of the bones, soft tissue elasticity, thickness, surgical technique and the magnitude of surgical movement. However, this study highlighted the regions of the face significantly affected by the osteotomy movements.

The role of the occlusal wafer and training elastics in postoperative proprioception was evaluated. The patients ($n=100$) were randomly divided into three groups; a) training elastics and occlusal wafer, b) elastics but no wafer and, c) no elastics and no wafer, for the first 2 postoperative weeks. The findings indicated that routine use of occlusal wafers and training elastics did not lead to a significant difference in the postoperative occlusion. The theoretical value of providing proprioceptive guidance was concluded to be more comforting for the surgeon than the patient. However, it is believed to provide a visible means of clinical assessment. Results of this investigation would contribute significantly in diagnosis, treatment planning and postoperative management of orthognathic surgery patients.

DEDICATED TO MY FATHER,

MEHMET SAIT SONCUL (1933-1991)

*Living is no laughing matter:
you must live with great seriousness
like a squirrel, for example-
I mean without looking for something beyond and above living,
I mean living must be your whole occupation.*

NAZIM HIKMET (RAN)

February 1948

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Declaration

I hereby certify that the work embodied in this thesis is the result of my own investigations, except where otherwise stated.

Murat Soncul

2001

London

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CHAPTER I

INTRODUCTION

AND

REVIEW OF THE LITERATURE

1.1 Aesthetics of the human face

Facial aesthetics is an important daily issue, which interests many people around the globe. It affects several issues including self-esteem and other parts of human psychology. A beautiful human face inspires pleasure and interest and often attracts attention.

Facial appearances tend to influence the opinion of those we meet. Etcoff (1994) claims that even two month-old infants prefer to gaze at the same faces that adults find more attractive. There is a natural and sometimes unconscious attraction to a beautiful person. Whether this indicates that there may be some inherent predisposition towards certain types of appearance, or not, is unknown.

Our attitude to our own physiognomy and body structure is a potent factor in the emotional and intellectual development of the individual. Schilder (1999), in *'The Image and Appearance of the Human Body'*, says that we should not underrate the importance of beauty in human life. "Beauty can be a promise of complete satisfaction and can lead up to this complete satisfaction. Our own beauty or ugliness will not only figure in the image we get about ourselves, but will also figure in the image others build up about us and which will be taken back again into ourselves. The body image is the result of social life. Beauty and ugliness are certainly not phenomena in the single individual, but are social phenomena of the utmost importance. They regulate and thus become the basis for our sexual and social activities." Beauty is interrelated and identified with the secondary sexual characteristics.

Darwin suggested that beauty was a form of sexual selection for mating purposes and Freud states, "The science of aesthetics examines the conditions under which we experience beauty. It can not give an explanation of the nature and genesis of beauty." (Parisi 1999).

Many patients with facial deformities have problems in coming to terms with their facial disfigurement, which they try to hide or mask. Their ability to overcome the problem depends on their attitude and personality and upon the feedback and support they get from their environment. One patient with a treated facial deformity defined happiness as, "when you go around the supermarket without anyone staring at you" (Moss *et al.*, 1995).

1.2 Early approaches to facial aesthetics

Ever since man has tried to define the different components of beauty in order to be able to reproduce it in art, he has searched for formulae of beauty and its measurement (Gonzales-Ulloa, 1962). With the development of Egyptian culture in the Nile valley approximately 5000 years ago, aesthetic attitudes were abundantly recorded in art. The statuary of Egyptian royalty found in monuments and tombs tend to display the Egyptian ideal of beauty, harmony, and proportion, while maintaining only a vague resemblance to the persons represented (Figure 1.1).

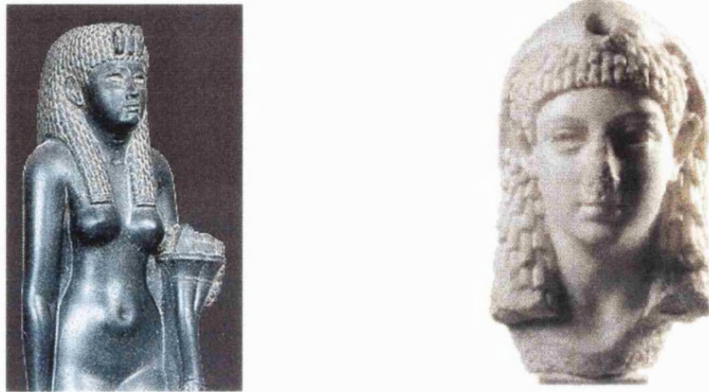


Figure 1.1- Black basalt statue of Cleopatra VII. The State Hermitage, St Petersburg. Courtesy of The British Museum (left). Marble statue of Cleopatra VII. 1st century B.C. Courtesy of Musei Capitolini, Rome (right).

Just as ancient Egypt appears as the first culture to have captured facial resemblance in stone, classical Hellenic civilisation emerges as the first to express sensitively the qualities of facial beauty through philosophy and sculpture (Figure 1.2). Greek philosophers, notably Plato and Aristotle, questioned the intrinsic meaning of beauty and introduced “aesthetics” as both the study of beauty and the philosophy of art. Plato assessed that “the qualities of measure and proportion invariably constitute beauty an excellence” (Peck and Peck, 1970).

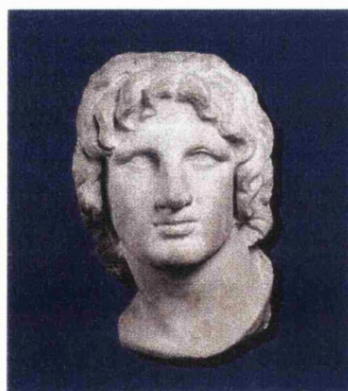


Figure 1.2- Marble portrait of Alexander the Great, dating to about 150 years after his death in 323 BC. Courtesy of The British Museum.

Just like the ancient sculptures and paintings from the Egyptians, Greeks, Romans, and many other great civilisations, famous artists during the last millennium, especially during the Renaissance conveyed to us the perception of beauty in their times with their immaculate work. As early as the 15th century, artists like Albrecht Dürer and Leonardo da Vinci studied the human body and facial proportions. Dürer (1591) studied facial disharmonies and gave a series of measurements, from which he created his 'ideal face' (Gonzales-Ulloa, 1962). He is the first artist who is known to have painted a self-portrait (Figure 3.7) and had a great knowledge of human facial aesthetics based on diagrams defining facial proportions. Da Vinci produced immaculate masterpieces of art and study drawings of the human face and body, which accumulated a great amount of material on proportions (Figure 1.3). He tried to establish individual characteristics in accordance with these various proportions (Gonzales-Ulloa, 1962).



Figure 1.3- Head of a Warrior by Leonardo da Vinci, which was produced as a study for "The Battle of Anghiari" (1504-1506) from Szepmuvesti Museum, Budapest.

Apart from artists, and surgeons such as Gonzales-Ulloa (1962), Lee and Lee (1979), Farkas and Posnick (1992), Farkas *et al.* (1999), also orthodontists; Merrifield (1966), Ricketts (1982) have tried to establish norms and guidelines for assessment of a beautiful face.

1.3 What is aesthetics?

Aesthetics is concerned with the study of of beauty together with ethics, logic, politics, and metaphysics, and is a branch of philosophy. The understanding of beauty is considered as a subjective concept, hence the saying "beauty is in the eye of the beholder" by M. Hungerford (Knowles, 2001).

Questions like "what is beauty", and "is there any difference between the concept of beauty and attractiveness" have not been clearly answered, but it has been possible to define facial beauty as the harmony and balance in the proportions of all facial structures, both soft and hard tissues.

Ricketts (1982) states that "a beautiful face will have rhythm and rhythm is produced by the dynamic action of proportion on a uniform recurrence". The word 'rhythm' means to flow. Rhythm is seen in time, dimension, music, and poetry. It is pleasing to the ear, the eye, and the psyche. The beautiful human face has rhythm, both transversely or in width and height.

Although some aspects of the judgement of facial beauty may be influenced by culture or individual history, the general geometric features of the face that give rise to a perception of beauty may be universal (Moss *et al.*, 1995).

1.4 Search for perfection

Many studies have been done on evaluation and perception of facial aesthetics using different methodology. Basically these studies can be divided into two categories;

- 1) The studies that assessed the perception of facial beauty between groups of people by using different type of panels.
- 2) The studies which tried to establish quantitative measurements, 'the golden proportions' and characteristic features for a beautiful face.

Riedel (1950) traced the soft tissue outline from the cephalometric radiographs of 24 children and asked 72 orthodontists to rate them as good, fair, or poor. He found that there was greater agreement on poor profiles than those that were considered good. He concluded that the relation of the maxillary and mandibular apical bases in an anteroposterior dimension (ANB angle), the convexity of the skeletal pattern (N -A -Pg angle), and the relation of anterior teeth to the face and the respective apical bases were important influences in the soft tissue outline. He also evaluated the facial profiles of 30 Seattle 'princesses' from cephalometric radiograph (Riedel, 1957). These females were selected by public opinion and were considered to be beautiful and to have charming personalities. It was observed that the profile was closely related to the skeletal and dental structures. The long axis of the maxillary and mandibular incisors crossed exactly at the A - Pogonion line in nine cases with a maximum deviation of 3 mm from this line in nine others. He concluded "the general concepts of acceptable facial aesthetics are

apparently in good agreement with standards established by orthodontists on the basis of a stable occlusion". Iliffe (1960) conducted an interesting study of preferences in feminine beauty. He made arrangements with a major London newspaper to publish twelve photographs of female faces taken under uniform conditions. The girls, aged twenty to twenty five, were carefully selected to represent various facial types. Nearly 4300 readers responded to the request to rank the twelve faces according to their pleasing facial aesthetics or 'prettiness'. Each response was correlated to the age, sex, and occupation of the respondent. He concluded that a common basis for judging facial beauty indeed existed, and men and women of all ages in all parts of England in almost all occupations shared that basis. Martin (1964), a sociologist, examined the relationship between racial groups and judgement of female beauty by males. He asked a panel to rank ten black and white facial photographs of Afro-Caribbean females from the least Negroid to the most Negroid. The least Negroid type was understood to have the most Caucasian appearance. After the panel ranked the photographs, three groups of men, fifty Caucasian Americans, fifty Afro-Caribbean Americans and fifty Africans were asked to rank the photographs according to attractiveness. They strongly supported the proposition that Caucasian and Afro-Caribbean Americans share a common aesthetic standard for judging beauty, the Caucasian facial model. This study also confirmed that Caucasian features were considered more attractive than Negroid features in American society. However, the African group rated Caucasian facial features 'attractive' less often than either of the American groups.

Peck and Peck (1970) made a similar study on the faces of beauty contest winners, and unlike Riedel (1957), concluded that the lay public admire a fuller and more protrusive dentofacial relationship than one based on orthodontic standards. Cox and Van der Linden (1971) compared the aesthetic assessment of 10 orthodontists and 10 laypersons based on full head silhouettes for good facial balance, and reported that the subjects with poor facial aesthetics had convex faces. Foster (1973) used six groups of professionals and laymen to evaluate male and female faces at ages 8, 12, 16, and as adults. His results showed that there was a general agreement between the groups for age and gender of the full-face silhouette profiles. All groups related full profiles to the female and to the younger ages and straight profiles to male and to older age groups. In a similar study, Lines *et al.* (1978) found significant differences in evaluations of facial profile silhouettes among orthodontists, oral surgeons, other dental professionals and laypersons. Although orthodontists were more critical in their assessments than oral surgeons, both were significantly different in their evaluations from the other two groups. It was also observed that males had larger noses and chins than the females.

Andersen *et al.* (1979) studied differences in perceptions of dentofacial morphology among orthodontists, general dental practitioners, and parents of patients. Significant differences were found between the evaluations of the parents and the professional groups, but no significant differences between the evaluations by orthodontists and general dental practitioner. Ricketts (1982) did a profound study in facial beauty by using measurements of

plaster models of subjects with normal occlusion and lateral and frontal cephalometrics. He used frontal view photographs from advertisements in the magazines. Variations of the beautiful photographic models were analysed together with computerised composites of patients with ideal occlusions. Several key relationships were found like the association of canine width with soft tissue nasal width in the smile. The study strongly suggested that aesthetics could indeed be made scientifically rather than the need to resort to subjective perceptions as in the past.

Bell *et al.* (1979) reported that laymen's ratings of an individual's profile are similar to the ratings given by dental specialists in orthodontics and oral surgery, but they tend to perceive others as more normal than dental specialists. It was also reported that oral surgeons and orthodontists evaluate facial profiles similarly. Dunlevy *et al.* (1987) assessed composite photographs of 19 female patients who underwent bilateral sagittal split osteotomy advancement and showed general agreement among laymen, orthodontists, and oral and maxillofacial surgeons concerning patients' improvement in facial appearance following orthognathic surgery. The panel were asked to rank the patients in order of improvement in facial appearance.

Lundstrom *et al.* (1987) set up a panel, which consisted of 20 individuals (orthodontists, artists, laymen, senior orthodontic students, and junior orthodontic students). They made independent aesthetic evaluations of the facial appearance of 64 subjects (32 of each sex). The panel showed good

agreement in ranking the subjects in five categories; very good-looking, good looking, average, disharmonious, and very disharmonious.

Kerr and O'Donnel (1990) used a panel of orthodontists, dental students, art students, and the parents of the children undergoing orthodontic treatment who assessed full face and profile photographic transparencies of 60 subjects divided equally among Angle Class I, II, and III malocclusions, taken before and after treatment. The Class I subjects were rated more attractive than subjects with Class II and Class III malocclusions. Art students and parents of children were less critical in the appraisal of facial attractiveness than orthodontists or dental students. Czarnecki *et al.* (1993) assessed the role of the nose, lips, and chin in achieving a balanced facial profile. Five hundred and forty five professionals evaluated constructed androgynous facial silhouettes. The silhouettes had varied nose, lip, and chin relationships as well as changes in the facial angle and angle of convexity. These varied facial profiles were graded on the basis of most preferred to the least preferred. It was found that in men a straighter profile was preferred in comparison with a slightly convex profile for the females. Among the various unfavourable combinations, the worst ones were either an extremely recessive chin or those with excessively convex faces. More lip protrusion was found acceptable for both male and female faces when either a large nose or a large chin was present.

Moss *et al.* (1995) used a 3-dimensional technique in analysing facial aesthetics. Forty men and women with a Class I skeletal pattern and

occlusion were scanned and an average face was obtained for each group. The averages were compared with those derived from a group of 9 men and 15 women employed as professional models. The group of professional models were further analysed to see whether they measured up to the “golden proportions” described by the ancient Greeks. The groups did not fit the “golden proportions” and they instead represented a range of malocclusions and a wide range of cephalometric values. A group of normal Asian teenagers were also scanned to investigate ethnic differences.

Freihofer and Mooren (1997) showed the variations in personal views and perception. Ten unbalanced profile drawings were given to seven experienced surgeons with the request that they draw the profile line they would like to give to these patients. The evaluation showed that some surgeons drew profiles which resembled each other to some extent in proportions and inclinations, while others produced variations without any evident regularity and basic concept. Cochrane *et al.* (1997, 1999) manipulated black and white photographs from 4 Class I adult Caucasians to produce Class II and Class III malocclusions and long face profiles for each individual. Each series of photographs were shown to 40 Caucasian orthodontists (20 of each gender) and 40 Caucasian adult laymen (20 of each gender). The assessors were asked to rank each series in order, from the most pleasing to the least pleasing facial profile. The only significant difference was between orthodontists and non-orthodontists.

In summary, numerous studies show that the 'perception' of beauty differs significantly amongst different cultures, racial groups, genders, age groups, and between health professionals and 'laymen'. Clearly therefore, the search for 'the perfect face' will be infinite and individual; however facial characteristics presented by the patient as a problem can be analysed by the surgeon and the orthodontist using existing methods for assessment of the sections of the face and its components.

1.5 Assessment of the face

In order to assess a face in frontal view, the total face height is divided in three parts. The upper, middle, and lower facial thirds may be defined as the distance from trichion to glabella, glabella to subnasale, and subnasale to gnathion, respectively (Figure 1.4). In an ideal face, all facial thirds are equal and the upper lip constitutes one third of the lower facial height (Zaoli, 1994).

Koury and Epker (1992) stated that the ratio of the upper, middle, and the lower facial thirds to the total facial height in a normal beautiful Caucasian is 0.30, 0.35, and 0.35 respectively.

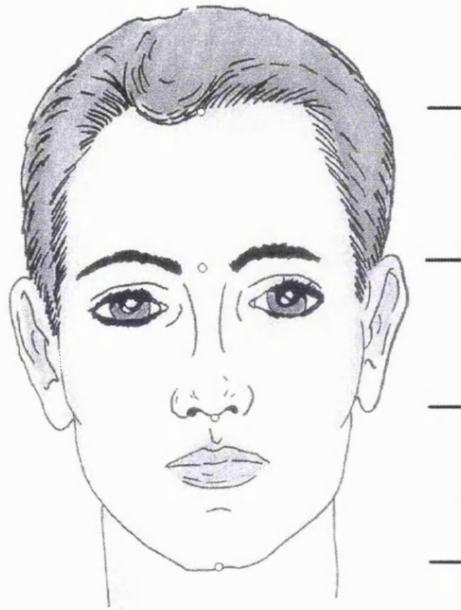


Figure 1.4- The upper, middle, and lower facial thirds may be defined as the distance from trichion to glabella, glabella to subnasale, and subnasale to gnathion, respectively.

1.5.1 Upper third of the face

Forehead

The upper facial third is perhaps the most variable, since it is affected by the hairline and hairstyle. The morphology of the upper facial third may be quantified by calculating the ratio of the bitemporal width ($Ft - Ft$) to the height of the upper facial third ($Tr - G$). According to Epker *et al.* (1995), the ratio for Caucasians is approximately 2.20. Values less than 2.20 should indicate a long/narrow third; greater than 2.20 a short/wide third. Shape and symmetry of the temporal areas, frontal areas, eyebrows, and supraorbital rims are also observed.

1.5.2 Middle third of the face

The morphology of the middle third of the face is quantified by calculating the ratio of the bizygomatic width (Zy - Zy) to the height of the middle third (G - Sn). Again according to Epker *et al.* (1995), this ratio is approximately 2.20 in female Caucasians, and 2.30 in males.

Eyes

Evaluation of the eyes and orbits should begin with measurements of intercanthal and interpupillary distance (Figure 1.5).

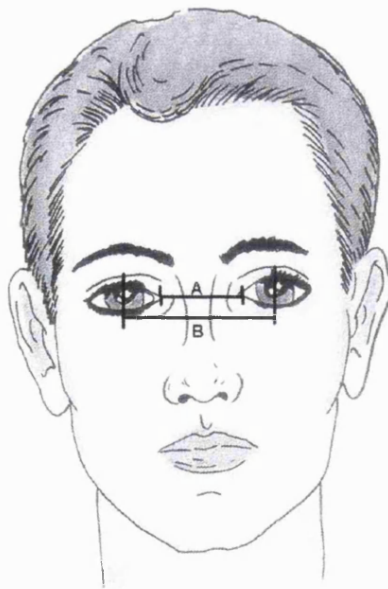


Figure 1.5- A) Intercanthal distance B) Interpupillary distance.

The mean values for Caucasian adults are; intercanthal distance, 34 ± 4 mm, and interpupillary distance 65 ± 4 mm (Epker *et al.*, 1995). The vertical symmetry of the inner and outer canthi is recorded. Generally a true horizontal line will bisect the inner and outer canthi of both eyes. The upper

and lower eyelids are evaluated for right to left symmetry and especially for the presence of ptosis, ectropion, or entropion. Deep-set eyes, as well as their protrusion, also affect the aesthetic appearance of the face.

Nose

The nose is a subject of special interest in facial aesthetics and cosmetic surgery. How much the morphology of the nose affects the appearance of the face is known for centuries. Agnolo Firenzuola in the 16th century expressed it thus: "Those who do not possess a perfect nose cannot have a beautiful profile...The nose must be of correct proportions...It should be narrow rather than wide and tapered from the root to the base...The tip should be turned up a little and project as if sculptured. The nostrils should be thin and sharp cut." (Zaoli, 1994).

There are three parameters by which the proportions of the nose can be determined, namely the length, the width of the base and the height of the tip. In addition the size, and characteristics of alae, lobule, columella complex are of aesthetic importance (Skinazi *et al.*, 1994).

Length- To compare the length of the nose with that of the face; the nose constitutes the middle third of the height of the face.

Width of the base- In a well proportioned Caucasian face, to establish the distance which the various parts should have from the midline, it is divided by six vertical lines which go from helix to helix forming five equal portions, the middle one of which includes the nose, should be equal to the width of the

eye (Figure 1.6). For Caucasians, the width of the alar base should be equal to the intercanthal distance (Zaoli, 1994; Hunt and Rudge, 1984).

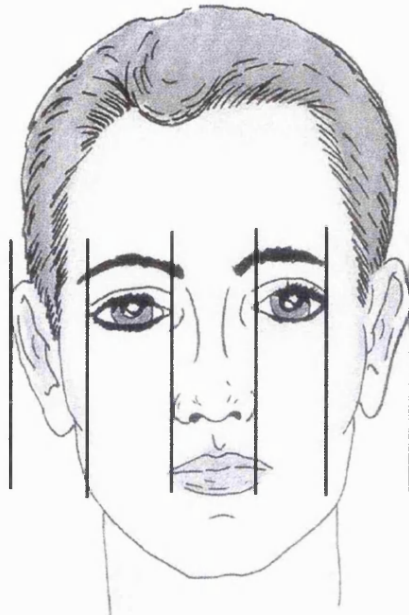


Figure 1.6- A well proportioned Caucasian face is divided by six vertical lines, which go from helix to helix forming five equal portions, the middle one of which includes the nose should be equal to the width of the eye.

Examination of the middle third includes assessment of the nasal dorsum and nasal tip, the fullness of the cheeks and the anteroposterior position of the infraorbital rims, which should project between 0 - 4 mm in front of the globe (Fish and Epker, 1987).

Cheeks

Evaluation of the cheeks consists of sequential assessment of the malar eminences, infraorbital rims, and paranasal areas for symmetry and normal projection. The malar eminences are normally present 10 ± 2 mm lateral and

15 ± 5 mm inferior to the lateral canthus (Epker *et al.*, 1995). However, such precise measurements are unlikely to be validated.

1.5.3 Lower third of the face_

The morphology of the lower facial third may be quantified by calculating the ratio of the bigonial width (Go - Go) to the height of the lower facial third (Sn - Gn). The normal ratio is 1.30 (Epker *et al.*, 1995). Ratios less than the norm indicate a facial third that is long and/or narrow; values greater than the norm indicate that the lower third is short and/or wide. The normal vertical length of the lower third of the face is approximately equal to that of the middle third. The ratio of the vertical distance from subnasale (SN) to upper lip stomion and that from upper lip stomion to soft-tissue gnathion (Gn) is about 1:2. The ratio of the vertical distance from subnasale to the vermilion cutaneous margin of the lower lip (labrale inferius) and that from the vermilion cutaneous margin of the lower lip (labrale inferius) to soft tissue menton is about 1:1 (Epker *et al.*, 1995) (Figure 1.7).

Lips

The lips are extremely important in the overall aesthetics of the face and are evaluated both at rest and during animation (e.g. smiling). At rest, the symmetry of the lips relative to the face and the dentition is noted. The lower lip should show 30 percent more vermilion than the upper (Fish and Epker, 1987). The width of the lips from commissure to commissure in an adult Caucasian is normally about equal to the interlimbus distance (the distance from the vertical tangent on the medial point of the junction of the iris and the

sclera of one eye to the tangent of the medial point of the junction of the iris and the sclera of the other eye), (Epker *et al.*, 1995). Farkas *et al.* (1984) showed that the upper lip occupied one third of the lower face, while the lower lip occupied more than one third of the lower face and the chin occupied the remainder (Figure 1.7). Skin covered 73.5% of the upper lip in males and 68% in females; it covered 63% of the lower lip in males and 61.1% in females. The remainder was occupied by the vermilion, more on the lower than on the upper lip and more protruding in females than in males.

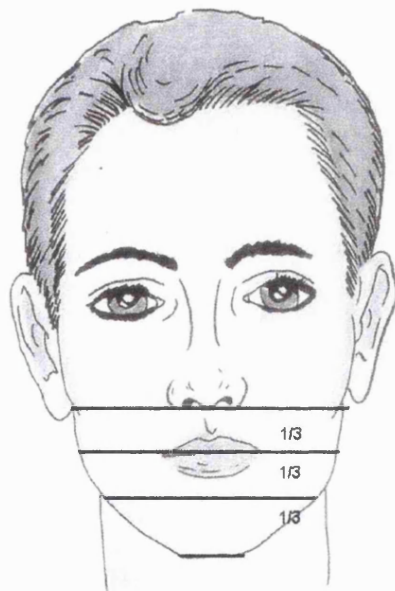


Figure 1.7- The ratio of the vertical distance from subnasale (SN) to upper lip stomion and that from upper lip stomion to soft-tissue gnathion (Gn) is about 1:2.

Teeth

Symmetry is the most important factor in producing an aesthetic smile. This includes the symmetry of both lip movement and tooth exposure. When the lips are at rest the interlabial distance should be 3.5 mm (Burstone 1967; Fish and Epker, 1987), and 2-3 mm of upper incisor tips should be seen. The

amount of exposed incisor teeth and gingival tissue should also be assessed while the patient is smiling. The least aesthetic condition exists when no exposure of the upper teeth occurs during smiling because the teeth are so superiorly located that despite normal lip movement, they never become visible. The lower teeth are seldom exposed at rest.

Mandible

Morphology of the mandible is of particular importance as well as the manner in which the dental arches articulate. The three type of articulation are:

- 1- Orthognathism; no change in facial profile, normal profile.
- 2- Retrognathism; the lower lip and chin project backwards.
- 3- Prognathism; the lower lip and chin project forwards.

The mandibular angles are evaluated with regard to both their symmetry and fullness as being deficient, normal or excessive. The definition of the mandibular angles and inferior borders of the mandible is an important consideration in the neck aesthetics. The mandibular borders become less well defined when tissue laxity, lipomatosis, chin deficiency, and/or hyoid bone sag become progressively worse.

Chin

An appreciation of facial harmony is profoundly influenced by the shape, size, and proportion of the chin relative to the other facial features. The morphology of the chin is determined by a combination of skeletal and soft tissue components.

In the lower third of the face, lips, the chin and neck-chin line should be assessed and their relative positions determined.

1.6 Profile view analysis

Looking at each facial third individually and finally at the overall balance is the basis of profile analysis (Neger, 1959). The position of the orbital rims, eyeballs and shape of the forehead are noted in order to assess their relative anteroposterior positions. Normally, the supraorbital rim should project 10 ± 2 mm beyond the globe of the eye (Hunt and Rudge, 1984).

Naso-frontal angle - In a profile view the naso-frontal angle is between two lines passing through the nasion, the first at a tangent to the glabella, and the second resting on the dorsum. The size of the angle varies between 125 and 135 degrees (Zaoli, 1994) (Figure 1.8).

Nasofacial angle - This is the angle between a vertical line which touches the glabella and the chin, and a second one which touches the dorsum of the nose (Figure 1.8).

The nasolabial angle - This angle is important as it measures the inclination of the columella in relation to the position of the upper lip, which is affected by the angulation of the teeth. The optimum should vary between 90 and 120 degrees. The lines, which form the nasolabial angle, intersect at the subnasale point. The upper one passes through the most projecting point of the columella and the lower one touches the muco-cutaneous line of the

upper lip. The point at which the lines meet is the subnasale point (Figure 1.8).

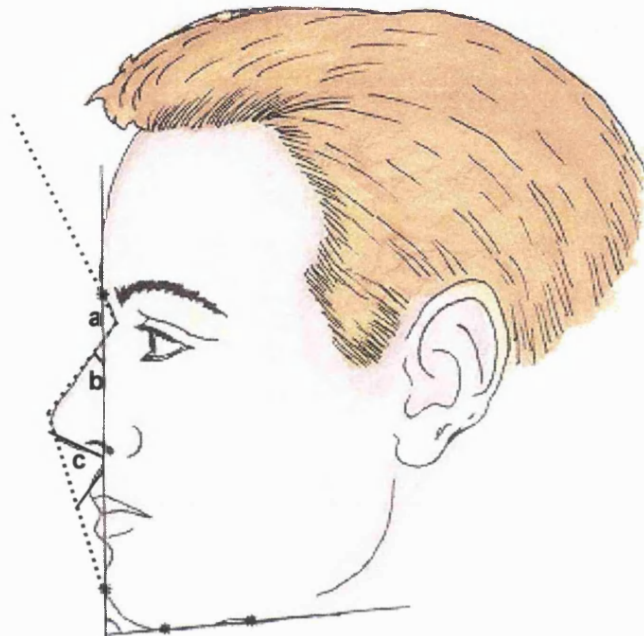


Figure 1.8- Angles used for profile analysis: (a) nasofrontal angle, (b) nasofacial angle, (c) nasolabial angle.

1.7- Evaluation of soft tissue changes following orthognathic surgery

The position of the underlying hard tissue is the main determinant of the overlying soft tissue morphology for the face. Certain parts of the face are very dependent on the underlying hard tissue support, whereas the relation and support between lips and teeth, chin and bony chin, cheeks and malar prominence may vary. Therefore, the changes observed following orthognathic surgery would be different in different regions of the face. It must also be noted that many other structural elements enter the configuration of

the face, like muscles, connective tissue and cartilage, therefore, all parts of the soft tissue profile do not directly follow the underlying bony structure (Subtelny, 1959).

Many evaluations of soft tissue changes after orthognathic surgery have been undertaken, and many correlation of soft tissue to hard tissue movements have been attempted. Changes in facial aesthetics after orthognathic surgery should be predictable if the planning is to be satisfactory. The skeletal elements are moved in a planned and controlled manner, but the soft tissue drape is not as precisely managed. This is mainly due to the lack of an agreed conclusion for correlation of soft to hard tissue movements.

Opposing many researchers, Bailey *et al.* (1996) compared the soft tissue changes occurring on patients who had orthognathic surgery and ones who had only non-surgical orthodontic treatment, and could not find significant difference between the changes occurring in each group of patients. They added that, especially in long-term follow-ups, external factors like normal ageing process could affect the soft tissues so doing isolated observation of soft tissues was difficult. The small soft tissue changes were probably due to a combination of hard tissue remodelling and continued maturation.

There is an increased interest in soft tissue changes especially after a better co-operation between the orthodontist and the maxillofacial surgeon.

1.7.1 Maxillary procedures

The interest of researchers have been towards mandibular surgery more than maxillary procedures till the 80's and these few studies were less than thorough. The sample sizes were small and many of them were mainly concerned with maxillary lip changes due to maxillary incisor change. Bell and Dann (1973) described a ratio of 0.7 ± 0.1 for upper lip movement relative to upper incisor movement in predicting upper lip position after anterior maxillary osteotomy. They could not present a meaningful correlation between vertical movement at the upper lip vermilion border and point A and anterior nasal spine, but described it as a final composite relationship. Two years later, Bell (1975) drew the attention to the widening of the alar base after Le Fort I maxillary advancement or impaction. In 1976, Dann *et al.* investigated the soft tissue changes occurring after anterior maxillary advancements. Using a small group of 8 patients, they proposed a horizontal change in the upper lip to a horizontal change in the upper incisor of 0.5 ± 0.1 ; a vertical change in the upper lip to the horizontal change in the upper incisor of 0.3 ± 0.15 ; a decrease in the nasolabial angle to the horizontal change in the upper incisor of 1.2 ± 0.3 degrees per millimetre; advancement of the nasal tip in a ratio of 2:7. They estimated a ratio of 1:2 for soft to hard tissue movement with total maxillary osteotomy. In addition, they stated that the nasal dorsum was unaffected, the thickness of the upper lip diminished, the length of the upper lip increased while the lower lip changed only slightly. Freihofer (1976) emphasised the importance of elasticity of the upper lip reflecting the movements of the underlying bones comparing cleft and non-cleft cases. He observed an increase in upper lip length after maxillary advancement. He presented the

ratio of movement at subnasale to point A as 4:7 and the ratio of movement at labrale superius to upper incisor as 5:9, which showed that the free end of the upper lip advanced nearly half the movement of the dental arch. In a study done by Carlotti *et al.* (1986) evaluating the facial changes after maxillary advancement, the ratio between incisor advancement and lip advancement was 1:0.9 and the changes in lip length and position of the nasal tip was not significant. Other variables including tissue thickness over surgically manipulated bony segments, magnitude of movement, accompanying vertical movement, and removal of anterior nasal spine were considered as crucial. In 1989, Stella *et al.* reported the results of a study taking all these variables into consideration but their results produced high standard deviations therefore, clinically relevant correlation between hard and soft tissue could not be made. Only when lip thickness was considered in a special grouping of patients with lips thinner than 17 mm, this showed a good correlation between hard and soft tissue changes. The change in subnasale/maxillary advancement ratio was 0.5 ± 0.1 but thicker lips produced a less predictable correlation. Schendel *et al.* (1976 a, b) investigated the results of maxillary impaction on soft tissues. Their results indicated that the ratio of posterior movement of the upper lip to retro positioning of the maxillary incisor is 0.76:1. Vertical change in the upper lip to vertical movement of the upper incisor showed a ratio of 0.38:1 and the nasal tip elevated slightly. There was no explanation offered by the authors for the lack of consistent upper lip response to superior movement of the maxilla, which can actually be explained by varying muscular factors. They also failed to examine the degree the nasal profile, nasolabial angle and nasal base were

affected, inversion and thinning of the upper lip, the effect of anterior nasal spine on soft tissue response for maxillary impaction. In a later study by the same investigator, 2.4 mm average elevation of the nasal tip with no change in upper lip length and thickness was reported (Scheldel and Williamson, 1983). Radney and Jacobs (1981) found that the most anterior point on the upper lip followed approximately 70 percent of the movement of the upper incisor after maxillary impaction and retraction, but the upper lip followed only 50 percent of the movement of the upper incisor when the maxilla was impacted and advanced. The vertical change in the upper lip was 40 percent of the vertical change in the maxillary central incisor. Mansour *et al.* reported similar findings to this study in 1983. An approximate ratio of 0.4:1 of vertical upper lip movement to vertical movement of maxillary incisor was shown. The 0.6:1 ratio of horizontal upper lip movement to the horizontal change in the maxillary incisor suggested by this study agrees with the results reported by Lines and Steinhauser (1974). The authors concluded that the upper lip followed the movement of the underlying skeletal tissue closely in the horizontal plane for maxillary impaction and the lower border of the upper lip moved superiorly approximately 40 percent of the vertical maxillary change. A reduction in the length of the upper lip vermilion border was reported. The nasolabial angle was unpredictable for impaction cases, but decreased in the majority of the advancement cases. Radney and Jacob in their study mentioned above (1981) found that the nasal tip moved superiorly 1 mm for every 6 mm of maxillary impaction without a significant correlation in the horizontal direction. They noted that soft tissue change occurred more at subnasale than at the nasal tip, and increase in the nasolabial angle was less

than expected when the maxilla was advanced because of the increase in the columellar leg of the nasolabial angle. The columellar leg was prone to decrease with maxillary impaction. The change in the lower lip was found to be unpredictable following maxillary intrusion. Bundgaard *et al.* (1986) claimed that pronasale and subnasale were not influenced by the change in maxillary position but the superior sulcus of upper lip followed the underlying hard tissue with a ratio close to 1:1. On the other hand, stomion followed the maxilla by 50% horizontally and 30% vertically. The angular displacements of the maxilla were found to be significantly predictable whereas, vertical and horizontal displacements were of minor influence. There was low correlation between the nose and the hard tissue movements, whereas, upper lip was more correlated to the bony movements. Rosen (1988) observed increases in nasal tip projection with advancement of the maxilla, but this was not statistically significant. His results showed that the movements of point A in both horizontal and vertical dimensions had a significant impact on nasal tip projection, but the correlation was poor. It was observed that alar rim width increased with anterior and/or superior repositioning of the maxilla, but increase in nasal tip projection occurred only when there was an anterior vector of maxillary movement. Eighty percent of patients undergoing maxillary impaction in this study had lip shortening ranging from 20 to 50 percent of the vertical maxillary reduction, but no statistically significant correlation could be demonstrated for lip shortening versus extent of maxillary impaction.

More recent studies had a different look at the soft tissue changes. The focus of research turned from the evaluation of the lateral profile to a multi-

dimensional evaluation of soft tissues. More researchers started considering the lips and the nose including their peripheral areas. Widening of the base of the nose, associated flattening and thinning of the upper lip were stated typically in most papers as a result of maxillary surgery. All these changes are secondary to alterations in the regional anatomy associated with surgical repositioning. In 1991 Sarver and Weissmann summarised the soft tissue changes associated with maxillary impaction as elevation of the nasal tip, increase in nasolabial angle, increase in alar base width, shortening of lip length and changes in upper lip position concurrent with horizontal movements of the maxilla. They clearly stated that all these changes occurred in the short term but many of the soft tissue characteristics returned to their preoperative measurements. Westermarck *et al.* (1991) derived their data to conclude that Le Fort I osteotomy with advancement and/or impaction increased alar base width, anterior and superior projection of the nasal tip and nasolabial angle. They described the alar base suture to reduce alar flaring and to add to the increase in the nasolabial angle produced by the surgical procedure. They claimed this technique did not influence the nasal tip projection significantly. The findings of this study supported earlier studies on the alar base suture done by Collins and Epker (1982), Wolford (1988) and Guymon *et al.* (1988). Guymon *et al.* (1988) reported a reduced flaring from 11 percent down to 3 percent with alar base suture. Despite all these studies, Westermarck *et al.* (1991) drew the conclusion that the alar base suture increased the nasolabial angle due to the suture crossing the midline thus compressing the soft tissue in the nasolabial region. Schendel and Carlotti (1991) stated that the subperiosteal dissection and elevation disinserted the

facial muscles from the nasolabial area and the anterior nasal spine leaving them free to retract laterally as they normally shortened when elevated resulting in flaring, widening and elevation of the base of the nose as well as loss of vermilion show and thinning of the upper lip due to inward rolling of the lip. The advancement and impaction of the maxilla could also rotate the base of the nose superiorly along with the closure of nasolabial angle. They pointed out the lip advancement followed by maxillary advancement by anywhere from 33% to 60 % of the skeletal movement and suggested this could be improved up to 90% by the use of V-Y closure of the vestibular incision. The use of V-Y closure of the vestibular incision supported earlier studies of Schendel and Williamson (1983), Phillips *et al.* (1986), Timmins *et al.* (1986) and Hackney *et al.* (1988). According to the results reported by Gassmann *et al.* (1989), the nasal tip rotated up with anterior and superior movement and down with posterior and inferior movement of point A. Only advancement of point A resulted in an increase in the columellar angle. Alteration of the supratip break angle was found to be unpredictable. The authors concluded that prediction of nasal structure after Le Fort I osteotomy was unpredictable. Ayoub *et al.* (1991) evaluated the soft tissue changes following anterior maxillary setback. They did not observe any significant changes from subnasale to glabella but the changes were notable in the upper and lower lips. They reported a decrease in interlabial gap after the posterior and superior autorotation of the lower lip to achieve a better lip-to-tooth relationship and an acceptable lip seal. They also pointed out an increase in the upper lip thickness and a marked increase of nasolabial angle from 92 to 110 degrees. The study defined the movement of the upper lip in terms of

translation and rotation and the centre of rotation was in the region between the nasolabial fold and anterior nasal spine. Hack *et al.* (1993) found strong correlation between anterior nasal spine and subnasale, superior labial sulcus, labrale superius one year after surgery but there was no correlation at the five-year follow-up. Superior labial sulcus and labrale superius followed point A more closely and this remained observable for the five-year follow-ups. Labrale superius followed incision superius in a horizontal direction at a ratio of 0.6:1 and this ratio would be 0.5:1 over the long term whereas, vertical ratios were not significant and that was probably due to relatively small mean vertical movements at surgery for their study. Van Butsele *et al.* (1995) investigated the effects of maxillofacial surgery to create lip seal. They found that the maxillary advancement moved the upper lip 30% upward. They supported earlier works of Freihofer (1976) and Stella *et al.* (1989) as they stated that lips thinner than 17 mm followed the movement of maxilla better than thicker lips. They concluded that prediction of the stomion superius to create a better lip seal was only possible in pure advancement cases. In 1996 Lee *et al.* studied the changes after impaction of the maxilla with Le Fort I. The upper lip moved about one third of the upward movement of point A and the maxillary incisor while the base and the tip of the nose moved slightly upward and forward. Changes in the position of the nasal tip were suggested to occur in the short term after maxillary surgery and disappear by the end of the first year. Obviously all lower soft tissue points were also affected by the superior positioning of the maxilla and moved upward significantly. Same year, de Assis *et al.* (1996) studied the postoperative nasal changes after isolated impaction of the maxilla, reporting an increase in nasal height, nasal

length and columellar length and a decrease in the angle of tip rotation and angle of columellar rotation. Nasolabial angle remained unchanged while the tip of the nose rotated upward. The nasal tip projection was reported as 1.2 mm after 2.3 mm superior and 1.5 mm posterior repositioning of the maxilla. McFarlane *et al.* (1995) worked on the nasal tip deflection. They stated that subjects with larger nasal tips exhibited more vertical tip deflection due to transmitting greater forces to the upper lateral cartilages. Their finding as the most important predictor of vertical nasal tip deflection was the magnitude of advancement. They also showed that superior repositioning made some difference at the nasal tip.

The correction of maxillary deficiency is frequently needed in repaired cleft cases, but only occasionally in non-cleft patients. Inferior positioning of the maxilla has probably been considered an unstable procedure in the maxilla (De Mol van Otterloo *et al.*, 1996; Rotter and Zeitler, 1999) so there are limited number of publications about the soft tissue changes after this procedure for non-cleft cases in literature. Most of the existing publications discuss the stability and the innovations to increase the stability of the procedure. The purpose of this procedure is, in the majority of the cases, to increase the facial height and upper incisor exposure. Bell and Scheideman (1981) reported an increase in the upper lip length, but could not find a significant correlation between lip lengthening and inferior movement of the maxilla in their small sample group. They calculated an increase of 3.6 ± 1.8 mm in the upper incisor exposure, 66% average relation of soft to hard tissue change in the anteroposterior plane and an absolute 2 mm vertical relapse in

the first two months. They also suggested 1 mm compensation for anticipated lip length.

1.7.2 Mandibular Procedures

The advancement of the mandible is mostly done to correct dentoskeletal Class II cases. Early techniques started from step osteotomies of the mandibular body at the beginning of this century. This was followed by vertical osteotomies, ramus osteotomies of different sorts with bone grafts, and sagittal ramus osteotomies (Athanasίου *et al.*, 1992). More vertical ramus osteotomies and mandibular coronoidotomies followed until inverted L osteotomy, C osteotomy and sagittal split osteotomy. Mommaerts and Marxer (1987), evaluating the long term soft tissue changes after mandibular advancements, found a good correlation of the horizontal change of labrale inferius, soft tissue B point, soft tissue pogonion, soft tissue gnathion and soft tissue menton with the horizontal change of bony pogonion and this correlation became stronger for the points closer to pogonion. The relationship in the change of the hard and corresponding soft tissue points seemed to be linear. The angle and the depth of the labiomental fold correlated well with the vertical change of menton but no correlation was found with the horizontal change of pogonion. The results of this study supported findings of former studies by Lines and Steinhauser (1974) and Quast *et al.* (1983). Lines and Steinhauser (1974) showed a 1:1 soft and hard tissue pogonion vector change, whereas, the lower lip moved 62 % of the distance of the advancement of the lower incisor and 67% at the vermilion border. Quast *et al.* (1983) included long-term follow-up data to take spatial

changes, remodelling and functional adaptations into consideration. Ratios at both pogonion and point B were 0.97:1 however; the ratio at labrale inferius was 0.38:1. The depth of the sublabial furrow decreased by 1.7 mm. Mommaerts and Marxer (1987) also found the one-to-one ratio between soft and hard tissue menton vertically. They concluded agreeing the most compromised linear one-to-one ratio of the chin region for the soft tissue points to the respective hard tissue points, both horizontally and vertically. They stated there was no effect of mandibular advancement over labrale inferius. In addition the soft tissue thickness under menton remained the same and sublabial furrow depth decreased. Moss *et al.* (1994) reported that the advancement executed was most prominent over soft tissue pogonion and this decreased gradually up to the lower lip. Their study gave a more visual idea than numbers using a colour coding system over the facial soft tissue three-dimensionally as a difference from previous works. Van Butsele *et al.* (1995) pointed out the flattening of the labiomental fold due to forward displacement of the lower part of the lip, whereas, the upper part remained unchanged helping to establish a better lip seal like his co-workers did earlier (Mommaerts and Marxer, 1987). Keeling *et al.* (1996) claimed that mandibular advancement had no long-term effects on the upper lip position, and there was poor association with the horizontal surgical change on the lower incisor, point B and pogonion for the lower lip position in the anteroposterior direction. Their mean horizontal change data also indicated a 1:1 ratio between soft tissue and osseous pogonion, but they thought this was less certain in the long-term. They also examined the association between soft tissue thickness and soft tissue changes but could not find any associations. Albrechtsen and

Larson (1997) worked on the lower lip cross-sectional area after mandibular advancement, and suggested that individual variations were too great for this alone to assist in predicting the postoperative outcome from a patient's preoperative records. The ratio of soft tissue of the lips to lower incisors in this study was 0.67:1. The ratio at pogonion was lower than most of the previous research (0.72:1). Ewing and Ross (1992) reported a 1:1 ratio of soft to hard tissue advancement at pogonion and point B after mandibular advancement. Some of their cases underwent advancement genioplasty as well as maxillary advancement, resulting in the same soft to hard tissue ratio but did not show consistency. The positional change pattern of the lower lip was very different depending on the existence of genioplasty in the procedure. The thinning of the lip was twice as prominent with genioplasty. After genioplasty, an inferior shifting of the soft tissue pogonion was also observed relative to the bony pogonion.

Total mandibular setback for the treatment of mandibular prognatism was also researched widely for its effects on soft tissues. Examination of outline profiles showed Knowles (1965) the shortness and eversion of upper lip and an absence of the proper rolled outline as the vermilion border of the lower lip passed into the skin above the mental prominence. He suggested an improvement to the lower lip and chin outline and a lengthened upper lip, which lost the everted outline. Aaronson (1967) reported changes in soft tissues below superior labial sulcus after subcondylar osteotomy. The least change occurred in the upper lip and maxillary sulcus of the upper lip, whereas, the greatest amount of change was seen in the lower lip, the

mandibular sulcus of the lower lip, and the soft tissue chin. They were all displaced posteriorly. He also observed a downward displacement of the lower lip and the soft tissue chin, and a more acute angulation at the mandibular sulcus contour of the lower lip. Fromm and Lundberg (1970) reported an increase in the depth of the depression under the lower lip and in the length of the upper lip. Robinson *et al.* (1972) reported the results of their similar surgical intervention on a small group of patients. There was strong correlation between soft and hard tissue changes in the horizontal plane but not in the vertical direction in this study. This was mainly due to the landmark selection, which were appropriate to evaluate horizontal changes. Lines and Steinhauser (1974) found that the soft tissue chin followed the bony chin in a ratio very close to one-to-one, but the lower lip at the vermilion border only followed the lower incisal edge at 75%. Hershey and Smith (1974) reported 0.9 mm of soft tissue repositioning for each 1 mm of skeletal change in the chin region. It was found that 1 mm of change at pogonion resulted in approximately 0.8 mm change at inferior labial sulcus and 0.6 mm change at labrale inferius, which showed a significant correlation. The possible reason for this differential response was due to the backward rotation of the body of the mandible during repositioning according to the authors. They showed that 1 mm of posterior change at pogonion was associated with an average 0.2 mm posterior change at labrale superius and that was a significant relationship. They also claimed flattening of the upper lip and eversion of the lower lip after the surgical correction of mandibular prognatism. The increase in the prominence of the lower lip was twice the amount of upper lip flattening. Weinstein *et al.* (1982) studied the lip morphology after mandibular setback

and stated the consequences on the shape and size of the lip due to spatial changes and added that if the lips were brought together into a new relationship of contact areas, the interaction between the lips will be superimposed on that due to surgical manipulation. They also claimed they could not observe any significant relapse on the lip changes. Fanibunda (1989), using subsigmoid osteotomy for the surgical procedure, evaluated the soft tissue changes. He divided the facial profile into sections instead of investigating single landmark points. The soft tissue chin followed the movement of the mandible as a whole with a ratio near to one-to-one, and the maxillary soft tissues from tip of the nose to stomion projected 16% of the mandibular movement. He noted that nasal tip and nasal base often moved in the reciprocal direction to its 'accommodated' preoperative position due to relaxation of associated tissues. The position of the upper lip was determined by the lower lip to a certain extent. In most of the cases, posteroinferior shifting of the upper vermilion border and the lip junction following the lower lip vermilion border was observed. He also reported a 25% increase of the facial outline between upper lip vermilion border and lip junction. This change was 89% for the lower lip outline from the lip junction to the vermilion border. Soft tissue point B and soft tissue pogonion followed the best fit between the lip junction and gnathion increasing the concavity at point B. The section between soft tissue pogonion and soft tissue gnathion reflected the bony movement of the corresponding bone section 2.25 times due to either the dimensional difference between the soft and hard tissue sections or a tendency to 'double-chin' formation after mandibular setback. He also discussed external factors affecting soft tissue change like ageing, skin water

content and elasticity. The main weakness of this study was that the evaluation was done on lateral cephalograms ranging from 9 months to 7 years postoperatively.

Dermaut and De Smit (1989) reported changes in soft tissue thickness after sagittal split advancement of the mandible. Changes in the upper lip were less than 1 mm. At the level of upper incisor edge the soft tissue cover thickened due to the anterior displacement of lower incisor but the tissue extension at labrale inferius was reduced following flattening of the labiomentale sulcus. The regions lower to that remained unchanged. The authors also stated that the forward displacement of labrale inferius was 26% of the displacement of the lower incisor edge, but point B on the soft tissue moved 119% of the displacement of its bony correspondent. Likewise the anterior displacement of soft tissue pogonion was 110% of the change at bony pogonion. These results were all very close to the ratios given by other researchers. All landmarks except the gonion, stomion inferius and labrale inferius moved significantly downwards. The gonion moved upwards due to a postoperative resorption at the cortical plate. The other landmarks remained unchanged. Gjurup and Athanasiou (1991) worked out that posterior movement at point B and pogonion was accompanied by reductions ranging from 91% to 103% of the corresponding soft tissues.

Techalerpaisarn and Kuroda (1998) conducted a three-dimensional analysis so they could evaluate the regions other than the profile line. They claimed that the greatest amount of soft tissue change was found between soft tissue

pogonion and labrale inferius, and the amount of dislocation decreased in the lateral direction. This could be explained in the same manner as the 'radial explanation' which suggests degree of advancement decreases gradually towards the back of the maxilla and mandible as the jaws are U or V shaped (McCance *et al.*, 1992 a). They reported that the central part of the upper lip was affected less as this region was supported by the maxilla and the upper teeth, but the peripheral regions of the upper lip were affected more by the setback of the mandible. Scheideman *et al.* (1981) combined the mandibular setback with advancement genioplasty for the treatment of patients characterised by mandibular prognathism combined with flat labiomental sulcus, everted lower lip and an apparent lack of chin prominence, and observed soft tissue changes. The soft tissue to hard tissue movement ratio was 0.96:1 at pogonion, which is essentially a one-to-one ratio. This ratio was appropriate when a moderately large advancement genioplasty and mandibular setback were planned. The mandibular setback positioned the chin posteriorly, whereas, the advancement genioplasty repositioned it anteriorly, producing a negligible overall change in anteroposterior chin position. The submental length and the labiomental sulcus depth were unchanged because of the combination of the two procedures. The soft tissue changes were also associated with genioplasty at variable degrees. A broad soft tissue pedicle was found to be a reliable method for establishing predictable soft tissue change as well as maintaining the soft tissue chin postoperatively.

The genioplasty procedure was first described by Hofer but the intraoral approach was introduced by Trauner and Obwegeiser (1957). Some variations of the horizontal osteotomy were then introduced by Converse (1964) followed by Hinds and Kent (1969). Advancement genioplasty to augment the contour of the chin and reduce the chin height would give different results depending the osteotomy was done either horizontally or obliquely. McDonnell *et al.* (1977) presented a 4:3 ratio for surgical advancement versus horizontal change in the soft tissue chin. This ratio was given as 0.6 by Bell and Dann (1973) and 0.9 by Dann and Epker (1977). Busquets and Sasouni (1981), working on the changes in the profile, claimed that due to the anterior movement at pogonion, soft tissue marks at the lower face was affected, and the greatest change occurred in the soft tissue correspondent of the pogonion with less anterior change at the inferior labial sulcus and the least at labrale inferius regardless of the magnitude of movement. The soft to hard tissue movement ratio at pogonion was 0.8:1. Similarly the lower lip was repositioned anteriorly 44% of the movement of bony pogonion but this correlation was not as high as the other. Gallagher *et al.* (1984) supported the use of the maximised pedicle like his co-worker Bell. He suggested that when soft tissues of the chin were stretched, the proportion of soft to hard tissue movement decreased. His findings did not include any change in labiomenal sulcus depth like Scheideman *et al.* (1981). As expected, submental length increased. He suggested a 0.75:1 soft to hard tissue ratio in the horizontal plane. A year ago the same team reported the soft to hard tissue movement ratio as 0.85:1 for the similar kind of procedure performed with broad soft tissue pedicle (Bell and Gallagher, 1983). Davis *et*

al. (1988) reported that soft tissue chin closely followed the bony movement. The only inferior movement of the soft tissues was found to have occurred when the bony movement was in that direction, so there was no tendency for a chin droop. They related this to maximising the pedicle. The changes were found to be too variable to reach statistical significance. In the study done by Park *et al.* (1989), the ratio of soft tissue movement related to hard tissue movement was 0.97:1 horizontally, which proved a statistical correlation, whereas, vertically this ratio was 0.26:1, but they drew attention to individual variations. Vedtofte *et al.* (1991) supported the use of pedicled genioplasty for more predictable soft tissue changes and presented a mean ratio of 0.92:1 for soft tissue change at pogonion to bone advancement, which was similar to previous results given by researchers using the same technique (McDonnell *et al.*, 1977; Scheideman *et al.*, 1981; Gallagher *et al.*, 1984; Park *et al.*, 1989; Polido *et al.*, 1991). This ratio was 0.7:1 at the level of osteotomy. His finding using the free graft technique was a ratio of 0.53:1 at the soft tissue pogonion. His observation that the stomion rarely moved inferiorly after using pedicled grafts supported McDonnell *et al.* (1977) and Davis *et al.* (1988). Polido *et al.* (1991) suggested the 0.88:1 ratio for the soft tissue pogonion to osseous movement due to a 10% decrease in the thickness of soft tissues. This could be lessened by the soft tissue pedicle attached to the anterior and inferior surfaces of the advanced segment as the scar contraction would be less. Average horizontal soft tissue advancement was reported as 92% of the horizontal bony movement in Van Sickels' study (Van Sickels *et al.*, 1994). He suggested that as the magnitude of horizontal advancement of hard tissues increased, the proportional movement of the soft tissues decreased. The soft

tissues followed the bony movement at a ratio of almost 1:1 up to 8 mm advancement, but beyond this ratio decreased. He also added that the vertical bony changes influenced the horizontal soft tissue change. As the chin vertically shortened, the soft tissues tended to thicken.

After reduction genioplasty performed for the reduction of excessive chin prominence in the anteroposterior plane, the soft to hard tissue ratio was 1:3 in the horizontal plane and 1:4 in the vertical plane as reported by Hohl and Epker (1976) and 0.75:1 and 1:1 respectively as reported by Wessberg *et al.* (1980). Bell *et al.* (1981) reported that soft tissue changes were not proportional to the osseous changes. They gave a 58% ratio for soft to hard tissue pogonion movement and supported the maximisation of the soft tissue pedicle to the mobilized chin segment to stabilise the result in the long-term.

1.7.3 Bimaxillary Procedures

The challenge to achieve three-dimensional facial proportionality and occlusal stability in many patients with complex dentofacial deformities has been met by the development and use of maxillary, mandibular and chin surgery techniques in combination with efficient orthodontic treatment. A combined surgical and orthodontic approach may provide increased treatment efficiency and optimal aesthetic results (Bell *et al.*, 1986). The soft tissue response to bimaxillary orthognathic surgery was similar to the response seen in single jaw procedures except the changes in the nasolabial angle and in the lower lip and chin region according to Jensen *et al.* (1992). The conclusion they reached about the changes in the nasolabial angle was that they were

primarily due to rotational changes of the underlying hard tissues rather than their anteroposterior and vertical movements, which was discussed by many authors as a result of single jaw procedures. They reported a poor correlation between maxillary advancement and the nasolabial angle increase (an average of 0.65° for every 1 mm of advancement). The ratios presented were not any different to the ratios suggested for the lower lip and chin regions after single jaw procedures (72% for lower lip and 100% for pogonion). As expected, mandibular soft tissues followed maxillary impaction moving superiorly due to the autorotation of the mandible, but at an unexpected one-to-one ratio. In the mandible, the weak correlation between the movement of the lower lip and mandibular hard tissues was attributed to the freeing of the lower lip from the upper incisors after surgery. This way the lower lip stomion and labrale inferius showed greater vertical movement (1.13:1 and 1.5:1 respectively) than the underlying hard tissues. Labrale inferius reduced in thickness due to the same reason. Opposing previous authors, their group of patients with thicker lips showed more significant changes than thinner lips, but the range for thickness was different than previous studies observing this effect (9-11.5 mm and 11.6-13 mm). Nadkarni (1986) proposed that both the mandibular and the maxillary procedure affected the labiomental sulcus in opposite directions due to the uncurling of the lower lip. McCance *et al.* (1992 a, b) did not present any data suggesting the bimaxillary procedure would affect the soft tissues any different than the effects of procedures performed on either single jaw. Similarly, Lin and Kerr (1998) reported matching results to most of the previous studies, which were actually done separately on single jaw procedures. The main reason for that could be the approach of

researchers while evaluating the soft tissue changes as they tend to compare the soft tissue section with the 'corresponding' hard tissue rather than critically evaluating the reasons, like any effects from a neighbouring tissue, why the ratios and correlation between some increase and decrease whereas, some have a one-to-one ratio. The only main different result in this study (Lin and Kerr, 1998) compared to previous literature was the ratio of horizontal movement between lower lip and corresponding bony structures (0.9:1).

1.7.4 Summary

It is evident from previous studies that the soft tissue changes following orthognathic surgery vary with the regions of the face. The relation and support between certain parts of the face and the underlying skeletal structure may be different. Other structural elements like muscles, connective tissues and cartilages contribute to the configuration of the face, therefore, the soft tissue profile does not always directly follow the underlying bony structure. Other external factors like the ageing process have also important effects on the facial soft tissues.

For maxillary procedures, varying results were reported. Majority of the research though, proposed a ratio of approximately 50% for soft to hard tissue movement with maxillary osteotomy as a horizontal change. A vertical change of approximately 30% in the upper lip to the horizontal change in the upper incisor was presented by various authors but many others could not present a meaningful correlation between vertical movement at the upper lip and maxillary osteotomy. There was no explanation offered for the lack of

consistent upper lip response to superior movement of the maxilla, which can actually be explained by varying muscular factors. A decrease in the nasolabial angle, advancement and elevation of the nasal tip without any change on the nasal dorsum, and increase in alar base width were among observations. Many authors concluded that the change in the nasal structure after Le Fort I osteotomy was unpredictable. Changes in the nose were suggested to occur in the short term after maxillary surgery but disappeared by the end of the first year. Many studies failed to record the degree the nasal profile, the nasolabial angle and the nasal base were affected, inversion and thinning of the upper lip, and the effect of intact or otherwise anterior nasal spine on soft tissue response for maxillary impaction. Other factors, including tissue thickness overlying surgically manipulated bony segments, magnitude of horizontal movement, and accompanying vertical movement were considered crucial.

Following mandibular advancements, a good correlation between the bony pogonion's horizontal change and labrale inferius, soft tissue point B, soft tissue pogonion, soft tissue gnathion and soft tissue menton was found. This correlation was stronger for the points close to the pogonion. The hard and corresponding soft tissue points surgical change relationship seemed to be linear. A one-to-one soft to hard tissue pogonion change was shown, whereas, effects on the lower lip were debatable. The results for the lower lip showed a range from 30% to 70% of the lower incisor advancement. Various authors reported no effect of mandibular advancement over labrale inferius, whereas, others reported changes around 40%. It was also suggested that

individual variations were too great to assist in predicting the postoperative outcome. Effects on upper lip position in the anteroposterior direction were also noted. The majority of the research agreed that the soft tissue advancement was most prominent at the soft tissue pogonion and this decreased gradually towards the lower lip. The flattening of the labiomentall fold was observed due to the forward displacement of the lower part of the lip, whereas, the upper part remained unchanged, helping to establish a better lip seal. The greatest magnitude of change occurred in the lower lip, the labiomentall sulcus, and the soft tissue chin with mandibular setback. An increase in the depth of the labiomentall sulcus and the upper lip length was reported. There was also a differential response by the labiomentall sulcus due to the backward rotation of the body of the mandible during repositioning according to the authors. The debate on the lower lip changes has been continual; the lower lip at the vermilion border followed the lower incisal edge at 60% to 75%. A significant relationship was found between posterior change at pogonion and labrale superius. After the surgical correction of mandibular prognathism, flattening of the upper lip and eversion of the lower lip were reported. The maxillary soft tissues from the nasal tip to stomion reflected approximately 15% of the mandibular movement. Three-dimensional analyses claimed that the largest amount of soft tissue change was found between soft tissue pogonion and labrale inferius and the amount of dislocation decreased in the lateral direction.

The soft tissue responses to bimaxillary orthognathic surgery were reported to be similar to those seen in single jaw procedures. The changes in the

nasolabial angle were primarily due to rotational changes of the underlying hard tissues rather than their anteroposterior and vertical movements, which was discussed by many authors as being a result of also the single jaw procedures. In the mandible, the weak correlation between the movement of the lower lip and mandibular hard tissues was attributed to the freeing of the lower lip from the upper incisors after surgery. The lower lip stomion and labrale inferius showed greater vertical movement than the underlying hard tissues for this reason. Labrale inferius showed a reduction in thickness due to the same reason.

While evaluating the soft tissue changes, many authors tend to compare the soft tissue section with the 'corresponding' hard tissue rather than critically evaluating the reasons, like any effects from a neighbouring tissue.

1.8 Imaging of facial soft tissues and morphometrics of the human face

The prediction and visualisation of the soft tissue changes of the human face has been an area of concern in the evaluation and planning for the orthognathic surgery patients. Recording the facial details to supply materials for diagnosis and treatment planning started with the early days of orthodontics. Case (1908) recorded plaster casts of his patients' faces. Due to inherent difficulties, this technique was not used widely. Therefore, most of the work on soft tissue changes has been based on quantitative analysis of the lateral profile soft tissue outline on the facial midline as recorded on lateral cephalometric radiographs.

1.8.1 The Lateral Cephalograph

The first x-ray pictures of the skull in the standard lateral view were taken by Pacini and Carrera in 1922 followed by a few other authors but accurate description of the methods were not given. It was not until 1931 that Broadbent (1931, 1981) developed standardised methods for the production of cephalometric radiographs using cephalostats (Rakosi, 1982). Cephalometric measurements, however, are influenced by several different sources of error, related to the equipment, procedure and the operator (Holdaway, 1983). Cephalometric errors fall in two main categories; systematic and random errors.

Systematic errors arise through magnification and distortion, which can be calculated from the geometry of the apparatus and can also be measured by the use of standard scales in the field of view. Random errors arise largely through uncertainty in the visual identification of radiographic landmarks on the film. This uncertainty can be due to sharpness, contrast and subjective element in the identification of some features (Cohen *et al.*, 1984; Cohen 1984; Burke, 1984). Factors like differences in facial expression from one recording to another may introduce considerable uncertainty in the reproduction of some soft tissue reference points. Hillesund *et al.* (1978) suggested that the radiographs might be taken in relaxed lip position to make the reproducibility acceptable.

Two-dimensional radiographs allow the evaluation of facial anatomy and prediction of changes in two dimensions only, anteroposterior and vertical.

The shape of the face is so complex that its measurement needs an advanced three-dimensional system.

1.8.2 Photogrammetry

Zeller (1952) was the first to design a method of recording the facial soft tissues, which could extend laterally from the midline and this was an example of *short-base stereophotogrammetry*. In this system, a pair of facial photographs was recorded in a stereometric camera and was placed in a plotting machine to produce an accurate three-dimensional record of the face in the form of a contour map. Unfortunately the mapping equipment was too large, expensive and not easily accessible. This technique was used to measure faces by a few researchers like Haga *et al.* (1964) and McGregor *et al.* (1971). An effort to simplify the technique without loss of accuracy was tried by Burke and Beard (1967) and was used for the assessment of facial deformity (Burke, 1971). In 1975 Baumrind introduced a technique integrating hard and soft tissue measurements using stereophotogrammetry, study models and pairs of cephalometric radiographs. Burke *et al.* (1983) then used the technique to measure the change in facial soft tissue morphology after mandibular surgery. According to Rasse *et al.* (1991) due to the short time required to take photographs in this method, the body would remain motionless to avoid errors. The method was improved in time and made simpler lowering the cost. Later the system was criticised for being subjective despite carrying the advantages of a three-dimensional imaging system and being non-invasive by Burke (1992). He pointed out the necessity for a better system citing to the laser scanning systems, which had been recently

developed at the time. Actually one of the main disadvantages of the method is the need for a considerable technical proficiency to draw contour lines despite many improvements to simplify it. Later Ferrario *et al.* (1996) obtained soft tissue measurements using three-dimensional digital infrared photogrammetry, which analyse only the relative positions of facial soft tissue landmarks. This system can neither image the internal hard tissue nor the overlying soft tissue, so was regarded more as a three-dimensional measuring tool rather than an imaging method. Some advantages were that the linear measurements were not sensitive to changes in the head posture, it was a non-invasive technique and was described as inexpensive.

Adding on the principles from the eighteenth century, Lovesey (1966) made the major leap in the development of a telecentric system for facial recording. He tried to provide information on the facial dimensions of aircrews to design better oxygen masks. He was projecting black strips on the side of subjects' faces and photographing them at a perpendicular point from the projection axis to produce a contour pattern. This idea was improved and a telecentric lens was used to photograph the projections and was called *contour photography* (Robertson, 1976), and then *telecentric photography* (Robertson and Volp, 1981). Contour photography was related to the measurement of surface areas and slopes, whereas, the latter one was primarily concerned with linear measurement. Robertson and Volp (1981) stated that this technique was as accurate as other systems, facial landmarks were easier to identify than cephalometric radiographs and may be less expensive than the other systems.

1.8.3 Morphoanalysis

Using a technique called morphography, *morphoanalysis* was formed. This technique also provided a structural language for recording, comparing and assessing craniofacial structures with standardisation and co-ordination using radiographs, photographs and lithograms (Rabey, 1977-78 a). The clinical application of morphoanalysis for oral and maxillofacial surgery dates back to 1963, and with the progress of this technique a centre was formed in Manchester. In this technique, as a first step histomorphograms were formed to provide three-dimensional data about the variation in craniofacial structures in a population and then in the second stage, morphograms of a particular patient were compared to the populations' standards to diagnose the three-dimensional nature of the disharmony (Rabey, 1977-78 b). This equipment was described as extremely elaborate and expensive and the technique was time consuming and not very practical for everyday use.

1.8.4 Moire Topography

Moire topography is a three-dimensional optical method of biomorphology (Hojo, 1981). Optical methods gained great acceptance since they allowed three-dimensional morphometry without contact at the site of measurement. Although stereophotogrammetry was seen more accurate than Moire topography for years, with its simplicity as well as its accuracy (Kawano, 1987), Moire technique gained popularity after its application to morphometry of large irregular-surfaced three-dimensional objects (Shioiri, 1978). Some of the problems reported by Kanazawa and Kamiishi (1978) about this method

included the positioning of head as a source of error as the Moire pattern changed greatly by even fine movements of the face.

1.8.5 Stereolithography and 3-D CT Scans

Stereolithography is a method of organ-model-production based on *computed tomography* scans, which enables the representation of complex three-dimensional anatomical structures. Models of surfaces and internal structures of organs can be reproduced by polymerisation of UV-sensitive liquid resin using a laser beam. The principles of stereolithography were developed in 1982 but were first used in 1987 (Bill *et al.*, 1995). The main disadvantages obviously were the radiation from CT scans and the cost of the procedure. On the other hand it enables the advantages of 3D modelling of structures (Anderl *et al.*, 1994). The use of this method was aimed at the skeletal structures, which were not normally visible rather than soft tissue imaging (Arvier *et al.*, 1994). 3D computerised tomography was used in combination with the stereolithography mainly to reproduce models but it was also seen as a 3D imaging technique for soft and hard tissues. Many researchers reported it to be an accurate and reliable measuring method (Matteson *et al.*, 1989; Waitzman *et al.*, 1992). Waitzman *et al.* (1992) listed some problems associated with CT images, including window setting, partial volume effects, spatial uniformity and resolution, scan noise and artefacts to influence the quality. Kragsskov *et al.* (1997) could not find any evidence that 3D CT scans were more reliable than conventional cephalographs for standard lateral and frontal cephalometric points. Despite their value in reproducing 3D models as these models are exceptionally important for internal hard tissue modelling for

better diagnosis, simulation surgery, and reconstruction of defects (Santler *et al.*, 1998), they have very limited use for soft tissue imaging especially due to the fact that repeated investigations are not possible because of the hazards of radiation from the CT scan to the patient and repeated examination of soft tissues especially in the postoperative period is essential for orthognathic surgery.

1.8.6 The End of the Millennium

Kobayashi *et al.* (1990) used another method for three-dimensional analysis of facial soft tissue morphology. They marked the reference points on the face with a black eye-liner and two pairs of photographs were taken simultaneously at an angle of 25 degrees from right and left sides of the face with the head in a metal reference frame on which the standard points of known three-dimensional values were set. From this data the computer produced a "wire-frame" model of the face in three-dimensions. Although it was useful for diagnosis, planning and assessment of postoperative changes, and was easy and economical to use, it did not provide sufficient amount of data to predict soft tissue change three-dimensionally and was relatively time consuming as it required manual input of two-dimensional co-ordinates with a digitiser.

Ayoub *et al.* (1996) developed a low-cost system called *C3D-clinical*, which was based on the use of stereo television cameras and special textured illumination to provide quick capture times. This system produced a lifelike view of the face from any viewpoint in a process called *photorealistic*

rendering as well as shaded facial models and "wire-frame". The 3D model of the face could be rotated, enlarged and measured in three-dimensions and was based on photogrammetry. This system claimed to be accurate, cost effective, non-invasive and simple to use. It also provided accurate superimposition of soft and hard tissue images.

Apart from the optical surface scanner, which was a great leap in 3D imaging in the 1990's (section 4.7) Techalertpaisarn and Kuroda (1998) developed an imaging system and reported their results for facial soft tissue changes in mandibular prognathic patients. Their system was a high-speed patterned light-digitising system. They located the patient in a cephalostat and the head was positioned firmly against a headrest. The measuring unit had two liquid crystal display projectors and two charge coupled device cameras placed at either side of the cephalostat at a 45-degree angle to the patient's frontal view. Black and white stripes were projected on the face and a charge coupled device (CCD) camera formed three-dimensional co-ordinates of the facial surface using trigonometric formulae. The authors claimed that the errors pointed out by Bush and Antonyshyn (1996) for optical surface scanners were reduced to minimum. The duration of digitisation was only 2 seconds reducing the motion artefact and variable facial expression. The digitisation error was examined by the authors and differences were found to be 0.1 to 0.6 mm in all planes. The method error for superimposition used in this technique was within 0.5 mm for all reference points. None were considered to have a significant clinical effect.

Another important improvement was reported by Ayoub *et al.* (1998). They used their recent C3D software (Ayoub *et al.*, 1996), which was based on stereophotogrammetry. A computer controlled slide projector illuminated the subject with a texture pattern to facilitate stereo matching. Thus a three-dimensional polygonised face model could be produced which carried the capabilities of their previous work in 1996. They reported this as an accurate, non-invasive and cost-effective system, which captured the full face in a length of time as short as 2 seconds.

Both of the latter systems fulfilled the basic requirements for three-dimensional capture and would require controlled studies to assess their accuracy and validity.

1.8.7 The Optical Surface Scanner

Any successful 3D measurement system not only has to be accurate but also non-invasive to meet the requirements. Arridge and Linney (Arridge *et al.*, 1985) designed and built an optical surface scanning system. The first version of the system had two low power helium-neon laser beams, posing no risk to the patient's vision, projected on the face vertically and obliquely and recorded from the front with a video camera. The reason they used two laser beams was to eliminate blind spots due to shadowing by prominent features like the nose. In the later version of the system, a single beam replaced the two laser beams but the same goal was achieved by using specially set mirrors reflecting the beam. Full 360-degree information was obtained by rotation of the subject. The patient was seated in a chair that was rotated on a

platform under computer control. The patient's head was located against a headrest attached to the chair. The chair would rotate 15-30 seconds and the extent and duration of the rotation would depend on the needs of the particular scan taken. The data would be recorded by a charge coupled device (CCD) camera. The acquired image was then produced using approximately 4000 triangular surface elements and displayed only the facial surface. A three-dimensional model of the face could be viewed interactively, manipulated and analysed. This system was reproducible (Bush and Antonyshyn, 1996; Soncul and Bamber, 2000), non-hazardous to the patient, had a high resolution and did not involve contact with the patient's face. Moss *et al.* (1987) showed that even a change in the profiles produced by attaching a small disc of 0.5 mm thick cardboard was easily detectable. It only presented surface data but could be used together with a limited low dose CT scan to provide information on bone structure. The same authors used the two systems together in their latter study (Moss *et al.*, 1988). A similar study was conducted by Girod *et al.* (1995), who also integrated the 3D CT data of the skull with 3D surface data acquired by optical scanning and simulated the planned orthognathic surgery and computed the soft tissue changes resulting from the shifting of bony segments.

McCance *et al.* (1992 a, 1992 b) and Moss *et al.* (1994) used the optical surface scanning system to analyse the soft tissues of orthognathic surgery patients and showed it to be simple to use, and non-invasive method of measuring three-dimensionally. Aung *et al.* (1995) used the optical surface scanner and concluded that the surface scanner could be a useful tool for

rapid facial measurements especially in the nasal and circumoral regions but added that accurate localisation of landmarks and operator skills were important in reliability of the results. Bush and Antonyshyn (1996) used a very similar optical surface scanning system, which became commercially available. They could clearly visualise all labelled landmarks on the digitised image with a variance less than 0.6 mm in all planes. They worked on the head inclination as well and found that the effect of the head inclination on the reliability of landmark localisation was specific for each landmark and had to be determined according to the purposes of the scan being taken, but suggested a head inclination with the Frankfort plane elevated 10 degrees from the horizontal produced optimal results. They listed some potential errors. For example significant movement of the subject being scanned degraded the image and the duration of the procedure was long enough for the patient to move. Facial expressions during scanning could cause errors. Coward *et al.* (1997) also used the same system. They favoured the technique because being non-invasive it allowed repeated scanning to produce a suitable image of sufficient resolution to clearly identify the landmarks.

1.9 Morphometrics

Morphometry, in Greek, means shape measurement. It was a standard application of multivariate analysis till mid 1970's. The transition of morphometrics into a discipline in its own right as a synthesis of geometry, statistics and biology can be traced back as far as D'Arcy Thompson's 'On Growth and Form' (1961). Thompson suggested that changes of biological

form could be modelled and described as mathematical smooth deformations. There was not much progress in this area until Bookstein described biorthogonal grid representation (Bookstein, 1978). Even after that methods suggested by Bookstein (1984 a, 1984 b and 1986), Siegel and Benson (1982) for analysis of shape in two dimensions were firmly based on the movement of homologous landmarks, and this is not very suitable for gently curving surfaces like the human face.

Several methods were used to measure the human face, in studies for genetics, ethnic forms and norms for facial aesthetics. In orthognathic surgery, morphometric studies have been done to measure shape change and are rather limited in number. Euclidean distance matrix analysis (EDMA), finite element analysis, mesh diagram analysis, thin-plate splines analysis are reported by authors as methods for morphometrics of the human face before and after orthognathic surgery.

EDMA was proposed for comparison of shapes by Lele and Richtsmeier (1991) and has been applied in studies of craniofacial structures, and Ayoub *et al.* (1994) used it for assessment of chin surgery and reported it as a good method for quantitative evaluation of surgical change as it did not depend on a remote frame of reference or superimposition. In this analysis, basically there are two matrices, one representing the initial structure and the other representing the second shape and EDMA compares two by the ratios of each pair of corresponding distances.

Finite element analysis is described as a system that estimates the deformation that is expected to result from a specified pattern of stresses (forces) upon a system. Motoyoshi *et al.* (1993) used it to observe the influence of thickness and mechanical properties on changes in facial soft tissue following simulation of orthognathic surgery.

The mesh diagram analysis is also an application of transformation grids developed by Thompson (1961). Moorrees and Kean (1958) used it first in orthodontic patients for their soft and hard tissue evaluations. It is composed of a grid of rectangles scaled on the upper facial height and the facial depth. This grid is distorted to fit the proportionate location of a patient's cephalometric landmarks as compared to the norm to represent how that individual face deviated from the norm (Lebret, 1985). It is usually applied to lateral cephalographs but Ferrario *et al.* (1998) applied it to three-dimensional space.

Thin-plate splines analysis is based on ideas of Thompson (1961) as well. This analysis takes thin metal plates as a starting point and presents the mechanical deformation and shape change as mathematical transformations enabling quantitative and graphical evaluation of shape change (Bookstein, 1991). Coombes *et al.* (1991) claimed that the use of thin-plate splines in two-dimensions was a constraint on the accuracy due to the small number of homologous points on two curves but suggested use of it for further, in three-dimensions. Singh *et al.* (1997) used thin-plate splines and fine element analysis together for morphometry of cranial base and suggested that each

technique had relative achievements and could provide useful information so supported the use of any morphometric technique to provide a description, which could be used to hypothesise a mechanism.

CHAPTER II

STATEMENT OF THE PROBLEM

AND

AIMS AND OBJECTIVES

2.1 Statement of the problem

There is immensely growing awareness of the fact that facial appearance tends to influence the opinion of those we meet in our social and professional lives. Many feel uncomfortable with the idea that physical attractiveness makes such a difference to the potential and the quality of one's life. It has great impact on self-esteem, behaviour patterns, and personal interactions. The facial aesthetics has become very important not only for people on the streets but also for professionals like the maxillofacial surgeon, the plastic surgeon, the orthodontist, the psychiatrist and others.

Over the years, several studies have been done by many researchers from various disciplines on the aesthetics of the human face (Gonzales-Ulloa, 1962; Merrifield, 1966; Ricketts, 1982). These studies date back many centuries, as the search for a formula of facial aesthetics has provided a challenge for many artists (Figure 2.1) (Dürer, 1591). The conception of beauty has differed with culture and time, making the aesthetics of the human face an even more complex matter (Figure 2.2). As the civilisation brought people closer to each other physically and by communication, this complexity has become more obvious. In today's cosmopolitan societies where several different cultures and races inhabit together, former descriptions of the human beauty may be too restrictive (Martin, 1964). A young woman of an Afro-Caribbean origin living in Western Europe asking for surgery to acquire Caucasian features is an example of this cultural and racial complexity.

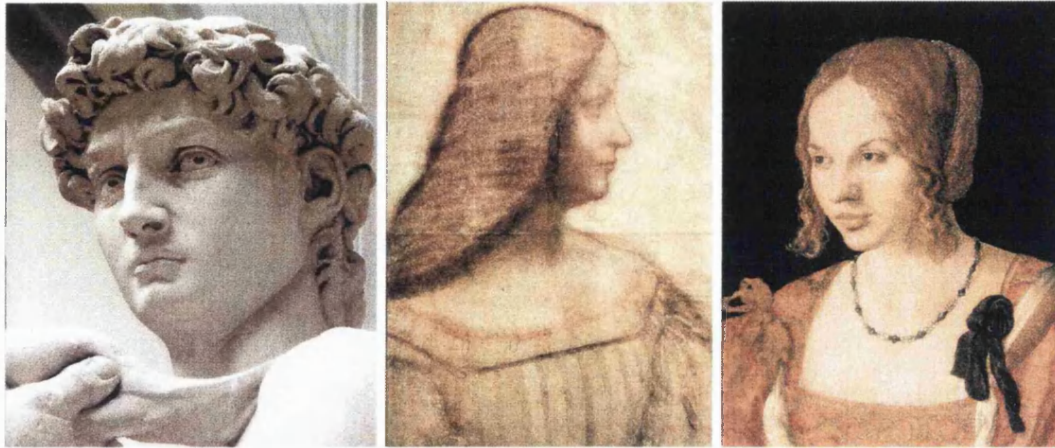


Figure 2.1- Masters of art were the first researchers of the human face aesthetics. Michelangelo's 'David' (1501-1504) at Accademia delle Belle Arti in Florence (left), da Vinci's 'Portrait of Isabella d'Este' (1499) at Musee du Louvre in Paris (middle), and Dürer's 'Portrait of a Young Venetian Woman' (1505) at Kunsthistorisches Museum in Vienna (right) were created with the knowledge gathered by the artists' many observations and sketches on the proportions of the human face and body.



Figure 2.2- The conception of beauty has differed from one culture to the other. On the left, a reserve head from the reign of Khufu during the Fourth Dynasty (from Kunsthistorisches Museum, Vienna), in the middle, the 'Head of a Blond Youth' made around 485 BC (from Acropolis Museum, Athens), and on the right, a male head from Benin made around 15th century (from National Museum of African Art) show the difference between the concept of beauty for ancient Egyptians, ancient Greeks and Africans.



Figure 2.3- The media imposing Caucasian features as an ideal; on the left, the cover of a beauty and fashion magazine published in the UK, in the middle, the cover of a worldwide magazine published in India, and on the right, a Korean model appearing in a worldwide magazine's Korean version.

The media sources have been imposing the Western European or North American Caucasian facial features as an 'ideal' for facial aesthetics (Figure 2.3). Most of the research done in the field also concentrated on the Western faces, giving not much information for the rest of the racial identities (Riedel, 1957; Peck and Peck, 1970). The existing research which had concentrated on facial features of Afro-Caribbean and Oriental individuals is insufficient as the facial features vary immensely also within these groups (Martin, 1964). It is difficult to evaluate populations of South-East Asia, for example, using the Oriental standards since there are differences within these groups. Similar problems are faced as one tries to categorise an individual from the Indian sub-continent. The facial features will be extensively different to the Oriental features and probably more similar to Caucasians. The characteristics of the Caucasians as described in the scientific literature are also difficult to meet the features of all Caucasian groups. The difference between the Western European Caucasian to the Eastern European Caucasian, which is actually geographically closer to 'Caucasus', can be prominent. The cross marriages

between different ethnic groups in today's cosmopolitan society have also made this matter more complex. For these reasons, a more up to date overview of the ethnic facial aesthetics was one of the aims of this study.

Beauty and ugliness are certainly not phenomena in the single individual, but are social phenomena of the utmost importance. Therefore, people with facial deformities have sought the help of surgical procedures for the correction of their disfigurement, which they may have difficulty in coming to terms with. The diagnosis, treatment planning, prediction and evaluation of the outcomes of the treatment can be more challenging than the actual surgical procedure to correct the facial disfigurement. The examination and investigation to point out the problem is crucial. The major difficulty in examination to reach a correct diagnosis lies behind the lack of an accurate imaging system. For decades, long into the last century, lateral skull radiographs have been the major tool for clinicians to detect three-dimensional deformities on a complex three-dimensional structure with the limitations of a two-dimensional imaging technique. These limitations in detecting the problem add to limitations in following up the outcomes of the correction (Rakosi, 1982). Several techniques to compensate the limitations of lateral skull radiographs and recent improvements in cephalometrics did not solve the poor reproducibility problems although these were accepted as useful clinical tools for diagnosis, prediction, treatment planning and evaluation of the results in the absence of anything better (Figure 2.4). Many researchers tried to develop better imaging techniques including three-dimensional ones but none proved to be satisfactory (Haga *et al.*, 1964; Burke and Beard, 1967; Robertson and Volp,

1981; Rabey, 1977-78 a,b; Waitzman *et al.*, 1992). This study aimed to validate and utilise one of the later 3-dimensional imaging techniques, the optical surface scanner, which is becoming a widely accepted clinical tool in determination of facial deformities and the follow up for orthognathic surgery (Arridge *et al.*, 1985). Its reproducibility was compared with the conventional cephalograph.

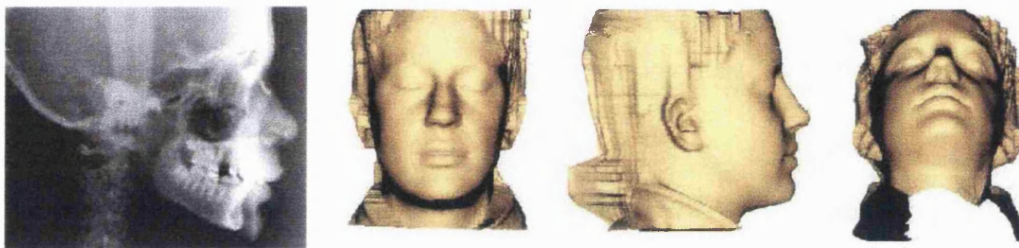


Figure 2.4- The conventional lateral cephalograph is unable to show complex 3D structures of the skull and facial soft tissues (left), whereas, optical surface scans is a 3D imaging system, which can illustrate the facial soft tissues with high degree of accuracy (right).

The prediction and follow-up evaluation of the facial soft tissue changes has been a problem for maxillofacial surgeons. Although the surgery is performed by shifting bony structures underlying the soft tissues by correcting the apparent deformity, the outcome is expected to reflect in the soft tissue mask, which we see in 3D, and as the need for the patients to be well informed is on the rise, the need for an accurate three-dimensional imaging tool has become more essential.

In order to produce both a graphical and a quantitative representation of the surgical change, this study used the supplementary functions of the optical surface scanner software, and to enhance and confirm these results, and to

represent biological deformation graphically, a multivariate statistical analysis and a novel morphometric tool, 'thin-plate splines' was used.

Osteotomy wafers (Figure 2.5) are used in orthognathic surgery as an intermediate guide for repositioning the mobilised maxilla relative to the intact mandible, and as an aid to achieving and maintaining the planned final occlusion. Bimaxillary cases principally require an intermediate wafer, which relates the mobilised maxilla during temporary intermaxillary fixation to the unchanged mandible. This is helpful in stabilising the maxilla whilst it is plated into its definitive position. The final wafer relates the osteotomised mandible to the fixed maxilla, both during the insertion of bicortical screws, and when the occlusion is not sufficiently stable for temporary or permanent fixation. A third role is the establishment of postoperative proprioception. After rigid fixation of the mandible, the wafer may be wired to the maxilla, or less frequently to the mandible, to provide postoperative proprioceptive guidance for up to 2 weeks. The wafer may thus help the patient to occlude into the planned occlusion, with or without the help of elastics (Figure 2.5), by overriding the patient's preoperative proprioceptive drive (Bamber and Harris, 1995). This combination may also help to eliminate the difference between the anaesthetized centric relation and active centric occlusion in addition to the overcorrection in the immediate postoperative period (Bamber *et al.*, 1999). But there is no controlled study reported in the literature assessing effective contribution of occlusal wafers and training elastics in postoperative rehabilitation. Therefore, this study also aimed to investigate proprioception

after orthognathic surgery and observe the effects of final occlusal wafer and training elastics.

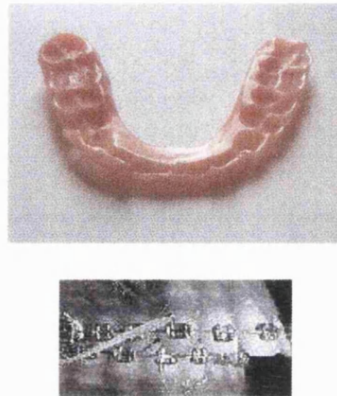


Figure 2.5- Occlusal wafer (top), and training elastics (bottom).

2.2 Aims and objectives

The overall aims and objectives of this programme were to improve the diagnosis, planning and prediction of the outcome of orthognathic surgery by:

1. Evaluating the norms of facial aesthetics.
2. Reviewing the differences of facial aesthetics between three ethnic groups.
3. Validating the use of the optical surface scanner as a three-dimensional imaging tool by comparing it to a conventional technique and testing its reproducibility.
4. Investigating the facial soft tissue changes following orthognathic surgery using the optical surface scanner, and presenting a graphical and quantitative representation of the change using a morphometric tool, thin-plate splines.
5. Evaluating the postoperative use of final occlusal wafer and training elastics and their role in the postoperative proprioception.

CHAPTER III

REVIEW OF ETHNIC FACIAL AESTHETICS

3.1 Introduction

Beauty is not an individual phenomenon, but a social phenomenon of the utmost importance. There is a natural and sometimes unconscious attraction to a beautiful person.

Ever since man has tried to define the different components of beauty in order to be able to recreate it in art, he has searched for formulae of beauty and methods of measurement and appreciation (Gonzales-Ulloa, 1962). Ancient Egypt was one of the first known cultures to express facial beauty in art and memorial sculpture in the Nile valley approximately 5000 years ago. The statuary of Egyptian royalty found in monuments and tombs display the Egyptian ideal of beauty, harmony, and proportion, while maintaining only a vague resemblance to the persons represented (Figure 3.1). On the other hand, the southern parts of the African continent had different ways of understanding and appreciating beauty (Figure 3.2).

The classical Hellenic culture comes into sight as the first to sensitively express the qualities of facial beauty through sculpture and philosophy. They were followed by the Romans (Figures 3.3 and 3.4). The archaeological finds that date back to Roman Britain shows similar examples (Figure 3.5). Greek philosophers, notably Plato and Aristotle, questioned the intrinsic meaning of beauty and introduced 'aesthetics' as both the study of beauty and the philosophy of art.



Figure 3.1- The left image is the painted wooden coffin of Passenhor, Thebes, 700 BC. The image on the right is a sculpture of Cleopatra VII. Courtesy of The British Museum.



Figure 3.2- African cultures reflected their perception of beauty, which showed differences to those from Europe, the Americas and northern Africa, in their sculptures. The bronze trophy head from Benin, Nigeria (around 1550-1650) shows the typical African beauty. Courtesy of The British Museum.



Figure 3.3- Head of Emperor Augustus from Monroë (Nubia), 27-25 BC as an example of Roman facial aesthetic norms. Courtesy of The British Museum.

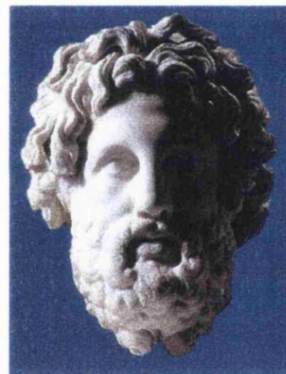


Figure 3.4- Ideas of beauty and perfection change with time and culture. For example, ancient Greek ideals of male beauty can be seen in these marble statues. Courtesy of The British Museum.



Figure 3.5- Cavalry sports helmet from Rochester, Britain, (late 1st-early 2nd century AD) shows the similarity of the Western European Caucasian facial characteristics to today. Courtesy of The British Museum.

Just like the ancient sculptures and paintings famous artists during the last millennium, especially during the Renaissance convey us the perception of contemporary beauty with their immaculate work (Figure 3.6).



Figure 3.6- The replica of Michelangelo's 'David' in Caesar's Palace (left). The Venus detail from 'The birth of Venus' (1485) by Botticelli in Florence (right). Such classical models, along with mathematical ideas of proportion and ratio, were taken up in the 15th century Italy (the Renaissance) and became the standard by which Western art was made and judged for centuries, which affected the perception of human facial aesthetics to our time.

As early as 15th century, artists like Dürer and da Vinci studied the human body and face proportions. Dürer is the first artist who is known to have painted a self-portrait (Figure 3.7) and he had a great knowledge of human facial aesthetics based on diagrams defining facial proportions, which are considered to be applicable to the norms accepted today. Leonardo da Vinci is another artist of the same era who produced immaculate pieces of art and many study drawings of the human face and body (Figure 3.8).



Figure 3.7- The self-portrait of Dürer at the age of 28 (1500), who produced similarly perfect portraits due to his great interest and knowledge of human facial proportions (from Alte Pinakothek, Munich) as well as his unique talent.



Figure 3.8- Leonardo da Vinci's 'Study of Grotesque Heads' (1490) from the Royal Library, Windsor Castle and 'Head of a Woman' (1510) from Musee Bonnat, Bayonne.

What do we know about people's tastes of facial aesthetics today? Do most people like the same faces, are they influenced by fashion, or are their aesthetic preferences as random and diversified as their backgrounds and experiences? Our tastes are, to a large extent, fostered by our culture and influenced by multiple factors such as the mass media. Seldom can a member of society completely isolate himself from these universal influences. These factors have a profound influence on our aesthetic judgement and preferences, setting unconscious standards of beauty. Nevertheless, although some aspects of the judgement of facial beauty may be influenced by culture

or individual history, the general geometric features of the face that give rise to a perception of beauty may be universal (Moss *et al.*, 1995).

After the review of the literature, the following questions still remain unanswered:

- Do people from different ethnic backgrounds, age, sex, or occupation share a common basis for the judgement of facial beauty?
- Is beauty measurable beyond certain basic proportions? Or in other words, can we reduce beauty to a logical or mathematical formula by producing a so-called “norm” or is beauty an intuitive and imaginative idea influenced by the intrinsic as well as the extrinsic?

This investigation tried to answer these questions.

3.2 Aims

The overall aim of this investigation was to assess facial aesthetics in 3 ethnic groups; Afro-Caribbeans, Caucasians, and Orientals by;

1- assessment of subjects' photographs by 3 ethnic panels formed of laymen, surgeons and orthodontists,

2- measuring the following landmarks and structures:

- a) Interlimbus distance
- b) Intercanthal distance
- c) Nasal tip projection
- d) Alar base width
- e) Nasolabial angle
- f) Vermilion border

- g) Lip-incisor relationship
- h) Oral commissural width
- i) Chin profile.
- j) Upper lip length
- k) Chin depth

3- analysing a normal ratio of facial soft tissue structure of the least and most favoured faces in the 3 ethnic groups.

3.3 Materials and methods

3.3.1 Selection of subjects

48 adult males and females (Figure 3.9) between the ages of 18 to 33 from three different ethnic groups (Afro-Caribbeans, Caucasians, and Orientals) were included in this investigation. The subjects were labelled from number 1 to 48 (Table 3.1). Black and white photographs were taken in three different views; frontal, at smiling, and lateral view.

48 subjects in total	
Subject number	1 to 8 Oriental females
	9 to 16 Oriental males
	17 to 24 Afro-Caribbean males
	25 to 32 Afro-Caribbean females
	33 to 40 Caucasian females
	41 to 48 Caucasian males

Table 3.1- Subjects in the investigation



Figure 3.9- The 48 subjects included in the study

The subjects were chosen in equal numbers; 8 females and 8 males from each ethnic group. During the selection of the subjects, all efforts were made to choose subjects who were representative of these ethnic groups. They were randomly selected from students and staff at University College London, Kingsway College, and also the general public. The subjects were photographed in the Photographic Department at the Eastman Dental Institute. Three photographs of each subject were taken under same conditions, by the same photographer and the same camera; two frontal full-face, one with the face at rest, one with a natural smile and one lateral profile. In the lateral view the head was positioned so that the Frankfort plane was parallel to the floor and the median sagittal plane of the patient was parallel to the plane of the film, with the optical axis of the camera lens passing through the orbitale. The subjects were not wearing any make-up when photographed.

3.3.2 Selection of panel

An equally mixed panel of 12 maxillofacial surgeons, 12 orthodontists, and 12 laymen were selected from 3 different ethnic groups. Their ages ranged between 18 - 40. (Table 3.2)

<u>Panel (n=36)</u>		
<u>Afro-Caribbean</u>	<u>Oriental</u>	<u>Caucasian</u>
4 Laymen (2 F, 2 M)	4 Laymen (2 F, 2 M)	4 Laymen (2 F, 2 M)
4 Surgeons (2 F, 2 M)	4 Surgeons (2 F, 2 M)	4 Surgeons (2 F, 2 M)
4 Orthodontists (2 F, 2 M)	4 Orthodontists (2 F, 2 M)	4 Orthodontists (2 F, 2M)
<u>KEY:</u> F = Female, M = Male		

Table 3.2- The panel consisting of 9 sub-panels.

Although the initial plan was to form the professional panel of consultants, due to the lack of sufficient number of Afro-Caribbean and Oriental consultants, the panels were made up from MSc students, senior house officers and registrars.

3.3.3 Method of panel assessment

The panel assessed and ranked the photographs together in sub-panels by discussing each case. The photographs were spread on a board in front of the panel then the panel was asked to rank the most beautiful male/female subject in each ethnic group as number 1 to the least beautiful male/female subject as number 8. Where there was a disagreement, the opinion of the majority was accepted. Every subject was assessed by nine sub-panels. In this way the most and the least beautiful male and female were identified in each ethnic group. The data were then collected to be used for statistical analysis.

Additionally the photographs were sent to Malaysia, and assessed and ranked by 8 local maxillofacial surgeons individually. This would enable inclusion of another sub-panel, of Oriental ethnicity in their local milieu, as opposed to the other sub-panels of different ethnic backgrounds under a western European influence.

3.3.4 Clinical facial measurements

The following data were measured clinically and recorded:

- a. Skeletal relationship
- b. Anterior open bite
- c. Overjet
- d. Overbite
- e. Facial asymmetry
- f. Upper dental midline to facial midline
- g. Lower dental midline to facial midline
- h. Chin point to facial midline
- i. Chin position
- j. Maxillary incisor exposure at rest
- k. Maxillary incisor exposure at smile
- l. Upper vermilion width (minimum)
- m. Upper vermilion width (maximum)
- n. Lower vermilion width
- o. Alar base width
- p. Intercanthal distance
- q. Interlimbus distance
- r. Oral commissural width
- s. Occlusal plane
- t. Nasolabial angle
- u. Upper lip length
- v. Chin depth

All the measurements were taken using a Vernier calliper (Figure 3.10). The chin position was assessed, by using a combination of Gonzales-Ulloa (1962) and Obwegeser's (Obwegeser and Marentette, 1986) methods by drawing a horizontal line from upper tragus, parallel to the Frankfort plane. Then a vertical line (facial plane) was drawn from glabella to the soft tissue menton, perpendicular to the horizontal line. The position of the chin was measured in relation to the vertical line (Figure 3.11). A chin towards to the line was marked as positive, otherwise negative, i.e. anterior to the vertical line.



Figure 3.10- Clinical measurements were taken using a Vernier calliper.

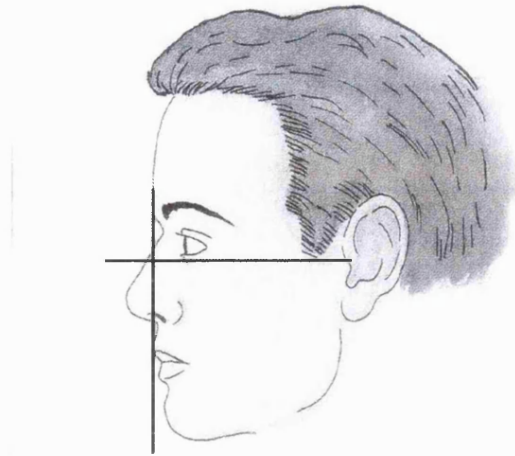


Figure 3.11- The chin position was assessed by drawing a horizontal line from upper tragus, parallel to the Frankfort plane, then a vertical line (facial plane) was drawn from glabella to the soft tissue menton, perpendicular to the horizontal line. The position of the chin was measured in relation to the vertical line.

3.4 Results

3.4.1 Panel assessment

The mean rank and the range of ranks awarded to the subjects by the panels are summarised in charts (Figures 3.12-3.29). The results of the Malaysian panel are in Figure 3.30.

Figure 3.12- Ranking of Oriental females by surgeons

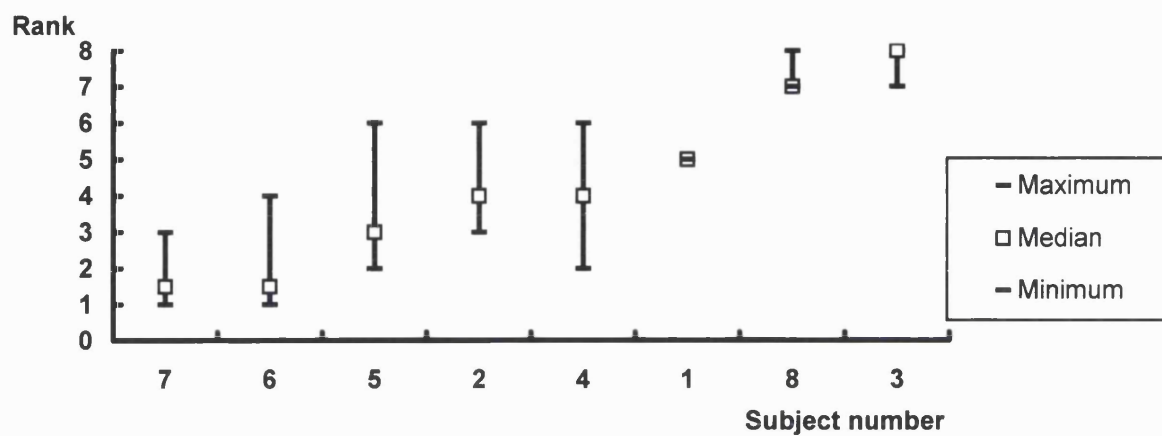


Figure 3.13- Ranking of Oriental males by surgeons

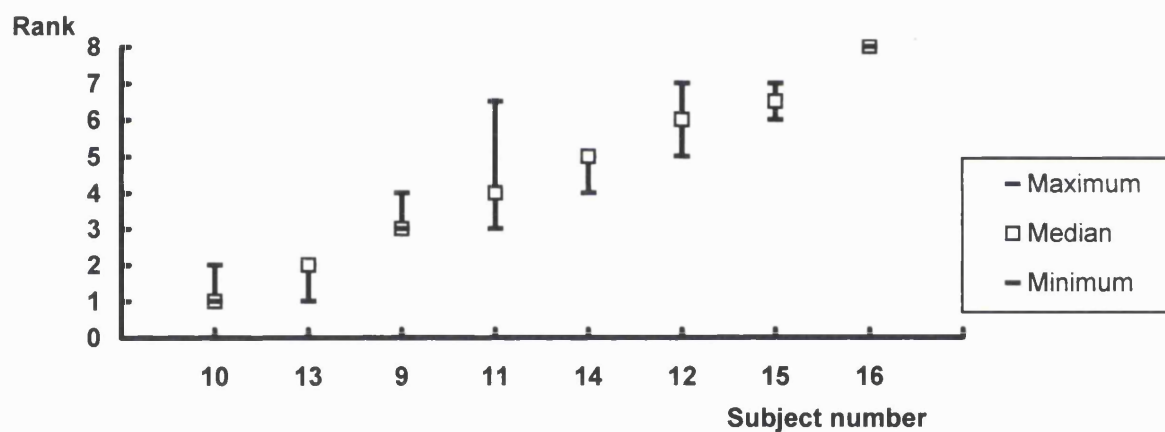


Figure 3.14- Ranking of Afro-Caribbean females by surgeons

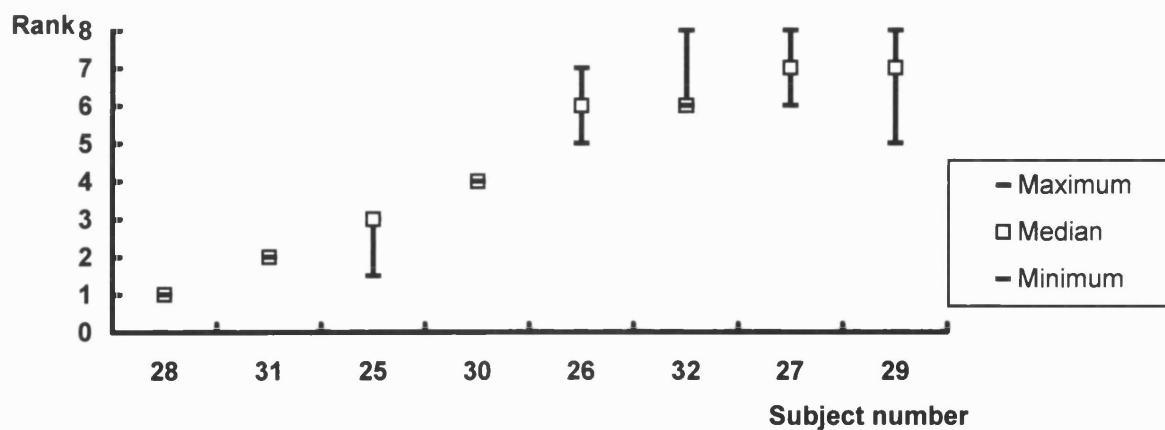


Figure 3.15- Ranking of Afro-Caribbean males by surgeons

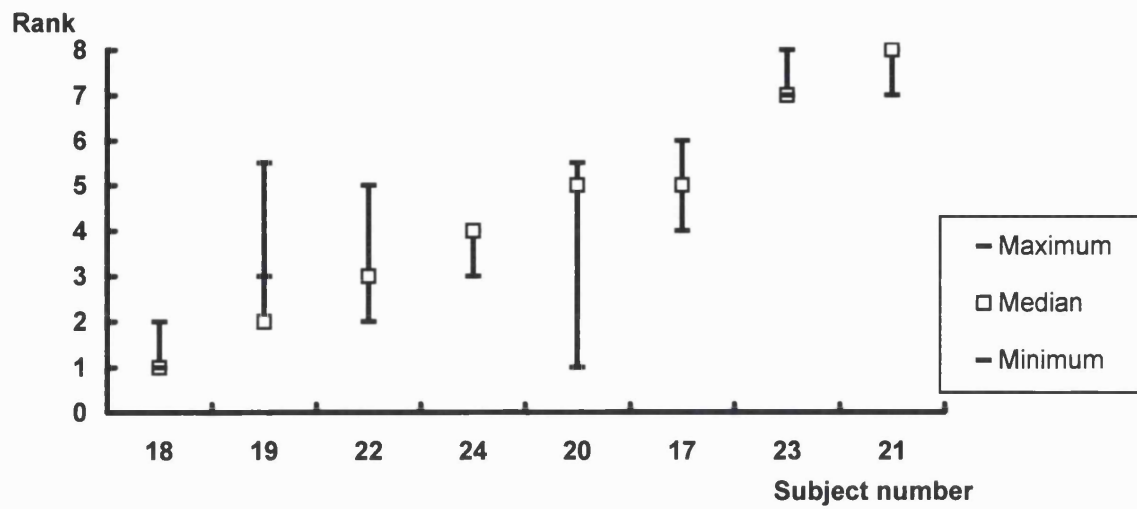


Figure 3.16- Ranking of Caucasian females by surgeons

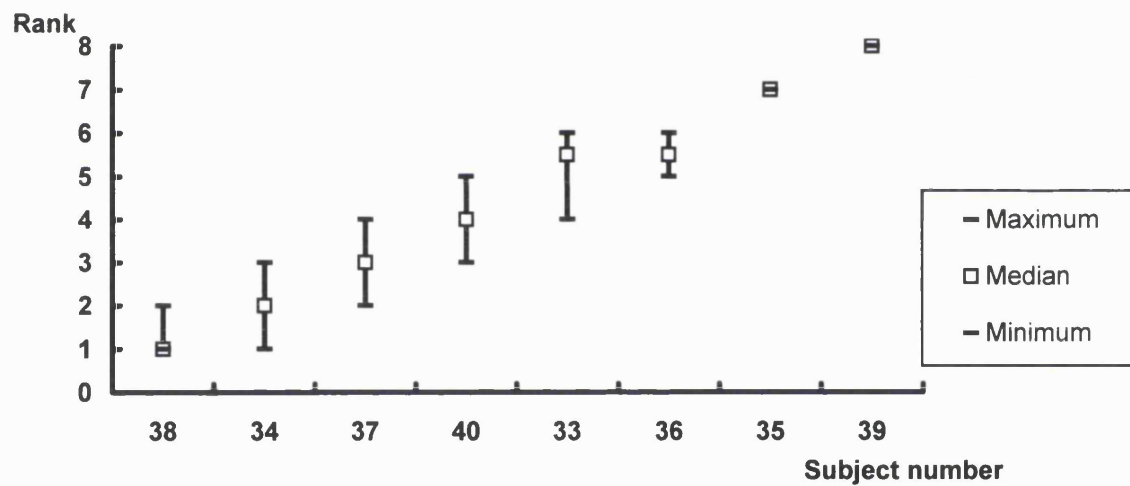


Figure 3.17- Ranking of Caucasian males by surgeons

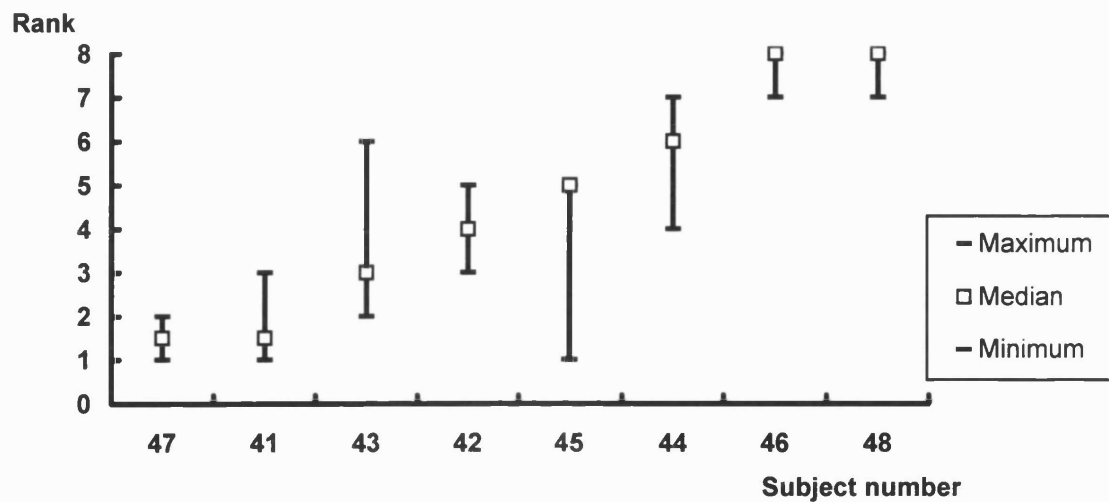


Figure 3.18- Ranking of Oriental females by orthodontists

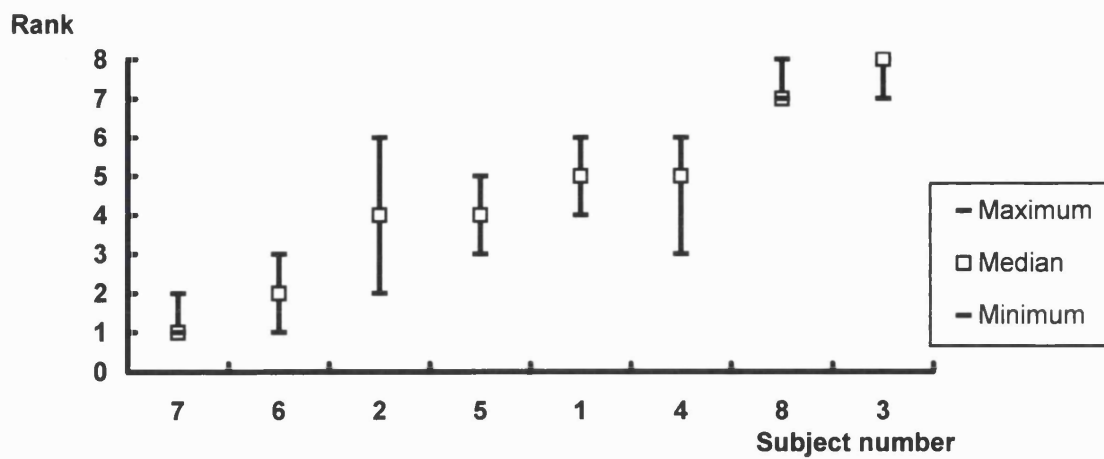


Figure 3.19- Ranking of Oriental males by orthodontists

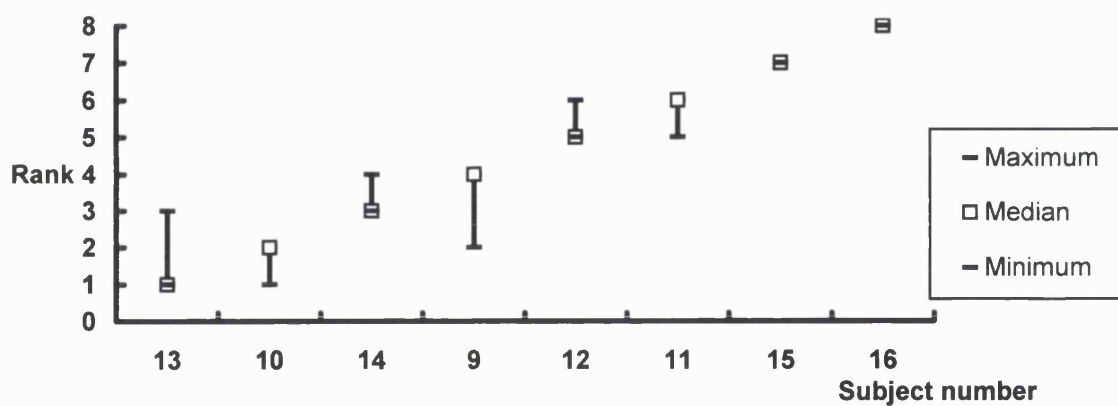


Figure 3.20- Ranking of Afro-Caribbean females by orthodontists

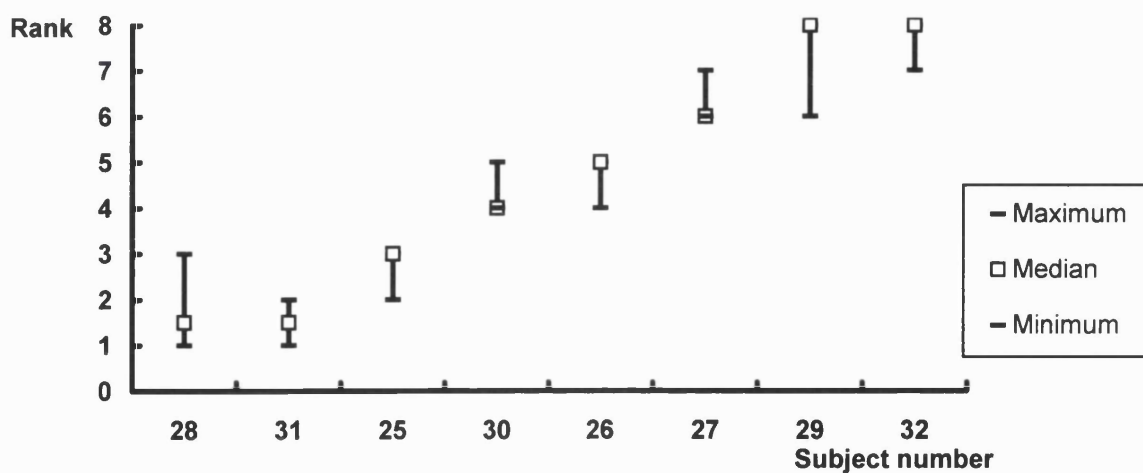


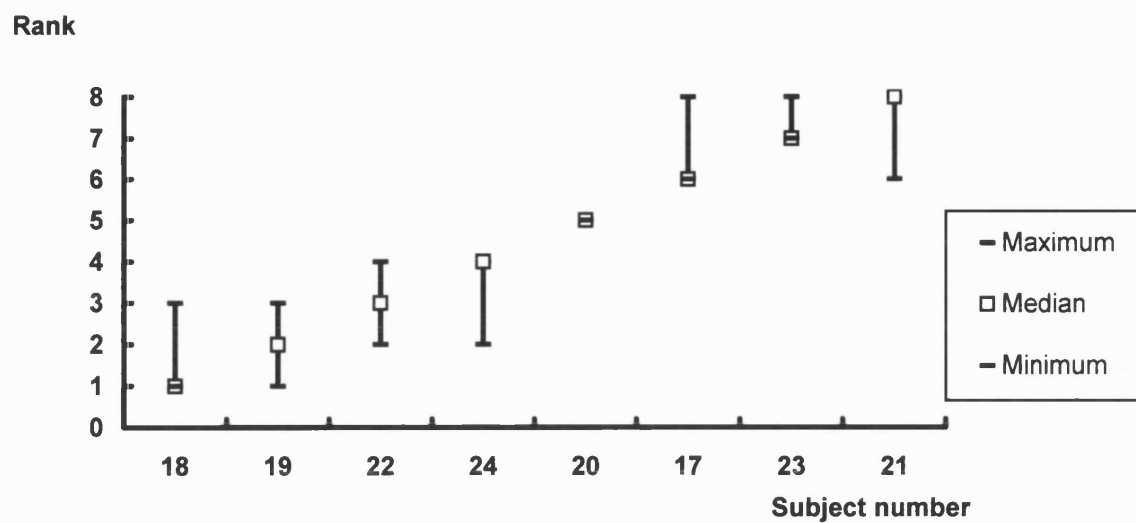
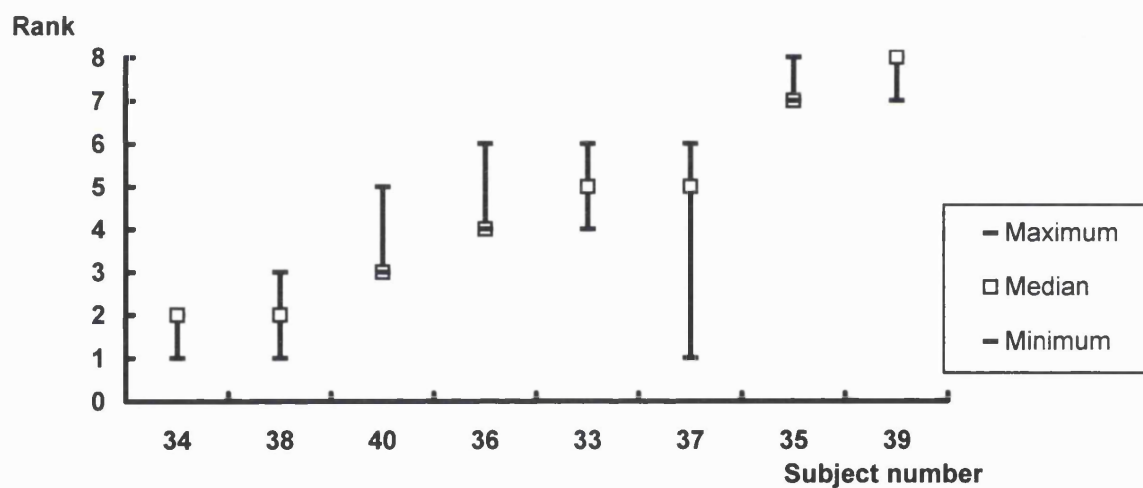
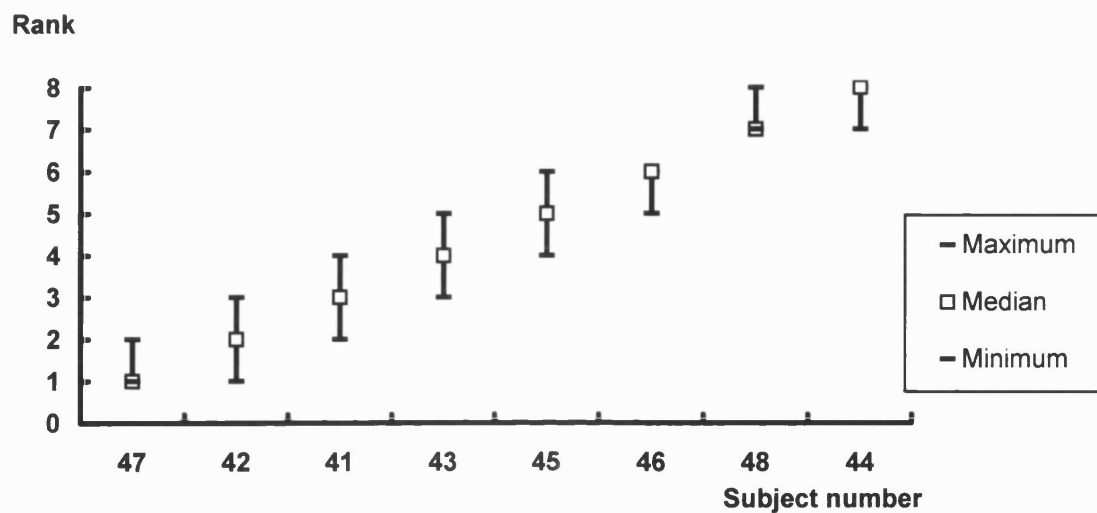
Figure 3.21- Ranking of Afro-Caribbean males by orthodontists**Figure 3.22- Ranking of Caucasian females by orthodontists****Figure 3.23- Ranking of Caucasian males by orthodontists**

Figure 3.24- Ranking of Oriental females by laymen

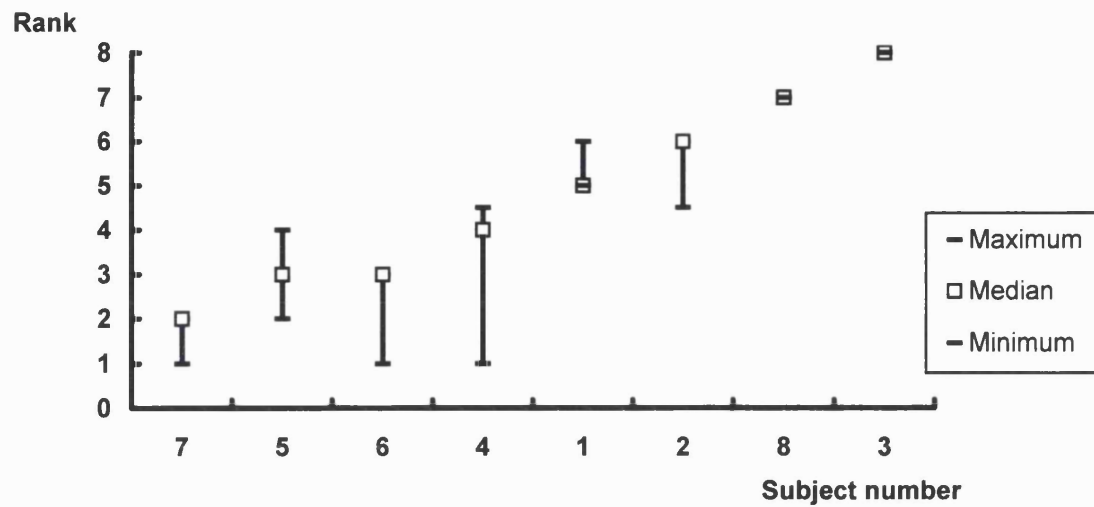


Figure 3.25- Ranking of Oriental males by laymen

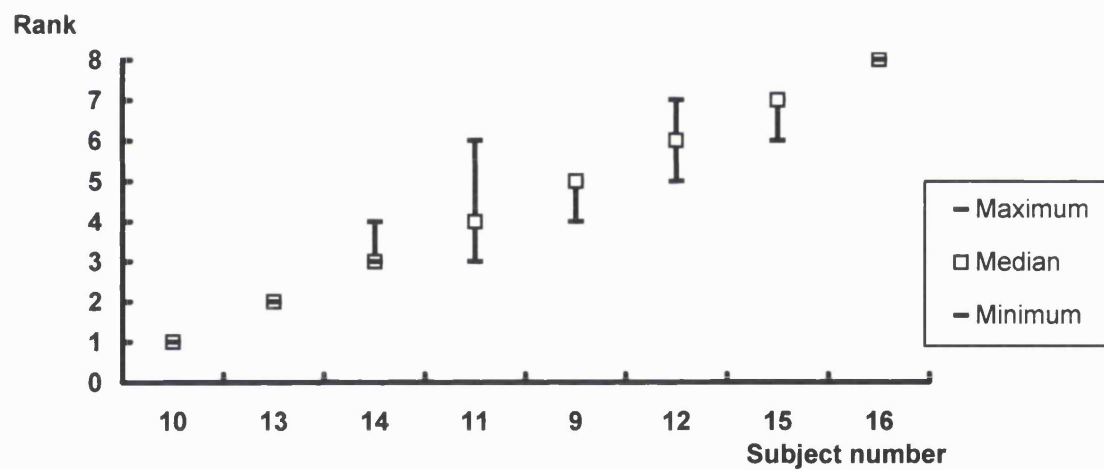


Figure 3.26- Ranking of Afro-Caribbean females by laymen

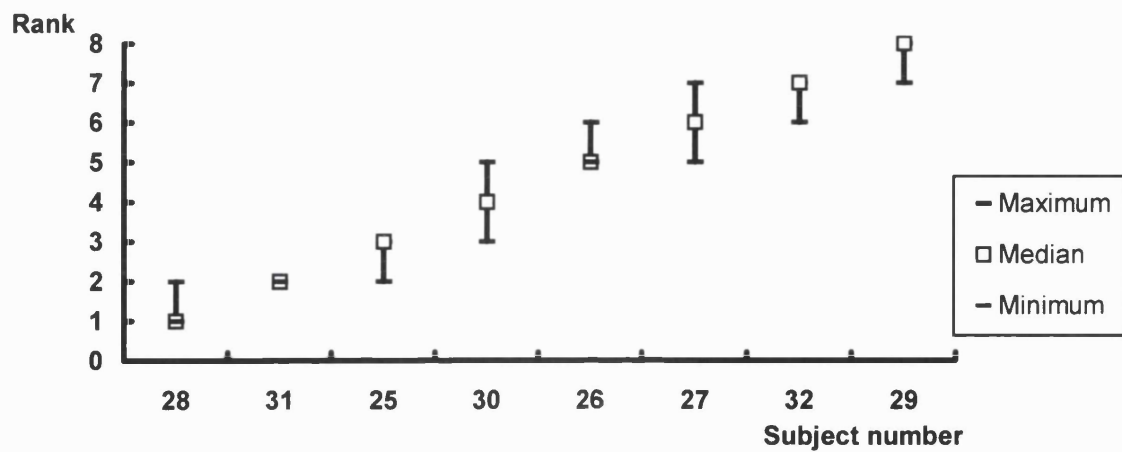


Figure 3.27- Ranking of Afro-Caribbean males by laymen

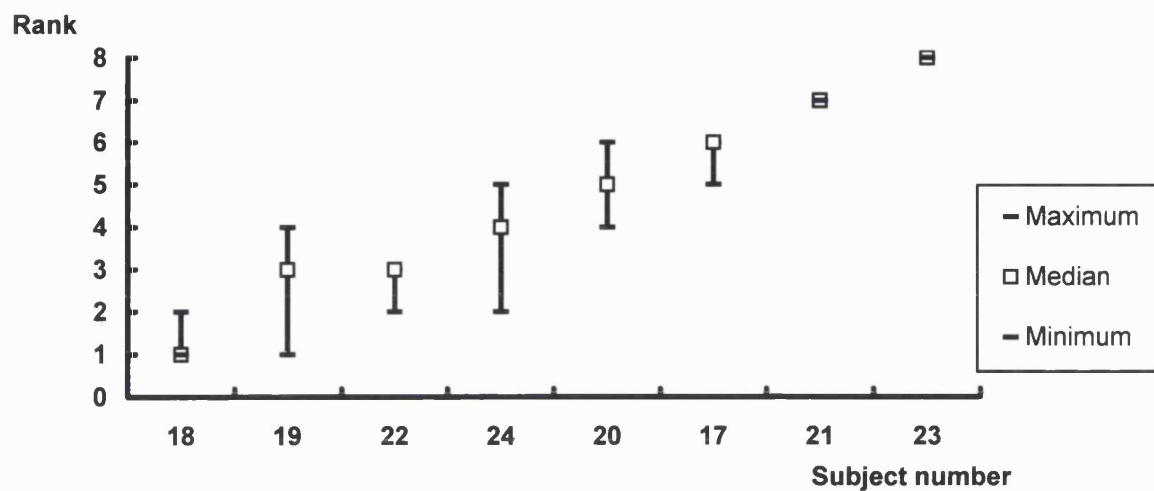


Figure 3.28- Ranking of Caucasian females by laymen

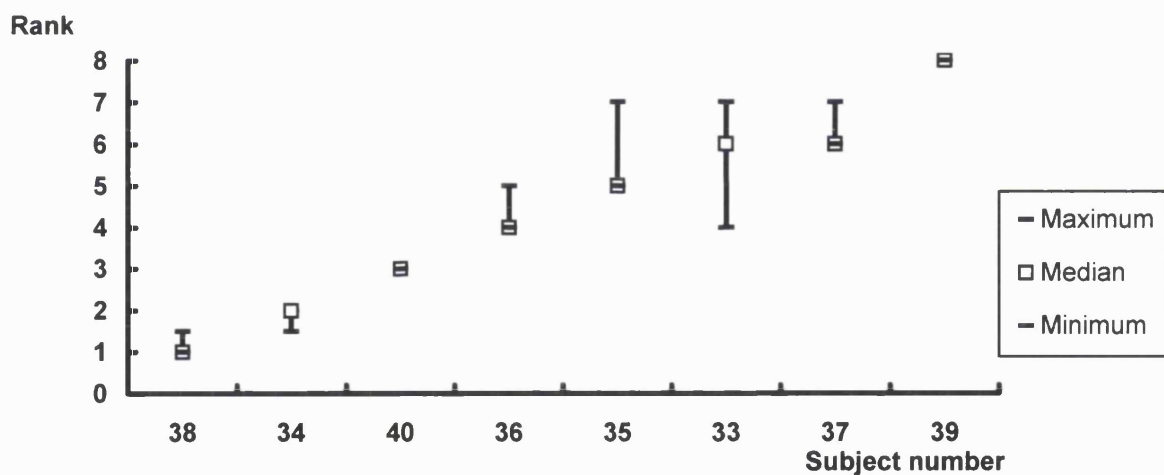
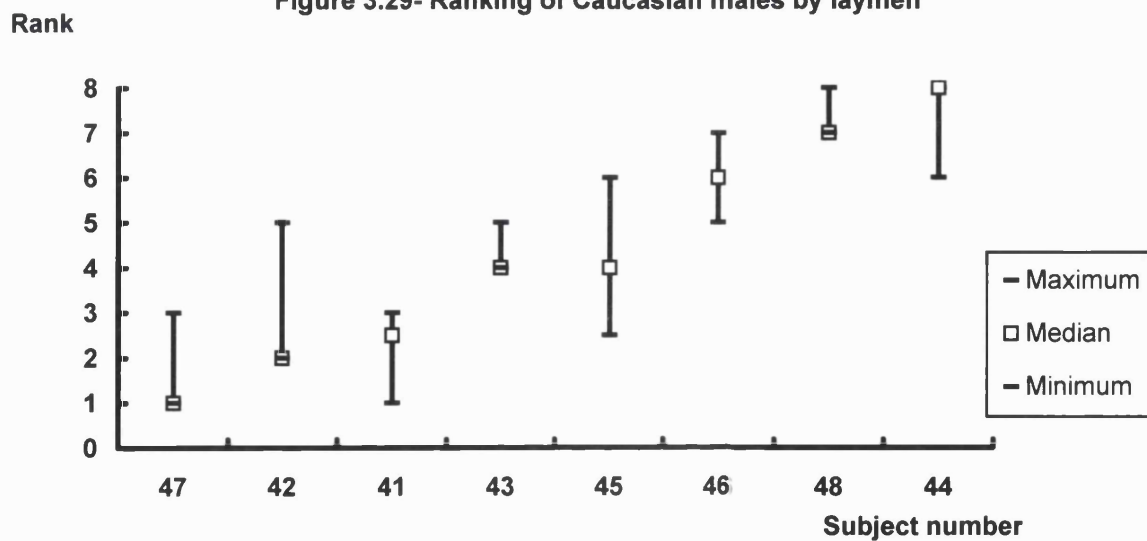


Figure 3.29- Ranking of Caucasian males by laymen



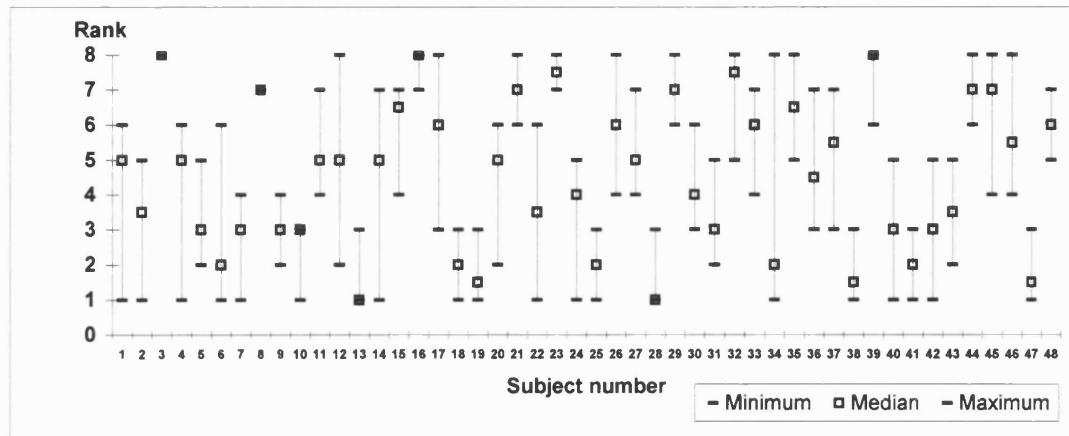


Figure 3.30- Ranking of subjects (Subject numbers 1-16: Caucasians, 17-32: Afro-Caribbeans, 33-48: Orientals) by the Malaysian panel.

3.4.2 Analytical statistics of panel assessment

Rank correlations were calculated between types of panel both within and between the three groups of operator. All showed high degrees of correlation ($p = .821$), indicating broad agreement in ranking for the 48 subjects.

Estimations were made of the coefficient of variation in ranking

- For each subject,
- For each panel type.

Coefficient of variation = Standard Deviation / mean

(Armitage and Berry, 1987)

$$CV = \frac{SD}{\bar{x}} \times 100$$

Parametric and non-parametric tests on coefficients of variation were carried out as follows:

a) *The difference between the 6 groups of subjects (ANOVA and Kruskal Wallis tests).* These showed no statistically significant difference between the groups in variation in ranking.

b) *The difference between genders (Student "t" test and Mann - Whitney "u" test).* These showed no statistically significant difference between genders in the variation in ranking.

c) *The difference between ethnic groups of subjects (ANOVA and Kruskal Wallis tests).* These show no statistically significant difference between ethnic groups in the variation in ranking.

d) *The difference between 12 subjects with the highest mean rank and 12 with the lowest mean rank (Student "t" test and Mann - Whitney "u" test).* These showed a highly statistically significant difference ($p < .001$) between the two groups in the variation in ranking. Those with the lowest mean ranks showed less variation in their ranking.

e) *The difference between the 3 types of panel (ANOVA and Kruskal Wallis tests).* These showed no statistically significant difference in variation in ranking between panels made up of laymen, orthodontists, and surgeons.

3.4.3 Facial measurements

Facial measurements are summarised (Table 3.3) separately for each ethnic group and gender. Table 3.4 shows the mean of the 2 most beautiful and the 2 least beautiful subjects in each group and gender.

Measurement (mm)	Afro-Caribbean N=16		Caucasian N=16		Oriental N=16	
mean (mm) ± SD	male	female	male	female	male	female
Overjet	1.9 ± 1.7	2.0 ± 1.6	2.9 ± 2.2	3.4 ± 2.8	2.1 ± 2.8	2.0 ± 0.9
Overbite	1.5 ± 1.2	1.9 ± 1.6	2.1 ± 0.8	2.1 ± 1.2	2.1 ± 2.1	2.0 ± 1.0
Chin position	0.4 ± 6.3	-2.2 ± 2.2	-2.4 ± 3.6	-4.4 ± 3.2	0.2 ± 5.1	-1.9 ± 3.8
Max. incisor exposure	2.4 ± 1.7	2.6 ± 1.2	3.3 ± 1.8	4.1 ± 1.5	1.9 ± 1.7	2.7 ± 1.9
Upper vermillion	11.0 ± 1.7	10.4 ± 1.5	7.6 ± 1.3	6.3 ± 1.6	8.1 ± 1.4	9.3 ± 0.9
Lower vermillion	13.0 ± 1.9	12.6 ± 1.3	9.5 ± 0.9	8.3 ± 2.3	10.0 ± 1.4	10.0 ± 1.1
Alar base	43.9 ± 4.1	38.4 ± 5.0	36.2 ± 3.2	31.5 ± 2.2	41.2 ± 4.0	36.0 ± 2.5
Intercanthal distance	33.8 ± 1.5	34.6 ± 5.6	32.4 ± 2.4	28.5 ± 2.1	35.1 ± 2.6	33.1 ± 1.9
Interlimbus distance	52.8 ± 1.8	50.4 ± 1.7	51.8 ± 2.3	48.0 ± 1.7	52.5 ± 1.6	50.0 ± 1.6
Commissural width	54.9 ± 3.4	52.9 ± 2.3	52.1 ± 3.6	48.5 ± 1.8	51.4 ± 4.8	49.4 ± 4.2
Nasolabial angle	93.1 ± 5.3	94.4 ± 5.0	98.0 ± 6.0	101.0 ± 1.1	91.9 ± 6.5	99.0 ± 7.8
Upper lip length	26.2 ± 2.2	22.8 ± 3.0	23.0 ± 2.0	21.0 ± 2.7	25.0 ± 3.3	22.5 ± 2.1
Chin depth	45.0 ± 8.7	43.6 ± 2.3	47.6 ± 1.8	42.8 ± 2.7	45.5 ± 4.3	42.8 ± 2.9

Table 3.3- Summary data of facial measurements in 3 ethnic groups

Key: Chin position is measured related to the facial plane (Figure 3.11).

	Afro-Caribbean		Caucasian		Oriental	
Measurements (mm)	male n=2	female n=2	male n=2	female n=2	male n=2	female n=2
Overjet	3.0	2.0	2.0	3.0	4.0	2.0
Overbite	2.5	2.0	2.0	2.5	3.0	1.5
Chin position	2.0	-2.0	0.0	-.05	-1.0	0.0
Max. incisor exposure	4.0	4.0	3.0	4.0	3.0	3.0
Upper vermillion	12.0	10.0	7.0	7.5	9.0	10.0
Lower vermillion	13.5	12.0	10.0	10.0	10.5	11.0
Alar base	38.5	34.0	34.5	30.0	38.0	34.0
Intercanthal distance	34.0	33.5	34.0	30.0	37.0	35.0
Interlimbus distance	52.5	52.0	52.5	49.0	53.0	50.0
Commissural width	50.5	50.0	53.0	50.0	53.0	49.0
Nasolabial angle	97.5	100.0	100.0	97.5	92.5	95.0
Upper lip length	24.0	21.5	23.0	19.0	22.0	20.0
Chin depth	48.0	43.0	47.0	42.5	45.0	41.0

Table 3.4- Comparison of the facial measurements between the most beautiful subjects in 3 ethnic groups.

Key = Chin position is measured in profile view related to the facial plane (Figure 3.11).

The facial measurements in Table 3.4 showed no significant difference between the most beautiful subjects in different ethnic groups, with the exception of the alar base width, which is broader in Afro-Caribbeans and Orientals, and the vermillion border, which is broader in Afro-Caribbeans. This shows that, generally, the intercanthal distance is equal to the alar base and similarly, the interlimbus distance is equal to the commissural width in the most beautiful subjects.

	Afro-Caribbean		Caucasian		Oriental	
Measurements (mm)	male n=2	female n=2	male n=2	female n=2	male n=2	female n=2
Overjet	0.0	0.5	2.5	0.5	1.5	2.5
Overbite	-0.5	1.5	5.0	5.5	0.5	2.0
Chin position	6.0	0.0	-7.0	-8.0	5.0	0.0
Max. incisor exposure	2.0	2.0	5.0	5.5	2.0	2.5
Upper vermillion	10.0	11.5	8.0	6.0	9.5	8.5
Lower vermillion	11.5	13.5	9.0	6.0	11.5	9.0
Alar base	47.0	33.0	36.0	34.0	37.5	39.0
Intercantal distance	32.0	34.0	31.0	30.5	32.0	32.0
Interlimbus distance	52.0	50.0	44.5	49.0	52.0	51.0
Commissural width	59.0	54.5	46.5	51.0	57.0	50.0
Nasolabial angle	87.5	90.0	95.0	95.0	82.5	102.0
Upper lip length	27.0	22.5	22.5	21.0	23.0	23.0
Chin depth	50.0	42.0	47.5	41.0	49.5	43.5

Table 3.5- Comparison of the facial measurements between the least beautiful subjects in 3 ethnic groups

Key = Chin position is measured in profile view related to the facial plane (Figure 3.11).

3.4.4 Analytical statistics of measurements

- 1- All variables were entered onto PC using SPSS statistical software package (SPSS for Windows, Release 10.0.5, Standard version, © SPSS Inc. 444 N. Michigan Ave., Chicago, Illinois 60 611) for every subject.
- 2- Comparisons were made between measurements and variables for the 12 subjects with the lowest mean rank (most beautiful) and the 12 with the highest mean rank (least beautiful). Each group of 12 included 2 subjects from each gender and each ethnic group.
 - a. Comparison between frequencies in the case of qualitative variables (using chi square test) showed statistically significant differences in facial asymmetry ($p < .001$).
 - b. The following measurements showed statistical significant difference:
 - i. Chin position ($p < 0.001$),
 - ii. Maxillary incisor relationship ($p < 0.003$),
 - iii. Alar base width ($p < 0.009$),
 - iv. Commissural width ($p < 0.004$),
 - v. Nasolabial angle ($p < 0.017$).
 - c. Comparison of means in the case of quantitative measurements (using Student "t" test, Mann-Whitney "u" tests) showed no significant difference between the 12 better and the 12 worse except in the case of alar base width ($p < .008$) (Figure 3.30) (Table 3.6).

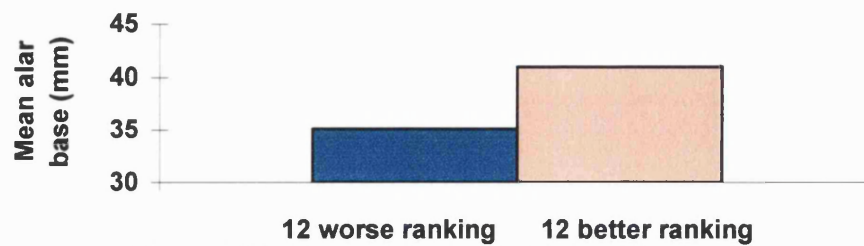


Figure 3.31- Mean alar base width in the 12 subjects with the best and the 12 with the worst mean ranks

Measurements (mm)	More beautiful subjects n=12	Less beautiful subjects n=12	Student t test	Mann Whitney U test
Overjet	2.6 (± 1.2)	2.3 (± 3.9)	N.S	N.S
Overbite	2.3 (± 1.0)	1.3 (± 2.0)	N.S	N.S
Chin position	0.0 (± 2.0)	-1.2 (± 6.9)	N.S	N.S
Max. incisor relation	3.4 (± 1.0)	3.3 (± 2.2)	N.S	N.S
Upper vermillion	9.1 (± 2.0)	9.0 (± 2.6)	N.S	N.S
Lower vermillion	11.2 (± 1.5)	10.4 (± 3.2)	N.S	N.S
Alar base	35.0 (± 3.3)	41.0 (± 6.0)	P< .008	P< .002
Intercanthal distance	33.9 (± 2.8)	32.7 (± 4.7)	N.S	N.S
Interlimbus distance	51.8 (± 2.2)	50.6 (± 1.8)	N.S	N.S
Commissural width	51.1 (± 4.0)	52.1 (± 5.1)	N.S	N.S
Nasolabial angle	97.0 (± 3.3)	92.0 (± 9.4)	N.S	N.S
Upper lip length	21.3 (± 1.9)	23.2 (± 2.9)	N.S	N.S
Chin depth	44.8 (± 2.6)	45.6 (± 4.9)	N.S	N.S

Key: N.S. = Not significant

Table 3.6- Summary of facial measurements for the 12 most beautiful and 12 least beautiful subjects (mean $\pm$ SD)

During the comparison of the 12 most beautiful and 12 least beautiful subjects, the presence or absence of chin deviation appeared to be another important factor (Figure 3.32).

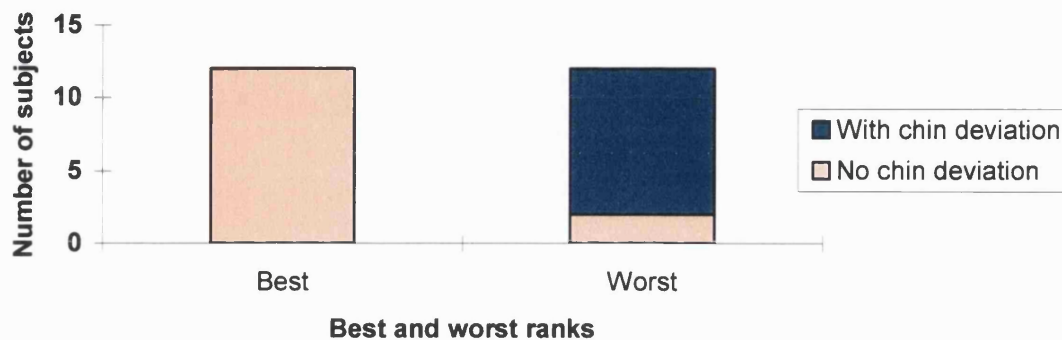


Figure 3.32- Numbers of subjects with and without chin deviation in the 12 most and least beautiful subjects

3.5 Discussion

The results of this investigation showed that facial beauty is not a varied concept when it comes to the 'most beautiful or the 'least beautiful' person. Variations in individual choice appear to relate to the middle range of appeal.

Statistical analysis of the panel's sub-group assessment showed a general agreement between different groups with different ethnic backgrounds in the appreciation of facial beauty; i.e. there was a universal and common basis for judgement of beauty within the social context of the experiment. The universality of the outcome is supported by the assessment of the subjects by 8 maxillofacial surgeons in Malaysia, which matched the results of this study.

The aphorism that facial beauty is purely subjective and that "beauty is in the eye of the beholder" by M. Hungerford (Knowles, 2001) is not completely confirmed by these results. Our results demonstrate that facial beauty is to a certain extent objective and Hungerford was undoubtedly referring to the middle range where personal attractiveness is in the eye of the beholder, not beauty. We must distinguish between beauty and attractiveness. Attractiveness is an overall, multi-dimensional judgement of an individual. It includes not only facial features, but also facial expression, animation and personality, which may be modified by make-up, dress, attitude, body shape, and posture.

Communication technology and the media and their availability around the globe provide daily reinforcement of commercially selected facial aesthetics. Psychologists say that our perception of forms depends on the development of "form concepts". We usually find any diversion from this orientation quite confusing. Form concepts similarly influence our perception of faces. The more frequently we observe a particular facial pattern, the more likely we perceive it as "correct" (Peck and Peck, 1970).

It is largely the mass media that determines our form concepts in the 21st century. Newspapers, fashion magazines, films, television are full of Caucasian/Caucasoid models or actors who automatically determine people's notions of beauty. Due to the homogenisation of culture throughout the world, our panel, although formed of racially different individuals, shared a common base for the assessment and judgement of beauty. If there had

been individuals available for the panel, who were not in contact or not influenced by western culture, the results might possibly be significantly different to what we have achieved. Specifically, the domination of Caucasian features on the worldwide media means that these facial features appear as more acceptable, natural, and therefore beautiful.

The convergence of opinions about facial beauty shown by this study does not mean that every face that fulfils the geometrical criteria and fall into the anthropometrical categories should be beautiful. There are of course factors that can not be measured, for example eye expression and facial animation. Another factor, which is not easily measurable in the perception of beauty, is the quality of skin.

Because there is little uniformity in the ideal profile, and a great variability in human faces, the reconstruction of a deformed face or any cosmetic facial surgery need not be based on a narrow geometrical formula, but is the art of optimising the craniofacial complex. (Seghers *et al.*, 1964).

The concept of a golden proportion was described by ancient Greeks and popularised in orthodontics and surgery as the 'divine proportion' by Ricketts (1982). He claimed aesthetics could be achieved scientifically rather than based on the need to resort to subjective perceptions. This study supports both the norm and the golden proportion suggested by Ricketts, which certainly can guide a surgeon towards the correction of facial deformity, however the search for an absolute formula for beauty is not practicable. The

knowledge of the appropriate relationships and proportions between the various parts of the head and face is indispensable. Aesthetic improvement is a strong motivating factor for many patients who decide to undergo orthognathic surgery. Hence an adequate training in evaluation and assessment of facial aesthetics is an important requirement for trainees in maxillofacial surgery.

As stated, the analysis of the panel assessment and facial measurements in this investigation indicated that, although there are significant differences in variability of the facial features in different ethnic groups, the best-ranked Afro-Caribbean and Oriental subjects had very similar facial features to Caucasians. Whether this is just a coincidence (because of the small sample size) or reality, is not well understood. But this similarity has been observed in the majority of the Afro-Caribbean and Oriental photographic models.

Chin deviation and alar base are strong markers for facial beauty. It is indicated that generally alar base is wider in both Afro-Caribbeans and Orientals than Caucasians (Table 3.5). Vermilion border is generally broader and fuller in Afro-Caribbeans, which is another marker for facial beauty according to this study. Other features for a beautiful face indicated by this study are; short lips (19 mm), upper incisor exposure of 4-5 mm, equality of the facial thirds in vertical height, equality of the alar base width and intercanthal distance, and equality of the interlimbus distance and commissural width (Table 3.4).

Gonzales-Ulloa (1962) developed a very useful method in assessing the facial profile, especially the chin (Figure 3.11). In addition to his ideal profile lines, this study found that, the mid-face does not coincide with the facial plane in a beautiful face, which on the contrary gives the impression of a flat face. The mid-face in the most beautiful subjects in this study were anterior to the facial plane.

Assessment of the chin position (Figure 3.11) showed that in the most beautiful subjects the chin is coincident (0.0 ± 3.0 mm) to the facial plane as suggested by Gonzales-Ulloa (1962). This means a relatively strong chin is one of the features of a beautiful face in both sexes. This study also supports the results of the studies done by Ricketts (1982), Farkas *et al.* (1985), and Epker *et al.* (1995). However, in the facial measurements, the mean interlimbus distance in Caucasians was 52 ± 3 mm for males and 48 ± 3 mm for females, whereas Ricketts (1982) reported a mean measurement of 65 ± 4 mm.

The results of this study contradict to the results of Moss *et al.* (1995) to some extent. They found no correlation between beauty and precise proportions or golden proportion. It has to be pointed out that their results were also based on cephalometric measurements, which may be unreliable in the assessment of the facial form due to the errors and limitations of two-dimensional cephalographs.

In conclusion, this investigation showed that, to a certain extent, facial beauty is objective, and precise measurements, proportions and balance is a practical way of assessment. People from different ethnic groups, occupations and gender share common bases for evaluation and appreciation of facial beauty, and there is a universal understanding for appreciation of facial beauty. The influence of the media and the fashion world, which depicts Caucasian features, has changed the view of other ethnic groups about beauty. Although facial features differ racially, Caucasian features are accepted more widely. In this investigation, in all ethnic groups, the facial features of the subjects who were ranked as 'most beautiful' were similar to Caucasian norms.

It is also shown that facial symmetry and alar base width are important markers for facial beauty. Assessment of the chin showed that in the most beautiful subjects, the chin was coincident to the facial plane.

Clinical assessment of the face is crucial. Assessment of the facial aesthetics and diagnosis must be mainly based on experienced clinical observation. The aid of an improved 3-dimensional imaging tool, like the optical surface scanner, where available, should be used to support the clinical diagnosis and help the treatment plan for the correction of facial deformity, especially as it has the unique advantage of a captured image that can be measured and manipulated to allow predictive change.

CHAPTER IV

VALIDATION OF THE OPTICAL SURFACE SCANNER

4.1 Introduction

The use of three-dimensional graphics for soft tissue evaluation in orthognathic surgery planning has many advantages over conventional radiography. The accurate recording and prediction of the facial soft tissue changes after orthognathic surgery is important for surgeons and orthodontists. Conventionally two-dimensional radiological and photographic techniques have been used for this purpose and have often proved to be inadequate. Secondly, the use of traditional radiography has also limitations due to unjustified radiation doses from repeated examinations. Recently several techniques have been introduced for the morphometrics of the human face, the optical surface scanning system being one of the latest major developments (Linney *et al.*, 1993). This three-dimensional optical scan has also contributed towards the photo realistic simulation of the postoperative appearance of a patient (Girod *et al.*, 1995).

The optical surface scanning system developed by Linney and his co-workers has been used regularly over the last decade for recording facial soft tissues (Linney *et al.*, 1993). This system was designed and is in regular use in University College London Hospitals. Its range of application has extended from surgical diagnosis and planning to prostheses and implant design, clinical growth studies, forensic science, archaeology, psychology research, sculpture and animation for advertising.

This optical surface scanning system (Figure 4.1) is based on the principle of triangulation. A beam of low power semiconductor laser light is projected on

to the subject's face and is distorted to reflect the contour of the surface anatomy. These reflections are then recorded by a camera situated adjacent to the laser projector (Linney *et al.*, 1993)

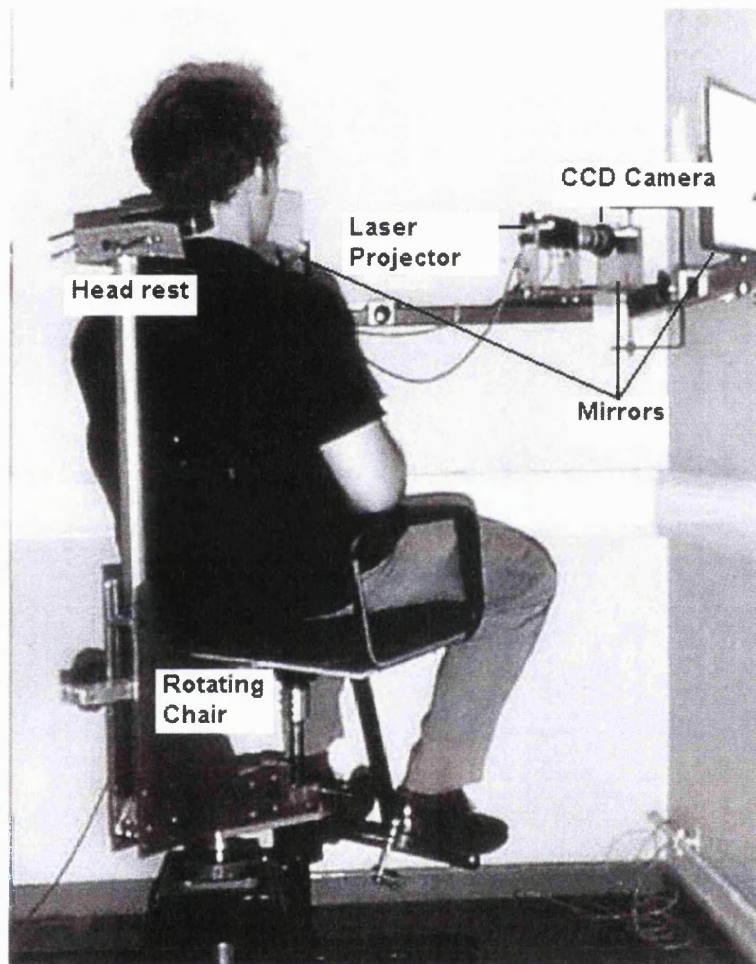


Figure 4.1- The optical surface scanner set-up.

The subject sits on a rotating platform, facing the camera and is rotated through 200 degrees in 10 seconds. Up to 258 profiles of the rotating subject are recorded in a scan (Linney, 1992). Specifically angled mirrors in the system enable the recording of additional views, so as to avoid the loss of data caused by the superimposition of prominent parts of the face, like the nose, on neighbouring facial structures. The angles at which these profiles

are recorded may be programmed to yield finer sampling over areas of greater interest where more detail is required. The recordings of the camera are sent to the transputer graphics system, which processes the video signals to form the scanned image on the video monitor.

Landmarks and facial structures can be recorded within a 0.5-mm accuracy, which meets the current clinical requirements of accuracy and the reproducibility for orthognathic surgery assessment and planning (Moss *et al.*, 1989). The output image is presented on the monitor as a translation of the surface. This may be observed from any perspective (Figure 4.2) and measurements can be taken across the surface in three dimensions. However there is a need to assess its accuracy and compatibility with conventional cephalography for its potentially wider clinical applications as systems based on similar principles are being marketed at reasonable costs.

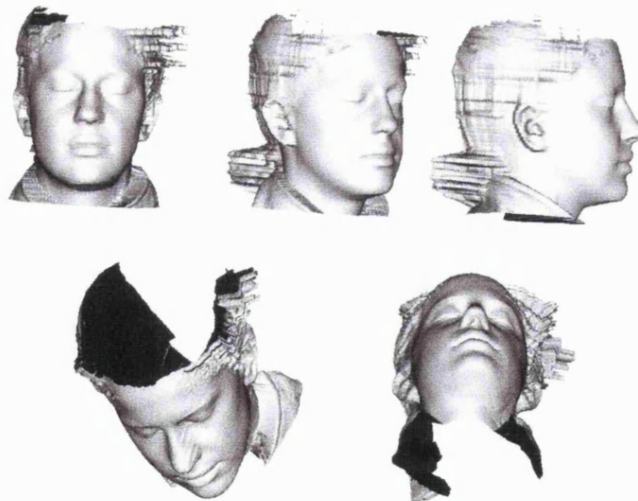


Figure 4.2- Various views of the optical surface scan.

For the validation of the optical surface scanner, two studies were conducted in this programme (Sections 4.2 and 4.3)

4.2 The comparison of the optical surface scan images to cephalographs for soft tissue analysis after orthognathic surgery

4.2.1 Aims

Aims of this study were to compare the conventional cephalographs and optical surface scanner images (lasergraphs) by measuring;

- a) the upper lip-incisor relationship (maxillary incisor exposure),
- b) the nasolabial angle,
- c) the nasal tip projection,
- d) the nasofacial angle,
- e) the nasomental angle and
- f) the labiomental angle in pre and postoperative orthognathic surgery patients.

The study also intended to validate the apparent advantages of the optical surface scanner for orthognathic surgery.

4.2.2 Materials and methods

Thirty bimaxillary osteotomy patients consented to and were included in this study. The clinical maxillary incisor exposure was measured after 3 minutes' repose:

- a) during the preoperative work-up,
- b) 6-8 weeks after surgery,

using a metric Vernier calliper, and on the cephalograph and the optical surface scan (lasergraph). The nasolabial, nasofacial, nasomental and labiomental angles and the nasal tip projection are not accessible for reproducible clinical measurements so were measured only on optical surface scans and cephalographs, as described in Figures 4.3, 4.4, 4.5.

The lateral skull cephalographs were taken in the conventional manner with the patient's lips in repose. Optical surface scans were obtained similar to cephalographs with the Frankfort plane horizontal. For this, the upper margin of the tragus and the orbitale were located manually and markers were attached to the patient's skin. The head position was then adjusted using a spirit level until the Frankfort plane was horizontal. Head-positioning is discussed in Section 4.3 in detail.

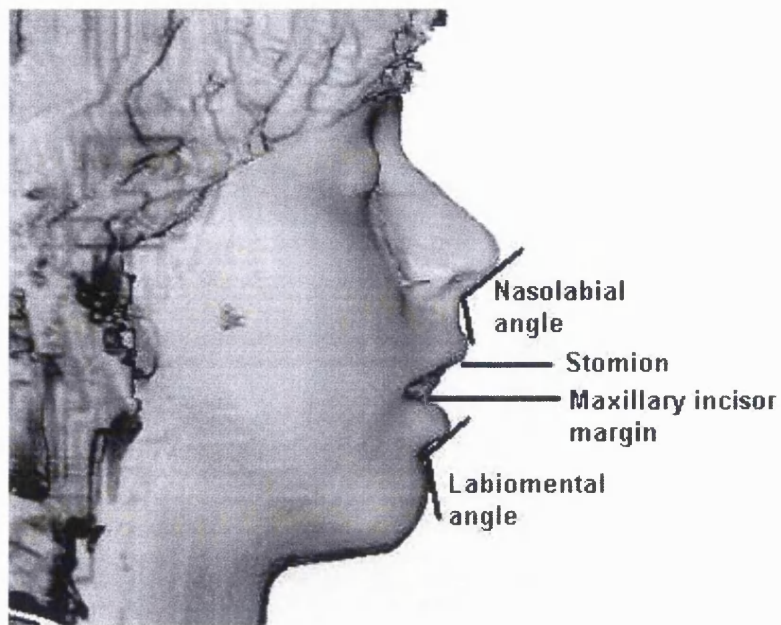


Figure 4.3- Maxillary incisor exposure, nasolabial and labiomenta angles, as measured on an optical surface scan.

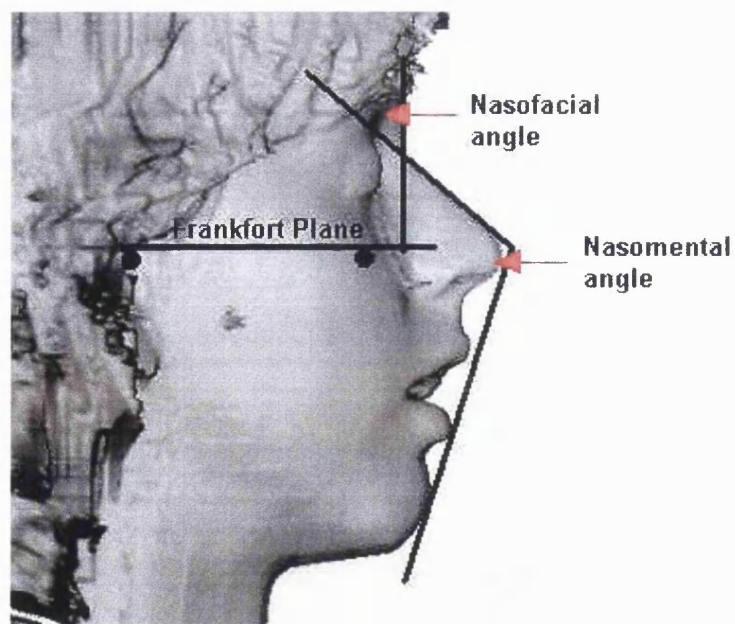


Figure 4.4- Nasofacial and nasomental angles on an optical surface scanner image.

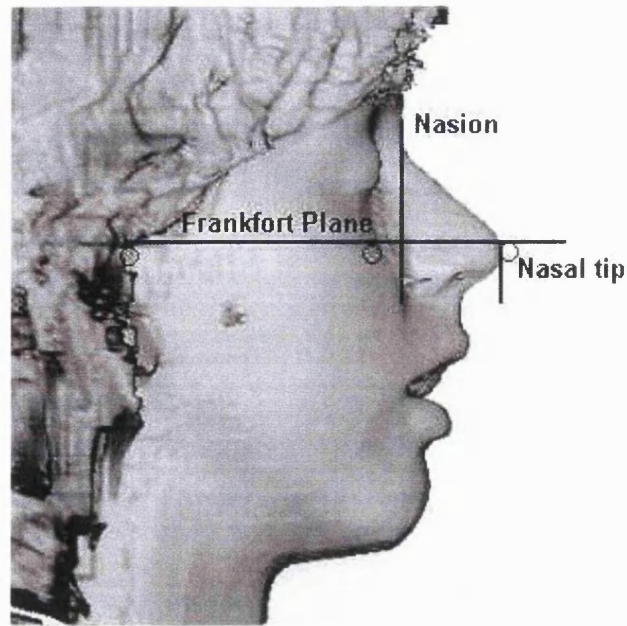


Figure 4.5- Nasal tip projection measurement on a surface scan.

Using a three-dimensional graphic display computer programme, the optical surface scan was retrieved onto the screen and two reference points, one at stomion superius and the other at the maxillary incisor edge were marked and the maxillary incisor exposure was determined by measuring the distance between these two points by the computer programme (Figure 4.3). An optical surface scan printout (lasergraph) was obtained and the nasolabial angle as defined by the intersection of two lines; one originating at subnasale and tangent to the lower border of the nose and the second line from subnasale to labrale superius, was measured (Figure 4.3). The labiomental angle is formed by the intersection of two lines originating at the soft tissue B point, one tangent to labrale inferius and the other one to the pogonion (Figure 4.3). The nasofacial angle was measured between a vertical line dropped from the nasion perpendicular to the Frankfort plane and a line

drawn tangent to the nasal dorsum (Figure 4.4). For the nasomental angle, a line from nasal tip to the pogonion is drawn and the angle between this line and the tangent to the nasal dorsum is recorded (Figure 4.4). The angular measurements were taken on both cephalographs and optical surface scans using a protractor and a ruler.

A perpendicular line from the nasion to the Frankfort horizontal plane was drawn on the surface scans and the distance to the nasal tip was measured for the nasal tip projection and changes after the surgery were calculated (Figure 4.5). For cephalographs, a line from nasion was dropped perpendicular to the surrogate Frankfort plane (a reference plane 7° above the sella-nasion line) and nasal tip measurements were taken (Figure 4.6) and changes with the surgery were calculated. The surrogate Frankfort plane was used instead of the original Frankfort plane as it is derived from two unilateral reference points (S and N) and is reported to be more reproducible than Frankfort plane (Begg and Harkness, 1995). All measurements were repeated three times and the mean of three measurements was used to calculate the pre to postoperative change. The differences between these three measurements were statistically insignificant ($p>0.05$). This change in the nasal tip projection was used to compare the cephalographs with the optical surface scans.

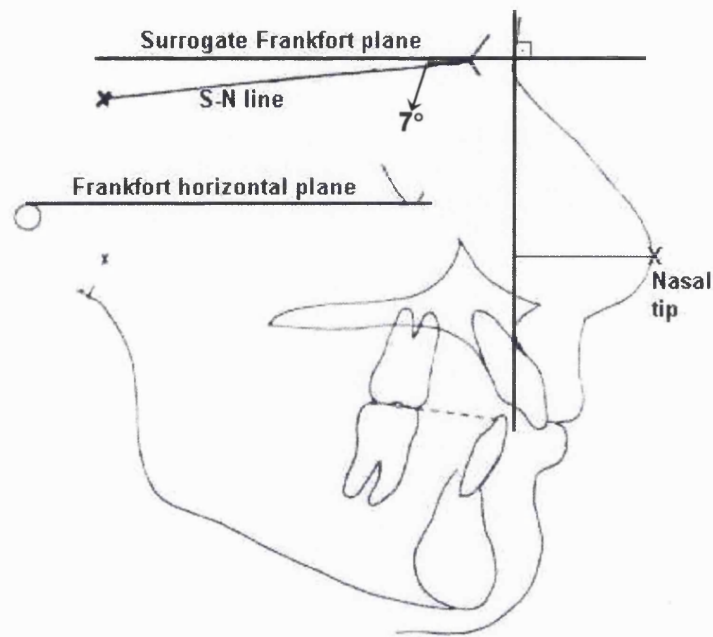


Figure 4.6- Nasal tip measurement on a cephalograph using surrogate Frankfort plane.

4.2.3 Results

- a) The means and standard deviations of the clinical, cephalographic and optical surface scan (lasergraphic) measurements of maxillary incisor exposure are presented in Table 4.1 and 95% confidence intervals of the mean are graphically illustrated in Figure 4.7. Although there was a significant change between the pre and postoperative maxillary incisor exposure, the differences between the clinical, cephalograph and surface scan measurements were not statistically significant ($p > 0.05$).

	Clinical		Cephalograph		Lasergraph	
mm	preop	postop	preop	postop	preop	postop
Mean	4.0	3.1	3.8	3.1	3.8	3.2
SD	2.4	1.6	1.8	2.1	1.9	1.6
t-test	p>0.05					

Table 4.1- The means and standard deviations of clinical, cephalometric and lasergraphic pre and postoperative upper incisor exposure in mm.

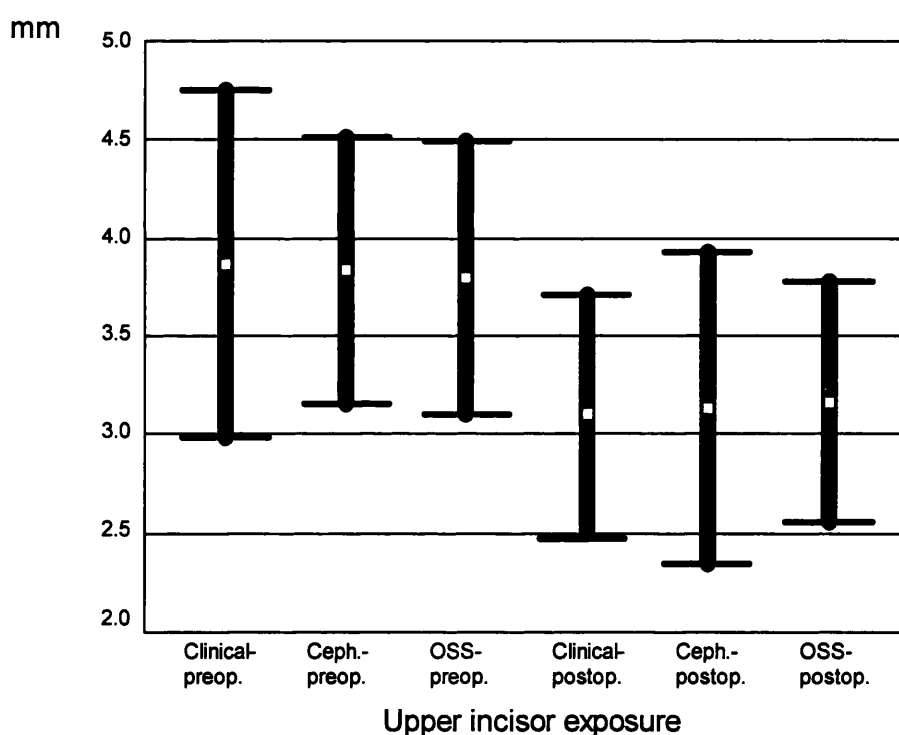


Figure 4.7- The 95% confidence intervals of mean clinical, cephalometric and optical surface scan (OSS) upper incisor exposure measurements preoperative and postoperative showing no difference between these methods.

b) The means and standard deviations of the nasolabial, nasofacial, nasomental and labiomental angles are in Table 4.2 and 95% confidence intervals of the mean are graphically presented in figures 4.8, 4.9, 4.10 and

4.11. The differences between the surface scan and cephalograph measurements were statistically insignificant ($p>0.05$).

a)	Cephalograph	Lasergraph	Cephalograph	Lasergraph
degrees	Preoperative		Postoperative	
Mean	98.0	98.9	100.7	101.4
SD	8.8	9.3	9.8	10.4
t-test	$p>0.05$		$p>0.05$	

b)	Cephalograph	Lasergraph	Cephalograph	Lasergraph
degrees	Preoperative		Postoperative	
Mean	36.2	36.3	36.5	36.0
SD	3.4	2.9	3.1	3.5
t-test	$p>0.05$		$p>0.05$	

c)	Cephalograph	Lasergraph	Cephalograph	Lasergraph
degrees	Preoperative		Postoperative	
Mean	126.5	126.4	126.5	126.6
SD	7.2	6.5	4.1	3.6
t-test	$p>0.05$		$p>0.05$	

d)	Cephalograph	Lasergraph	Cephalograph	Lasergraph
degrees	Preoperative		Postoperative	
Mean	142.2	142.1	144.2	143.9
SD	8.3	7.9	6.2	6.2
t-test	$p>0.05$		$p>0.05$	

Table 4.2- The mean and standard deviation cephalometric and lasergraphic pre and postoperative measurements; a) nasolabial angle, b) nasofacial angle, c) nasomental angle and d) labiomental angle.

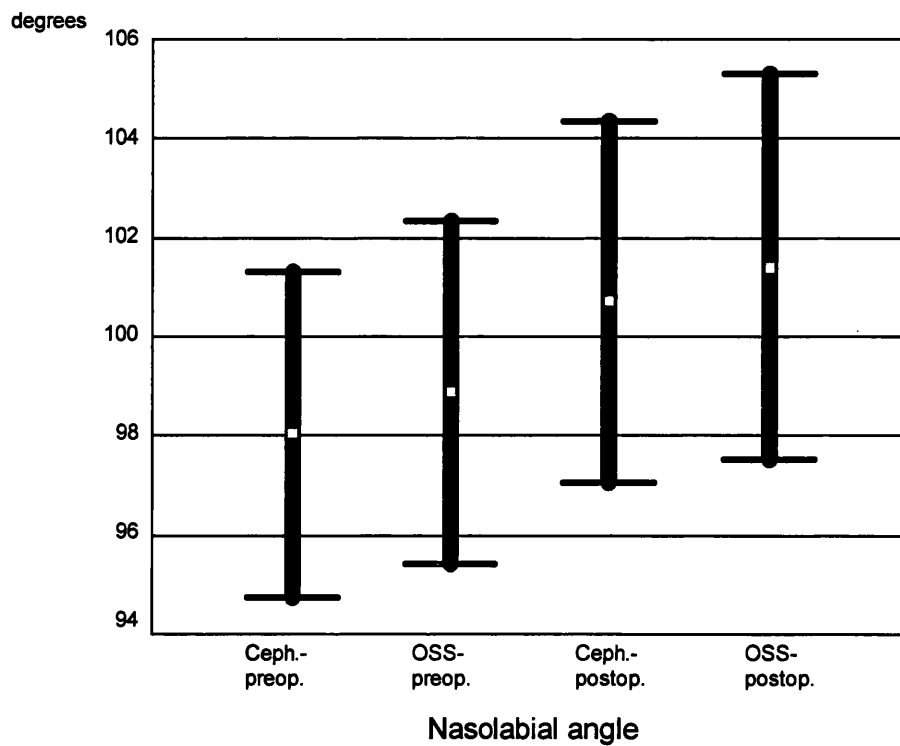


Figure 4.8- The 95% confidence intervals of mean cephalometric and optical surface scan (OSS) nasolabial angle measurements preoperative and postoperative showing no difference between these methods.

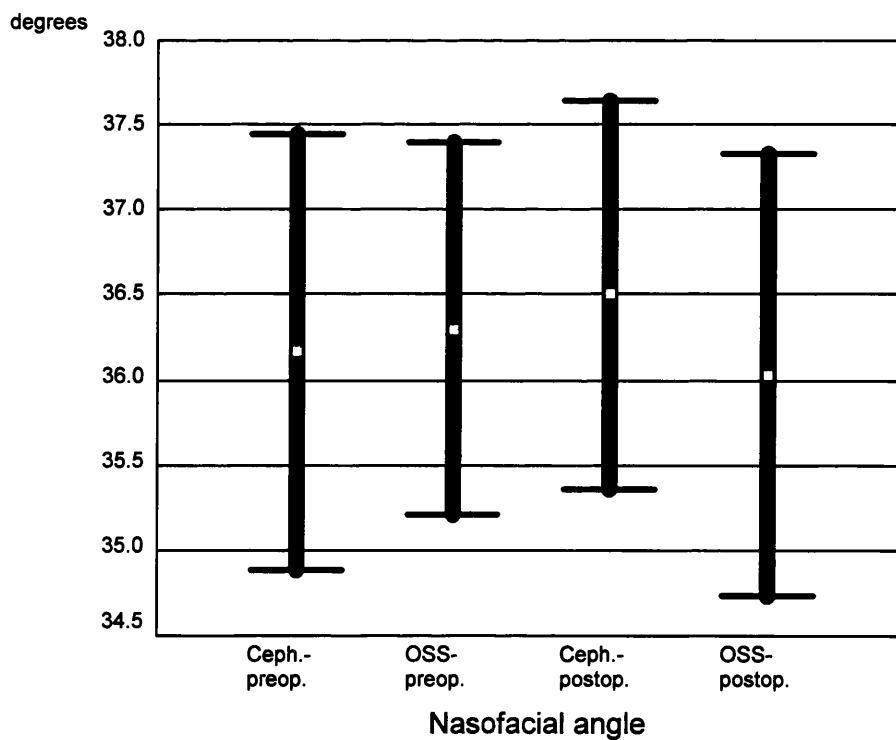


Figure 4.9- The 95% confidence intervals of mean cephalometric and optical surface scan (OSS) nasofacial angle measurements preoperative and postoperative.

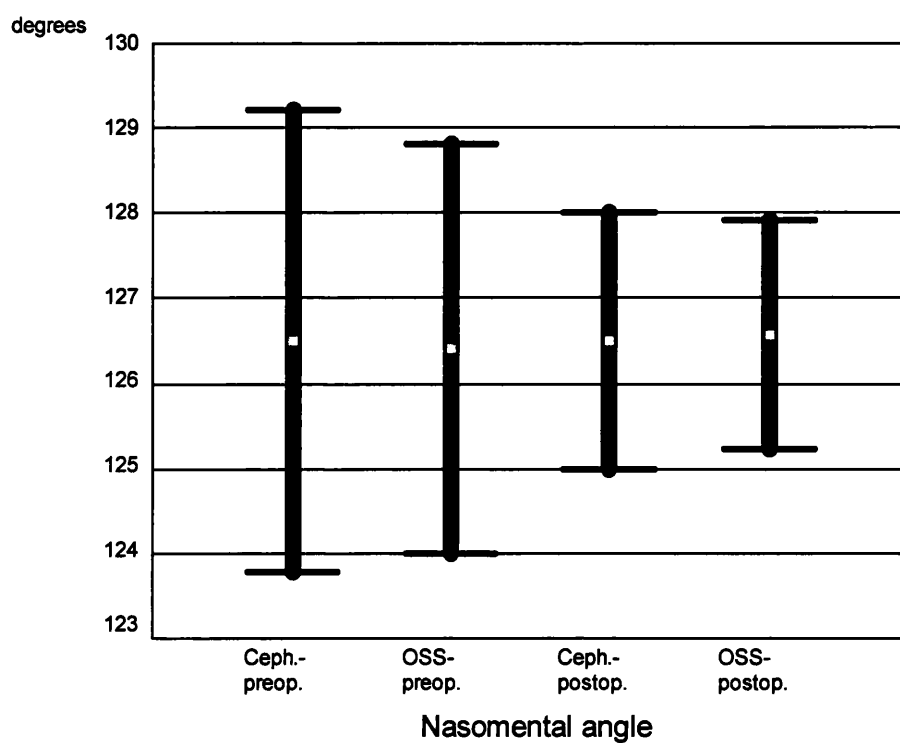


Figure 4.10- The 95% confidence intervals of mean cephalometric and optical surface scan (OSS) nasomental angle measurements preoperative and postoperative.

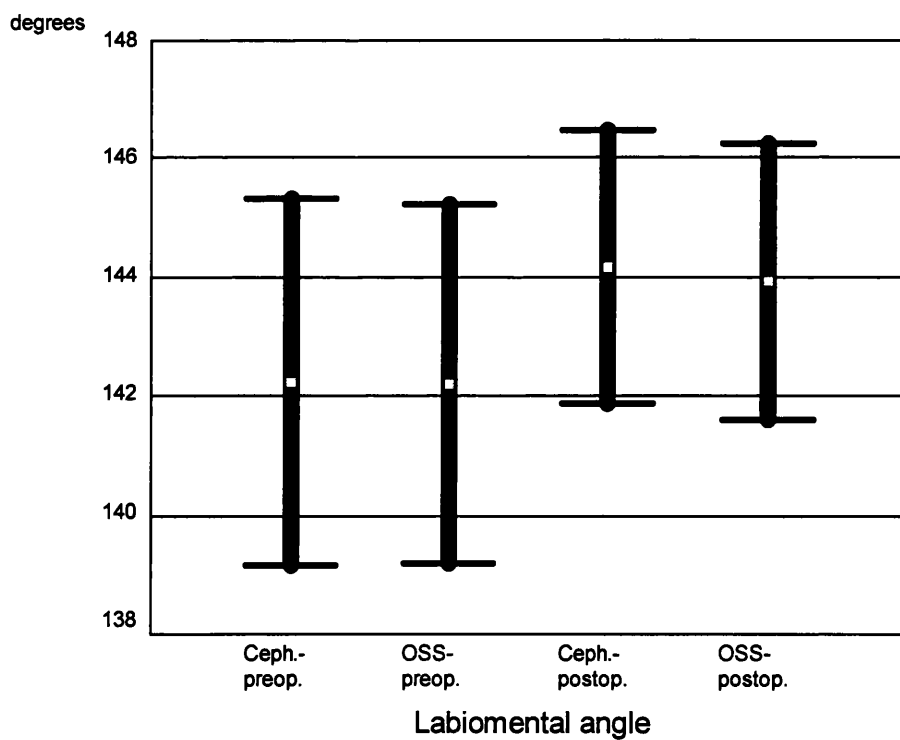


Figure 4.11- The 95% confidence intervals of mean cephalometric and optical surface scan (OSS) labiomental angle measurements preoperative and postoperative.

c) The mean changes in the nasal tip projection for both methods were; 1.5 ± 1.2 mm for cephalographs and 1.4 ± 1.1 mm for optical surface scans. The difference between the two methods was not significant ($p=0.5$) as can be seen in Figure 4.12 showing the 95% confidence intervals of the means for this data.

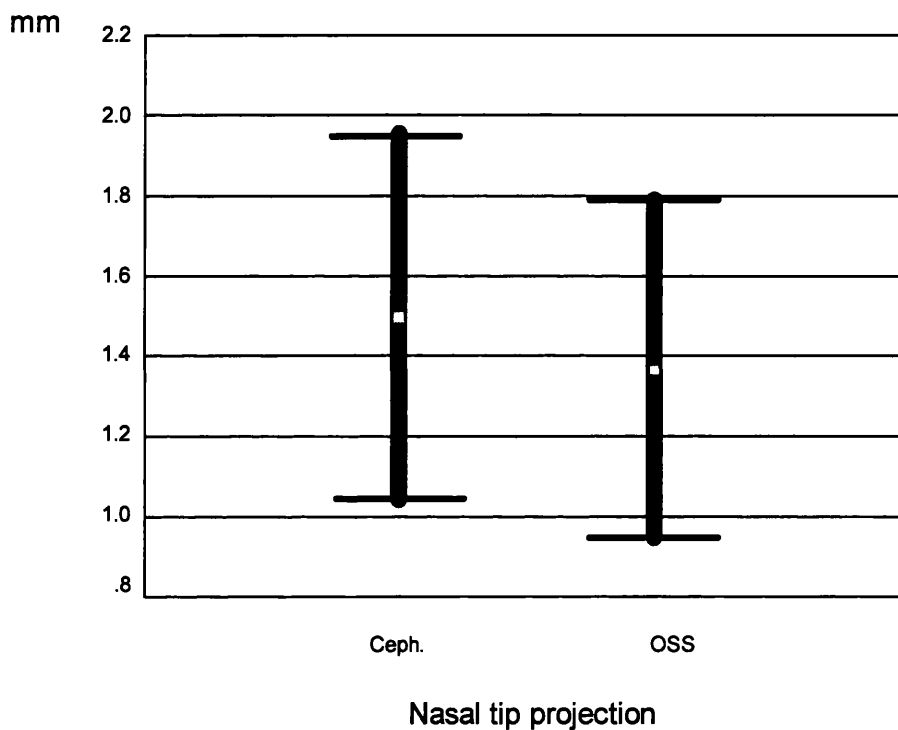


Figure 4.12- The 95% confidence intervals of mean nasal tip projection change after the surgery for the cephalograph and the optical surface scan.

4.2.4 Discussion

Soft and hard tissue analyses for preoperative surgical assessment and postoperative reviews have traditionally been done by measuring various angles and distances in two dimensions using craniofacial landmarks, planes and contrived reference points on lateral cephalographs. Although useful, the

system has inherent problems due to geometric complexity, magnification, the superimposition of craniofacial structures, distortion and low resolution (Bjork and Solow, 1962; Kragsskov *et al.*, 1997). For orthognathic surgery planning and postoperative follow-up, a technique capable of imaging low-density soft tissues with accuracy in all planes is required.

The results of this study showed that optical surface scans and cephalographs were comparable dimensionally as there was no significant difference in measurements using both of these methods. For lip-incisor relationship, their accuracy was also comparable to the direct clinical measurements. Hence we believe that optical surface scans can compliment or replace the cephalograph in soft tissue analysis for orthognathic surgery planning and postoperative review.

The optical surface scan is substantially easier to examine and analyse than the cephalograph and more important, the surface scan image is three-dimensional and can be viewed immediately from any preferred angle and position. Furthermore, the reference points on this image stay fixed as it is rotated. Although not used in this protocol, the measurements can be taken accurately across the surface as well as in a two dimensional linear manner (Moss *et al.*, 1991). It is also possible to focus on a particular surface section of the full image such as the nasolabial region and lip relationships.

The surface scan is not subject to magnification as the scale of the image is standardised by setting the appropriate number of pixels per millimetre. This

gives precise measurements for superimposition and determining the changes following orthognathic surgery, monitoring facial growth and the growth of tumours. Being a non-contact procedure, the system avoids any distortion of the soft tissue surfaces being measured. This system can display any view of the face in approximately 6 seconds (Moss *et al.*, 1988), which is faster than previously reported 3D imaging systems. It is also possible to demonstrate the soft tissue changes in three dimensions on the whole area of the face after surgery, whereas this is only possible in the midline using conventional cephalographs.

For long term follow-up, the optical surface scan is minimally invasive without the potential hazard of repeated exposure to ionising radiation and has the convenience of rapidly capturing an image which can be archived electronically. The images of the patients can also be stored on a hard disk drive or floppy disks enabling further clinical evaluation and research at a later date.

However, the procedure requires the patients' co-operation to keep a constant position and relaxed facial posture, as any movement during the recording period of 10 seconds will corrupt the image, resulting in motion artefacts. A separate study showed that using a headrest and a spirit level achieved a reproducible head position (Section 4.3) (Soncul and Bamber, 2000). The degree of irregularity of the surface can be another factor, which reduces the high resolution of the scan. Furthermore, with the application of thin plate splines analysis (Bookstein, 1991), both area and volumetric

changes in soft tissues can be calculated with greater accuracy, and with the introduction of this multivariate morphometric analysis the main problem of the lack of clear statistical method for soft tissue changes is solved.

Optical surface scans of soft tissues in conjunction with cephalometric analysis are routinely used in our unit for preoperative surgical assessment, planning and postoperative review of orthognathic surgery, and their use is very likely to increase with wider availability of various surface scanners in the market. The number of units using optical scanners is also increasing since they entered the imaging systems market. Nowadays with the wider availability, the cost has gone down to £5000. Considering units performing orthognathic surgery on an average of 100 patients per annum, the cost of the system per patient is minimal. The optical scanner serves other useful purposes for other patients' treatments, e.g. assessing facial swellings, designing facial prostheses. These three-dimensional surgical simulations using the surface scans also serve to guide the surgeons, and prepare and rationalise patients' expectations.

In conclusion, the surface scan is comparable to a good quality cephalograph for soft tissue profile assessment but has additional advantages of being three-dimensional, better quality, electronically storable and minimally invasive which supersede the traditional radiographic means of soft tissue analysis for postoperative follow-up.

4.3 Reproducibility of the head position for optical surface scans

Despite its many potential advantages in clinical applications, there is no agreed method of standardising head position for the optical laser scanner, which casts doubts upon the reproducibility of the achieved head position. Unless the head position is stabilised, the accuracy and the quality of soft tissue data may be affected. The three-dimensional surface that is presented to the projected laser light and in turn recorded by the camera is determined by the head position in any plane. Hence, it is possible that anatomic landmarks located in the areas of changing contour are affected by head inclination influencing the accuracy of soft tissue change measurements. This may be mainly caused by obstruction of some landmarks by others due to an unsuitable head inclination. Landmarks below the nose can be obscured by the prominence of the nose in a downward inclined head position. The procedure requires the patients' co-operation to keep a stable head position and relaxed facial posture, as any movement during the recording period of 10 seconds will corrupt the image, resulting in motion artefacts.

There are no standardised methods reported for the quantitative evaluation of 3D facial soft tissue data. Hence, we have endeavoured to coerce the thin-plate splines transformations to validate the standardisation of the head position for optical scans, which we believe can supplement the conventional cephalometric analysis.

The word "morphometrics" was first used by Blackith in 1965 and with the view of it being a standard application of multivariate analysis. It dealt with

“size” and “shape” derived from biological forms. Thompson (1961) suggested that the changes of biological form could be both modelled and described as mathematical smooth deformations, forming the basis of “thin-plate splines”. The thin-plate splines is an interpolating function that can be used to describe shape change as a deformation of a structure, in this case the change in head position for a surface scan.

4.3.1 Aims

This study aimed to test the reproducibility of the head position for optical surface scans by setting;

- a) Frankfort horizontal plane parallel to the ground using a spirit level, for setting horizontal surfaces,
- b) Axial plane perpendicular to the ground in frontal view by reflecting a narrow beam of laser light on the facial midline of the patient.

4.3.2 Materials and methods

Sixty optical surface scans of five subjects, twelve scans each, were taken at random intervals of 15 minutes to 24 hours. In between the scans, the subject was asked to walk around and relax. Three of the subjects were females and two males, three had a Class I skeletal relationship, one Class II and one Class III, including one with a facial asymmetry.

All the scans were taken by the same investigator following a protocol for the use of optical surface scanner (Linney, 1992). The subject's head supported by the head rest was adjusted using a spirit level, an engineering device for

setting horizontal surfaces consisting of a glass tube partially filled with alcohol and an air bubble indicating perfect levelness to the three planes in space (Figure 4.13), until the Frankfort horizontal plane was parallel to the ground. The axial plane of the head was adjusted and aligned perpendicular to the ground by shining the laser scanner source light longitudinally on the patient's facial midline (Bamber, 1995). These scanned three-dimensional images were saved on the host computer. For the digitisation an image was retrieved and absolute lateral and frontal views of each subject's surface scan were obtained by rotating the three-dimensional image on the screen (Figure 4.2). This custom designed software gives the same absolute frontal and lateral views repeatedly by default and the image manipulation process is calibrated and reproducible on the computer screen.



Figure 4.13- The use of a spirit level to align the Frankfort plane parallel to the ground.

Using custom designed software the lateral and frontal view images were digitised for thin-plate splines (TpsDIG32- Version 1.1 - A Windows 95/NT program developed by F. James Rohlf for geometric morphometric analysis).

The anatomical landmarks digitised on each lateral profile and frontal views of the scan are illustrated in Figure 4.14.

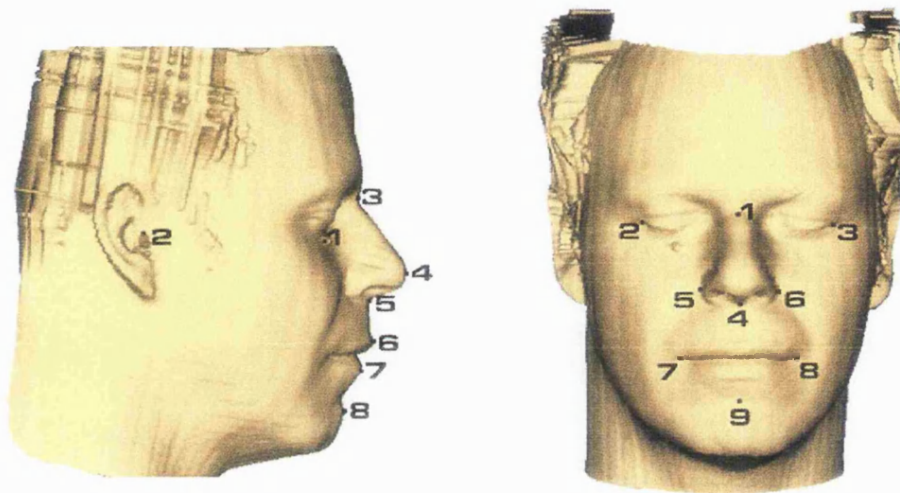


Figure 4.14: Lateral view optical surface scan (left) showing landmarks used for this investigation: 1) Soft tissue orbitale, 2) Upper margin of the tragus, 3) Soft tissue nasion, 4) Pronasale, 5) Subnasale, 6) Labrale superius, 7) Labrale inferius, 8) Soft tissue pogonion. Frontal view optical surface scan (right) showing landmarks used for this investigation; 1) Soft tissue nasion, 2) Right lateral canthus, 3) Left lateral canthus, 4) Subnasale, 5) Right alare, 6) Left alare, 7) Right cheilion, 8) Left cheilion, 9) Sublabiale.

The landmarks, which were difficult to localise on the surface scan were clinically located by small self-adhesive spheres placed as locators before scanning. The digitised surface scans were then compared to each other using the thin-plate splines (Figure 4.15) computer programme. This analysis produced a report giving results in a quantitative and a graphical form (Figure 4.16). The graphic data were derived from a mesh diagram based on co-ordinates of digitised landmarks of the scans.

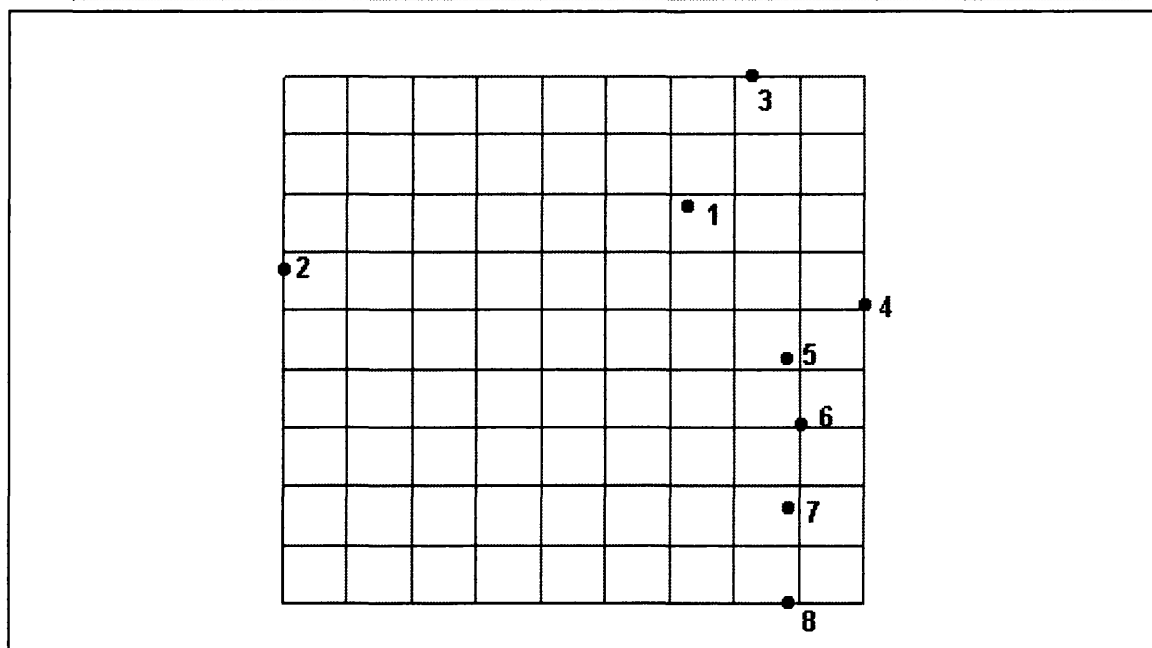


Figure 4.15- A graphic output of the thin-plate splines analysis after the digitisation of a preoperative optical surface scan.

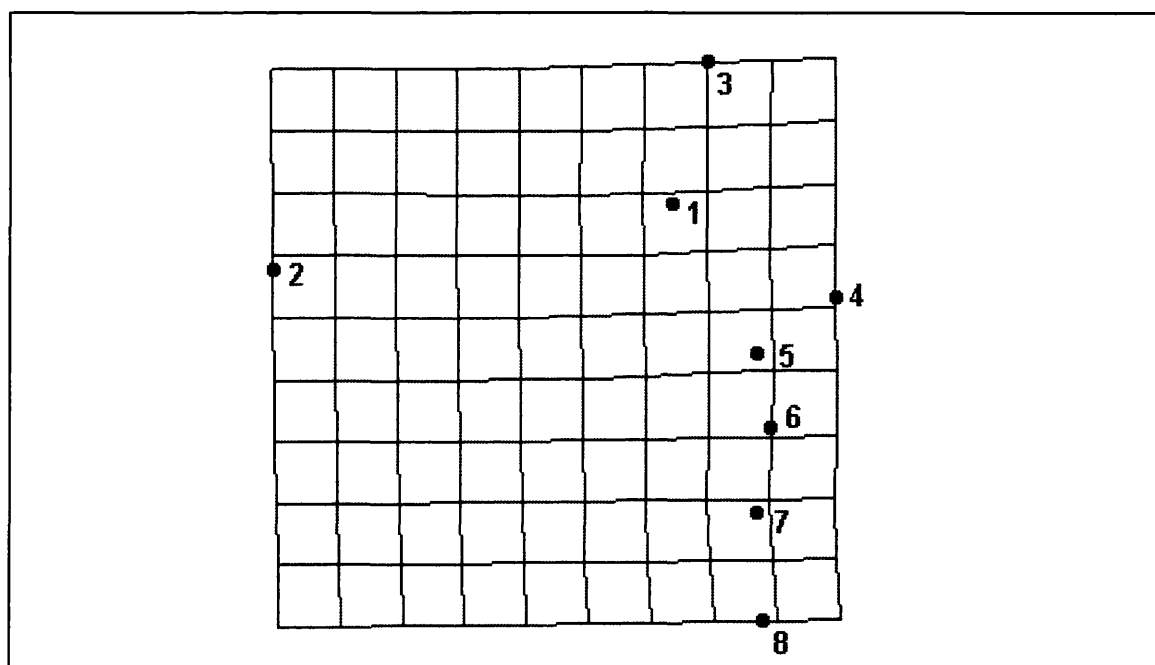


Figure 4.16- Graphic output of the thin-plate splines where the head position was intended to remain constant. The distortion of the image is caused by a slight change in the inclination of the head so that the digitised landmarks moved as a group.

The quantitative data report of the thin-plate splines analysis was based on the 'bending energy' required for the amount of deformation caused by alteration in the head position between scans. Bending energy is a metaphor borrowed for use in morphometrics from the mechanics of thin metal plates. It is the hypothetical energy that would be required to bend a metal plate (Bookstein, 1991). A deformation in the surface scan image (due to an osteotomy movement and/or a change in the head position) would be indicated by the change in the baseline landmarks' position. The bending energy value for change in head position was calculated for every combination of 12 scans (66 comparisons in each view) for each subject both in the lateral and the frontal views, 660 in total. These data were statistically analysed using parametric tests.

In order to calculate the landmark identification and digitisation method error, all the landmarks on a single optical surface scan were digitised ten times.

4.3.3 Results

The mean and standard deviations of the bending energy representing the change in the head position in both the lateral and the frontal views for each subject are in Table 4.3 and 95% confidence intervals of the means are illustrated in Figures 4.17 and 4.18.

Since the statistical analysis showed that there was no significant difference within and between subjects, all the data were integrated. The mean and standard deviation of bending energy values of all comparisons for the

subjects were; $0.0135 \pm 0.0109 \text{ g.cm}^2/\text{sec}^2$ ($n=330$) for the lateral profile and $0.0090 \pm 0.0054 \text{ g.cm}^2/\text{sec}^2$ ($n=330$) for the frontal view.

a)	mean	SD
Subject A	0.012	0.011
Subject B	0.011	0.006
Subject C	0.019	0.013
Subject D	0.015	0.015
Subject E	0.014	0.009

b)	mean	SD
Subject A	0.010	0.005
Subject B	0.013	0.006
Subject C	0.009	0.006
Subject D	0.007	0.004
Subject E	0.009	0.005

Table 4.3- The means and standard deviations of the bending energies for 5 subjects ($\text{g.cm}^2/\text{sec}^2$) a) in the lateral view, b) in the frontal view.

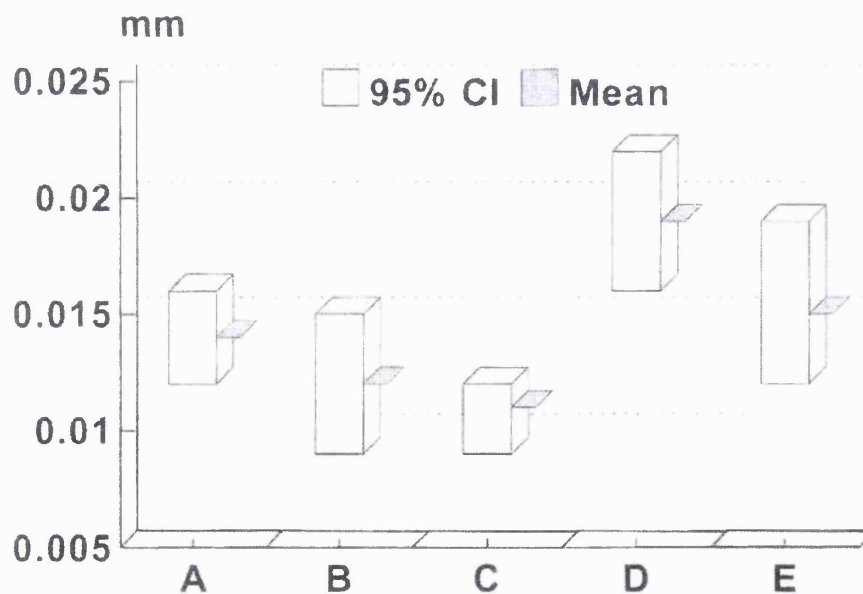


Figure 4.17- 95% confidence interval of the mean bending energies of 12 scans of 5 subjects in the lateral view.

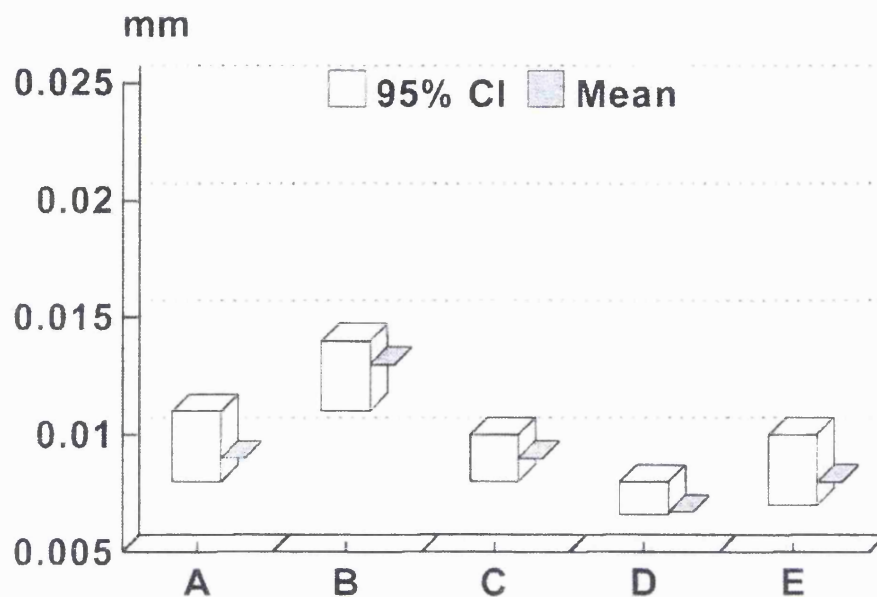


Figure 4.18- 95% confidence interval of the mean bending energies of 12 scans of 5 subjects in the frontal view.

These bending energy values were compared with the bending energy value derived from a patient who had a 6-millimetre advancement of the maxilla with 3-millimetre mandibular setback, which was calculated to be $0.51055 \text{ g.cm}^2/\text{sec}^2$ (Figure 4.19). The overall mean bending energy representing a variation in the head posture, including the digitisation error, was thus less than 2% of this typical surgical change.

The mean value of bending energy representing the landmark identification and digitisation error of optical surface scans was $0.0018 \pm 0.0012 \text{ g.cm}^2/\text{sec}^2$. This was not statistically significant.

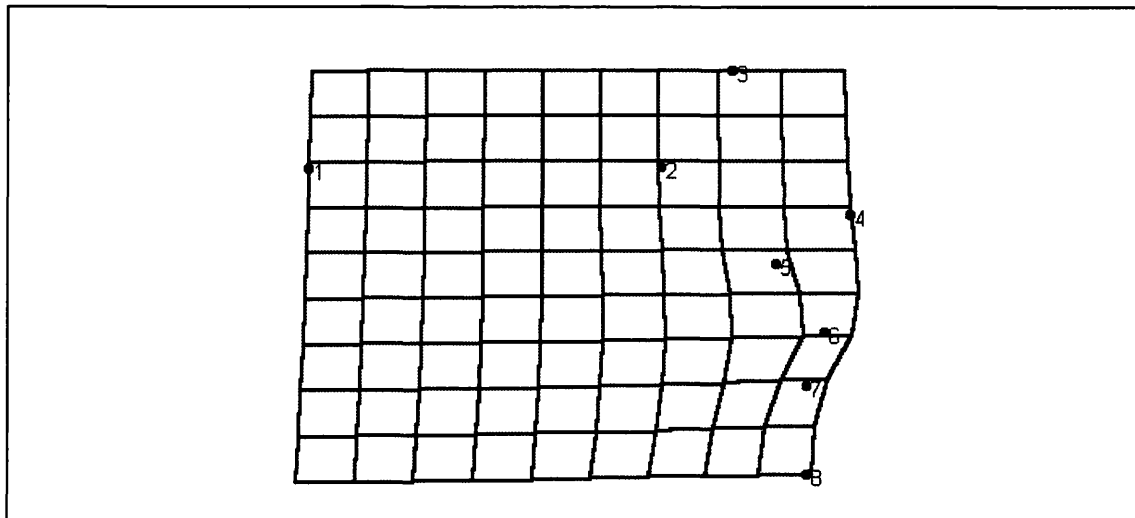


Figure 4.19- Graphic output of thin-plate splines showing the change after bimaxillary surgery with the 6-mm advancement of the maxilla and 3-mm setback of the mandible.

The effect of change in head position is illustrated in Figure 4.20. The surgical deformation as a result of osteotomy is more apparent when comparing the pre and postoperative scans of subjects who have undergone orthognathic surgery (Figure 4.19).

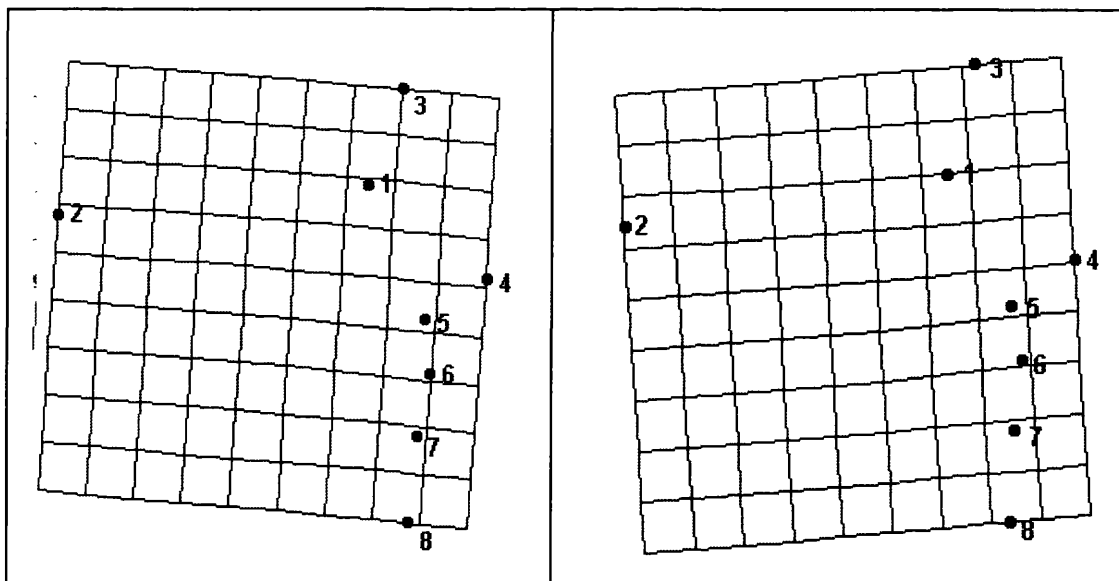


Figure 4.20- Thin-plate splines showing the change in head position with chin moving inferiorly (left) and with chin moving superiorly (right). When the repeated scans are compared to each other, the slight changes in the head position are demonstrated as a rotation of the grid but the images being compared here were otherwise identical, being free from magnification or movement of landmarks individually.

The change in head position in the axial plane (for the frontal view of optical surface scans) was minimal as illustrated with thin-plate splines graphical analysis output (Figure 4.21). The mean variation of 12 scans of five subjects showed no statistically significant difference between the subjects in either plane (Table 4.3 / Figures 4.17 and 4.18).

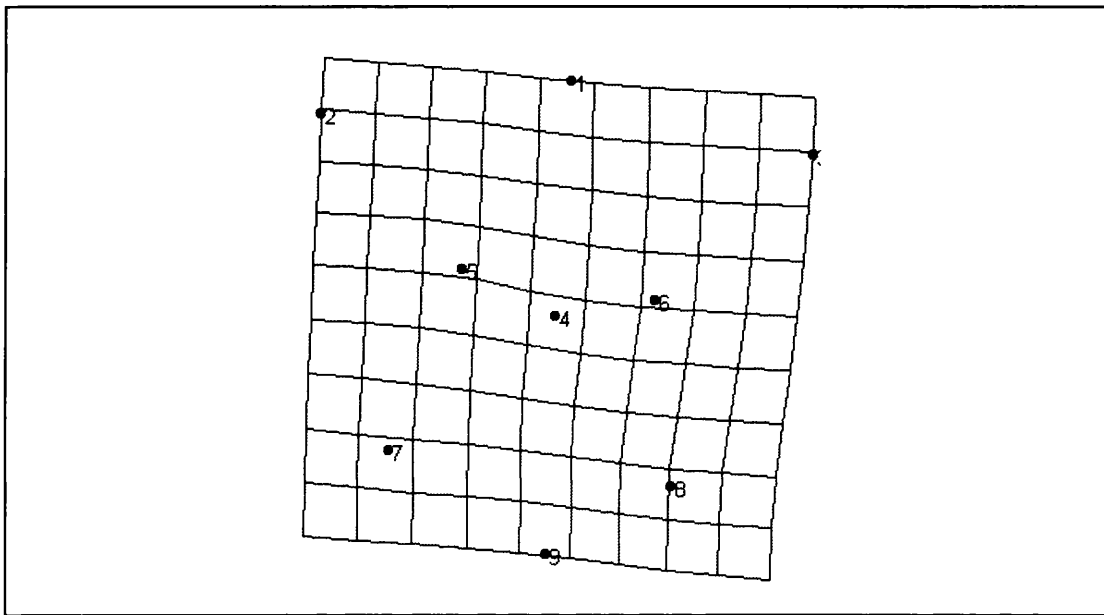


Figure 4.21- The tilting of the head around the axial plane on the frontal view of optical surface scans was more visible graphically in thin-plate splines analysis.

4.3.4 Discussion

This study has shown that clinically significant error can be introduced into optical surface scans due to lack of head stabilisation and change in head position, unless a strict protocol is followed. A novel method of morphometric analysis is described which could prove to be a useful tool for clinical research.

The lateral skull cephalograph has been, for decades, the principal method for evaluating the soft tissue change after orthognathic surgery despite being

based on two-dimensional image with soft tissue recordings limited to an outline of the lateral profile with poor resolution. Pirttiniemi *et al.* (1996) reported that although the head was positioned using a cephalostat, the geometric error due to head rotation in the cephalograph was up to 3.5 millimetres, which increased further in cases of facial asymmetry. In comparison, the errors in the optical surface scanner due to head position recorded by this study were small and insignificant. There is no other similar study reporting errors in soft tissue surface scans due to change in the head position to compare the results of this study. Additional advantages of this system are that three-dimensional surface imaging data in a digital format can be analysed with greater accuracy in any desired view, and optical surface scans are stored conveniently by any computer system. If required, a print out can also be obtained.

In the lateral profile, if the axis of rotation for the head was in the centre of the head's outline, the bending energy for the change in the head position would be zero as the grid would rotate evenly around this centre point. The head is inclined on the neck, however, causing rotation in the grid (Figure 4.20), which can be easily measured by the thin-plate splines analysis.

The head inclination has a direct effect on the three-dimensional surface data that can be captured on the digitised image. Depending upon the head position, some soft tissue landmarks may disappear completely. For this reason Bush and Antonyshyn (1996) supported a downward inclination of the

Frankfort plane for the head position. However, this increased the error in other landmarks.

Lundstrom *et al.* (1992) used the so-called natural head position as a reproducible position for head inclination in their cephalometric study based on normal profiles. It is, however, difficult to achieve a reproducible natural head position in patients with abnormal and disharmonious profile outlines, facial asymmetry, and posturing habits (Lundstrom *et al.*, 1991). Earlier studies reporting the reproducibility of the natural head position in adults showed an error of 2 degrees (Bjerin, 1957; Moorees and Kean, 1958). In a separate study, Lundstrom and Lundstrom (1995) reported that the natural head position, as a cephalometric reference for clinical purposes was not reproducible. Despite several investigations by many authors to find reproducible head position, Frankfort horizontal plane remains the most widely used reference plane for orthognathic surgery (Bamber *et al.*, 1996). This study showed that it could be reproduced with a simple technique of using a spirit level. The orientation of optical surface scans with the Frankfort horizontal plane also allows synchronisation of the clinical assessment, optical surface scan, cephalograph and anatomically mounted models for orthognathic surgery planning.

There are no other cephalograph and optical surface scan studies in the literature evaluating the position of the head from the frontal view to compare the results with. All previous investigators used two-dimensional imaging tools, which only reproduced the lateral facial soft tissue profile for the

analysis. This study, using a three-dimensional imaging tool, evaluated the head position in true lateral and frontal views; both these views are important for facial soft tissue analysis for surgeons and orthodontists.

The thin-plate splines analysis, using the mean bending energy was more appropriate as a multivariate analysis for a three-dimensional image. The errors in the frontal view of surface scans were less than the lateral view and clinically insignificant in both views. As a result of this study, it is advised to adjust the Frankfort horizontal plane parallel, and the frontal view axial plane perpendicular to the true horizontal plane for a reproducible three-dimensional optical surface scan.

CHAPTER V

EVALUATION OF FACIAL SOFT TISSUE CHANGES AFTER ORTHOGNATHIC SURGERY

5.1 Introduction

Optimal aesthetics of the human face has interested many researchers from various disciplines. Much of the research interest has been focused on divergence from the norms and correction of these gross facial deformities with orthognathic surgery has been the accepted solution for many.

As in every surgical intervention, the question must be asked about the predictability and reproducibility of the results. The osteotomies are performed on facial bones to correct dentoskeletal deformities but the patients see the outcome on their soft tissue facemask.

Many studies have been reported with varied results in the past evaluating facial soft tissues changes after orthognathic surgery. Mostly lateral cephalographs were used in the past to evaluate the profile changes but the cephalograph is not the ideal imaging tool, as it is unable to show the three-dimensional changes of a three-dimensional subject. The results of most of the previous studies in the literature have presented the changes on the lateral profile line but the changes caused by orthognathic procedures extended laterally from the profile line to cover most of the face. Even for an accurate evaluation of the changes on the profile line, the cephalograph was inadequate due to the poor image and inherent errors. The soft tissues can not be observed clearly either because of the low resolution of the image or superimposition of bony structures on soft tissues, resulting in landmark digitisation errors.

Hence, the search for a viable three-dimensional imaging tool for pre and postoperative soft tissue assessment continues. Optical systems like stereophotogrammetry, telecentric photogrammetry, Moire topography, 3D CT scans were probably the most remarkable methods developed for imaging facial soft tissues but they all had limitations. They either could not capture the soft tissue details clearly enough for accurate evaluation or were not easy to use by someone within the orthognathic surgical team or in some cases too expensive to be used routinely for repeated examinations of every patient. The soft tissue data captured from three-dimensional CT scans was not practicable as the amount of radiation the patient was exposed to was far too high especially considering the need for repeated examinations after the surgery.

The optical surface scanning system (Figure 4.1) since it was built by Linney and his co-workers at University College London, Department of Medical Physics, has been improved and was used to evaluate effects of orthognathic surgery on soft tissues. This system consists of a laser source, a charge coupled device camera, a rotating platform, mirrors and a PC. This system was described in detail in Section 4.1. The system is accurate, easy to use, minimally invasive, repeatable, cost-effective, has high resolution, and carries most of the advantages of a three-dimensional imaging tool. It is also supported with a comprehensive package of clinical and research software.

Several methods were used to measure the human face for genetics, ethnic forms and norms for facial aesthetics. In orthognathic surgery literature, the

morphometric studies are rather limited in number. For example, euclidean distance matrix analysis (EDMA) (Lele and Richtsmeier, 1991; Ayoub *et al.*, 1994), finite element analysis (Motoyoshi *et al.*, 1993), mesh diagram analysis (Moorees and Kean, 1958; Lebet, 1985, Ferrario *et al.*, 1998), thin-plate splines analysis (Bookstein, 1991) are reported as methods for morphometrics of the human face before and after orthognathic surgery.

Thin-plate splines analysis, as described earlier, takes thin metal plates as a starting point and presents the mechanical deformation and shape change as mathematical transformations enabling quantitative and graphical evaluation. (Bookstein, 1991).

5.2 Aims

This study aimed to evaluate the soft tissue changes after correction of Class II and Class III facial deformities with orthognathic surgery using the optical surface scanner as a three-dimensional imaging tool and thin-plate splines as a morphometric analysis.

5.3 Patients and methods

One hundred and two patients undergoing orthognathic surgery were recruited for this part of the study. Sixty-four were females and thirty-eight were males. Forty-seven of these patients had Class II and fifty-five had Class III dentoskeletal relationship. Thirty-seven in the Class II group were females and ten were males, whereas in the Class III group twenty-seven were females and twenty-eight were males. All patients underwent a single

jaw or bimaxillary orthognathic surgical procedure to correct the deformity to a Class I dentoskeletal relationship. The treatment plans are summarised in Table 5.1. Optical surface scans of all patients were obtained preoperatively and 6 months postoperatively using an optical surface scanner system. On these optical surface scans (lasergraphs) soft tissue changes were evaluated.

On 3D pre and postoperative optical surface scans, the following five markers were placed electronically;

- 1- left endocanthion
- 2- left exocanthion
- 3- right endocanthion
- 4- right exocanthion
- 5- soft tissue nasion

as seen in Figure 5.1.

In order to calculate these five points' identification method error electronically, five subjects were scanned and these five landmarks were digitised on the optical scans as seen in Figure 5.1. The digitisation of these landmarks for each subject was repeated ten times by the same investigator at separate sessions. Ten different digitisations of each subject's scans were compared to others using thin-plate splines analysis by superimposing using these points. The bending energy representing the error in electronic identification of landmarks was $0.0018 \pm 0.0012 \text{ g.cm}^2/\text{sec}^2$. This statistically insignificant error caused by digitisation constitutes 0.003 of the measured surgical change.

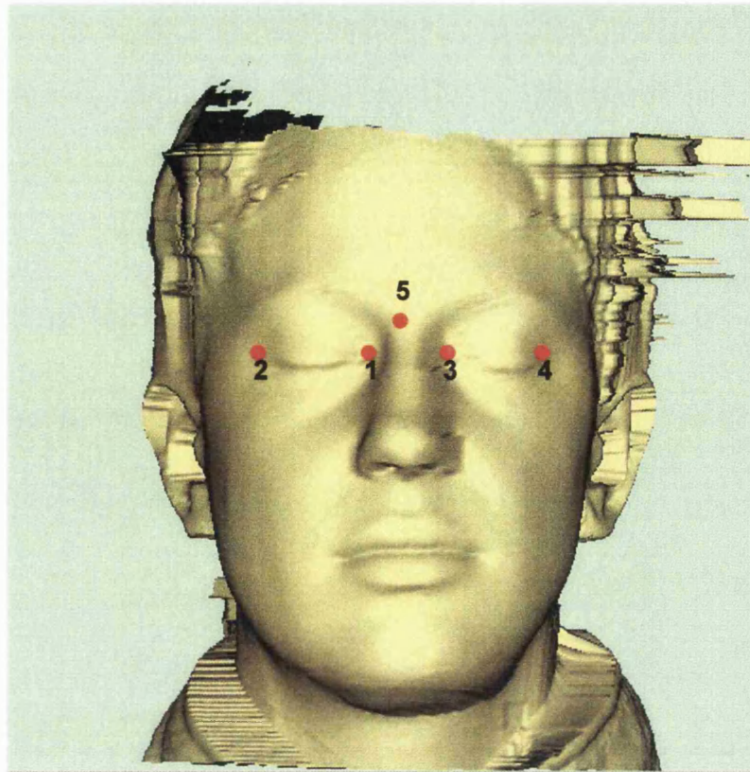


Figure 5.1- Five markers electronically placed on 3-D pre and postoperative optical surface scans on: 1. left endocanthion, 2. left exocanthion, 3. right endocanthion, 4. right exocanthion, 5. soft tissue nasion.

Treatment Plan		n	
<u>Class II</u>		47	
Single jaw procedure	BSSO (Bilateral Sagittal Split Osteotomy)	18	
Bimaxillary procedure	Maxillary impaction + BSSO	20	
	Maxillary impaction + BSSO + genioplasty	4	
	Maxillary advancement/push back + maxillary impaction + BSSO	5	
<u>Class III</u>		55	
Single jaw procedure	BSSO	5	
Bimaxillary procedure	Maxillary impaction + BSSO	4	
	Maxillary advancement + maxillary impaction + BSSO	3-mm advancement	14
		6-mm advancement	27
		9-mm advancement	5

Table 5.1- Summary of treatment plans

Using these markers, pre and postoperative optical surface scans were registered over parts of the face unaffected by the surgery. This superimposition enabled the production of colour maps (Figure 5.2) displaying difference of surfaces. This analysis was done using the optical surface scan

display software developed by Richards (Department of Medical Physics, University College London, 1999).

Colour maps displayed the areas and magnitude of change in facial soft tissues. The face was divided into ten regions based on the tendency of soft tissue change:

1. Nasal tip
2. Paranasal regions: The bilateral areas of the cheeks adjacent to the alae of the nose below the zygomatic arches.
3. Subnasale: The junction of the nasal collumella and the upper lip.
4. Subalar region: The middle third of the upper lip below the alar base of the nose excluding subnasale and the upper vermilion.
5. Supracommissural regions: The adjacent areas of the upper lip to the subalar region bilaterally above the oral commissures.
6. Upper vermilion: The vermilion of the upper lip.
7. Lower vermilion: The vermilion of the lower lip.
8. Subcommissural regions: The bilateral areas below the oral commissures lateral to the labiomental fold and the chin.
9. Labiomental groove: The groove below the lower lip and above the chin.
10. Chin: The circular area around the soft tissue pogonion. (Figure 5.2)



Figure 5.2- The colour map displaying the regions characterised with different magnitude of soft tissue change.

For thin-plate splines analysis, the true lateral view of the optical surface scans were captured and the following landmarks were identified:

- 1- Soft tissue nasion
- 2- Upper border of the tragus
- 3- Soft tissue orbitale
- 4- Tip of the nose
- 5- Subnasale
- 6- Labrale Superius
- 7- Stomion Superius
- 8- Stomion Inferius
- 9- Labrale Inferius
- 10- Labiomentale Groove
- 11- Soft tissue pogonion

(Figure 5.3)

These landmarks were digitised using the TpsDIG32™ (A Windows based software for digitising landmarks for geometric morphometric analyses by Rohlf. Version 1.14, 1998.) on the lasergraphs. The thin-plate splines analysis was then performed to compare the preoperative lasergraphs to the postoperative ones for soft tissue changes. Thin-plate splines analysis was performed using TpsSpln™ (A program to compare pairs of specimens by displaying a D'Arcy Thompson style transformation grid based on a thin-plate spline by Rohlf. Version 1.15, 1998). Soft tissue nasion, upper border of tragus and soft tissue orbitale were taken as stationary landmarks for

reference to the movement of other chosen landmarks for the thin-plate splines analysis.

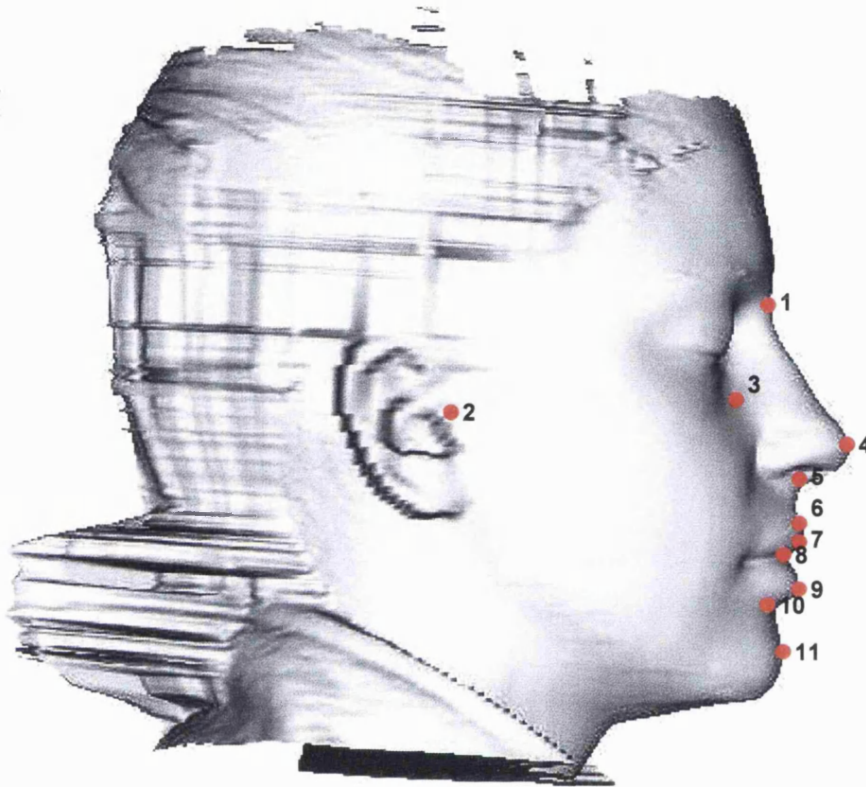


Figure 5.3- The landmarks used for thin-plate splines analysis on the true lateral view of the optical surface scans.

The pre and postoperative cephalographs taken during routine clinical examinations were also digitised and evaluated to check whether the preoperative treatment plan was achieved during the actual surgical procedure so that the changes in soft tissues could be compared to bony movements. The radiographs were traced and digitised by the SSI Microcad™ digitiser using Opal CogSoft™ (A digitising and orthodontic analysis software for Windows by Harradine and Chauvet. Version 1.1, 1997-98).

First, using point A, anterior nasal spine and posterior nasal spine for the magnitude of maxillary advancement and impaction, and point B and pogonion for the magnitude of mandibular setback was measured and achieved movements were recorded. They were also compared to the initial treatment plan to check whether the treatment plan was reproduced during the actual surgical procedure.

5.4 Results

The soft tissues were evaluated in order to:

- a) Find the amount of soft tissue change by superimposition of optical surface scans ('difference of surfaces' analysis) and,
- b) Identify the direction of movements by using thin-plate splines.

By superimposition of 3D optical surface scans, 'difference of surfaces' analysis presented the results in a colour map format (Figure 5.2) including magnitude of movements for infinite number of points on the soft tissue surface. Class II and III patients were evaluated separately. In each group, smaller sub-groups were formed based on the type of surgical procedure to relate the soft tissue change to the amount of bony movement. Four sub-groups were formed in the Class II group, and five in the Class III group. The treatment plans and grouping with number of patients are summarised in Table 5.1. Although some patients had different magnitudes of maxillary impaction, this procedure did not affect the results significantly so these patients' results were pooled into one group.

Patients displayed similar magnitude of soft tissue change for certain regions of the face, which allowed the evaluation of the facial soft tissues in sections, by breaking up into smaller regions for easier understanding of the surgical effects and clinical applications (Figure 5.2). In the middle third of the face, subnasale and paranasal regions bilaterally and the subalar region of the upper lip were the most affected parts, and the upper vermilion and supracommissural regions followed these areas. The least affected area was the nasal tip. For the lower facial third, the chin as a circular area with a diameter of 1 centimetre and the soft tissue pogonion as the centre point was affected most followed by the labiomental groove between the chin and the lower lip. Lower vermilion and subcommissural regions were relatively less affected.

5.4.1 Class II

5.4.1.1 Single jaw cases:

Eighteen patients underwent a single jaw procedure (bilateral sagittal split osteotomy), which involved only the mandible. The mean mandibular forward movement was 6.67 ± 2.03 mm. The chin followed that movement closely by 98%. Labiomental groove was advanced 86% of the mandibular movement. The lower vermilion followed the bony shift by 57% and the subcommissural regions by 52%. Despite the solitary mandibular movement, some soft tissue regions overlying the maxilla were also affected. These changes were less than 1 mm. The highest value was a mean of 0.86 ± 0.38 mm on the upper vermilion due to its interaction with the lower lip to create a better lip seal.

This was reflected minimally in the rest of the upper lip, the subalar region had a change of 0.59 ± 0.39 mm, supracommissural regions 0.21 ± 0.22 mm and subnasale 0.06 ± 0.13 mm. These mean values and percentile proportions are summarised in Table 5.2.

n=18			
Mean maxillary movement		0	
Mean mandibular advancement		6.67 ± 2.03 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0	0	n.a.
Paranasal	0	0	n.a.
Subnasale	0.06	0.13	n.a.
Subalar	0.59	0.39	n.a.
Supracommissural	0.21	0.22	n.a.
Upper vermillion	0.86	0.38	n.a.
Lower vermillion	3.83	1.24	57
Subcommissural	3.47	1.28	52
Labiomental groove	5.75	1.84	86
Chin	6.53	1.99	98

Table 5.2- The mean $\pm$ S.D. soft tissue changes and their percentile proportions to bony surgical change for single jaw Class II advancement cases that underwent a bilateral sagittal split osteotomy.

5.4.1.2 Bimaxillary cases:

Twenty-nine patients had a bimaxillary procedure. Twenty of these underwent a maxillary impaction and a bilateral sagittal split osteotomy on the mandible, four had a genioplasty procedure and five had a horizontal maxillary shift as well as maxillary impaction and mandibular osteotomy. The results of the patients who underwent maxillary impaction and bilateral sagittal split osteotomy were compared to the single jaw cases without any maxillary procedure but only bilateral sagittal split osteotomy, and the difference was statistically insignificant. It was concluded that a vertical movement of the maxilla didn't affect the soft tissues significantly in the anteroposterior plane so despite different degrees of maxillary impaction, all cases were grouped together for analysis.

The first group (n=20) underwent maxillary impaction and mandibular advancement. The mean magnitude of mandibular advancement was 6.60 ± 0.94 mm. The chin was advanced most by 94%, followed by the labiomentental groove, 80%. The lower vermilion reflected 60% of the mandibular advancement, whereas subcommissural regions showed 48% of the change. Although the maxillary procedure did not include a horizontal shift, the soft tissues overlying the maxilla showed insignificant changes, all less than 1 mm. The mean values and percentile proportions are summarised in Table 5.3.

n=20			
Mean maxillary advancement with impaction		0 + impaction	
Mean mandibular advancement		6.60±0.94 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0.21	0.19	n.a.
Paranasal	0.26	0.20	n.a.
Subnasale	0.28	0.13	n.a.
Subalar	0.27	0.13	n.a.
Supracommissural	0.06	0.10	n.a.
Upper vermillion	0.74	0.27	n.a.
Lower vermillion	3.98	0.88	60
Subcommissural	3.15	0.67	48
Labiomental groove	5.27	0.96	80
Chin	6.23	0.94	94

Table 5.3- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class II cases that underwent a maxillary impaction and a bilateral sagittal split osteotomy.

The second group (n=4) of the bimaxillary procedures in Class II patients underwent maxillary impaction and mandibular advancement as well as a genioplasty procedure. The mean mandibular advancement was 4.50±1.00 mm but because of the addition of genioplasty, the chin was advanced 136% of the mandibular advancement achieved by sagittal split osteotomy. Similarly the labiomental groove was advanced 111% of the mandibular osteotomy. The lower vermillion and subcommissural regions' changes were similar to other groups. The lower vermillion reflected 64%, and subcommissural

regions 54% of the mandibular advancement. The soft tissues corresponding the maxilla displayed insignificant changes, all less than 1 mm. The mean values and percentile proportions of change are summarised in Table 5.4.

n=4			
Mean maxillary advancement with impaction		0 + impaction	
Mean mandibular advancement		4.50±1.00 mm + aug genio	
	Mean (mm)	S.D.	% movement
Nasal tip	0.25	0.05	n.a.
Paranasal	0.40	0.18	n.a.
Subnasale	0.20	0.14	n.a.
Subalar	0.35	0.10	n.a.
Supracommissural	0.08	0.15	n.a.
Upper vermilion	0.90	0.26	n.a.
Lower vermilion	2.88	0.48	64
Subcommissural	2.43	0.68	54
Labiomental groove	5.00	0.82	111
Chin	6.13	0.63	136

Table 5.4- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class II cases that underwent a maxillary impaction, bilateral sagittal split osteotomy and a genioplasty procedure.

The third group (n=5) of the bimaxillary procedures underwent mandibular advancement and maxillary impaction with a horizontal shift. The mean mandibular advancement was 2.80±1.10 mm and the mean maxillary advancement was 4.20±1.64. The chin was advanced most by 99%. The labiomental groove followed this by 84%. The lower vermilion was affected more in this group compared to the first two. It projected 79% of the bony advancement. The soft tissues overlying the maxilla revealed more change as

the maxilla was shifted in the horizontal plane. The paranasal and subalar regions, and subnasale advanced approximately 65% of the maxillary change. The nasal tip was least affected, 20%. The mean values and percentile proportions are summarised in Table 5.5.

n=5			
Mean maxillary advancement with impaction		4.20±1.64 mm + impaction	
Mean mandibular advancement		2.80±1.10 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0.86	0.30	20
Paranasal	2.68	1.13	64
Subnasale	2.86	1.28	68
Subalar	2.76	1.04	66
Supracommissural	1.50	0.50	36
Upper vermilion	2.06	0.90	49
Lower vermilion	2.20	0.76	79
Subcommissural	1.18	0.57	42
Labiomental groove	2.36	1.11	84
Chin	2.76	1.38	99

Table 5.5- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class II cases that underwent a bilateral sagittal split osteotomy, maxillary impaction, and a maxillary horizontal shift.

5.4.2 Class III

Class III patients were evaluated in 5 groups. The first group had single jaw procedures.

5.4.2.1 Single jaw

Five patients underwent a single jaw procedure (sagittal split osteotomy), which involved a mandibular setback. The mean achieved mandibular movement was 5.40 ± 1.34 mm. The chin reflected 100% of the bony shift while the labiomental groove followed 84% of the mandibular movement. The lower vermilion followed the bony shift by 70% and the subcommissural regions by 50%. Although the maxilla was not corrected surgically, medial regions of the upper lip with the vermilion were affected insignificantly. None of them were over 1 mm. These mean values and percentile proportions of soft tissue change are summarised in Table 5.6.

n=5			
Mean maxillary movement		0	
Mean mandibular setback		5.40±1.34 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0	0	n.a.
Paranasal	0	0	n.a.
Subnasale	0.14	0.22	n.a.
Subalar	0.18	0.20	n.a.
Supracommissural	0	0	n.a.
Upper vermillion	0.86	0.42	n.a.
Lower vermillion	3.74	0.99	70
Subcommissural	2.70	0.57	50
Labiomental groove	4.54	1.33	84
Chin	5.40	1.34	100

Table 5.6- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for single jaw Class III cases that underwent a bilateral sagittal split osteotomy.

5.4.2.2 Bimaxillary cases

Fifty patients had a bimaxillary procedure. Four of these underwent a maxillary impaction and a bilateral sagittal split osteotomy on the mandible, and 46 had a maxillary advancement as well as maxillary impaction and mandibular osteotomy. Fourteen had 3-mm, 27 had 6-mm and 5 had 9-mm advancement of the maxilla (Table 5.1). The results of the patients who underwent maxillary impaction and the mandibular setback were compared to the single jaw cases without any maxillary procedure but only a mandibular setback, and the difference was statistically insignificant so despite different

magnitudes of maxillary impaction, all cases were grouped together for analysis.

Bimaxillary cases formed the remaining 4 groups for evaluation. The first of these was the patients who underwent a maxillary impaction and a mandibular setback (n=4). The mean mandibular shift was 4.75 ± 0.96 mm. Since this was a setback, the soft tissues showed change in the same direction. The chin was affected most by 96%. The labiomental groove, by 84%, followed this. Lower vermilion reflected 68% of the mandibular procedure, whereas subcommissural regions showed 49% of the change. Although the maxillary procedure did not include a horizontal shift, the soft tissues corresponding the maxilla displayed very insignificant changes, less than 1 mm. The mean values and percentile proportions are summarised in Table 5.7.

The other three groups of bimaxillary procedures were the patients who underwent maxillary advancement as well as maxillary impaction with a mandibular procedure. The first of these had 3-mm advancement of the maxilla (n=14). After evaluating the postoperative lateral skull x-rays, the mean maxillary advancement was found to be 2.99 ± 0.27 mm and the mandible was pushed back 2.86 ± 1.23 mm. Among the points corresponding the maxilla, subnasale, paranasal and subalar regions were the three most affected areas, 81, 79 and 79% respectively. The effects decreased as moved laterally in the supra commissural regions to 45%. The nasal tip was the least affected. It reflected 29% of the maxillary advancement. In the

mandible, the chin was affected the most, reflecting 97% of the mandibular change. It was closely followed by the labiomental groove, which projected 90% of the mandibular shift. Subcommissural regions were affected less, 46%. The upper and lower vermilions reflected the surgical change very similar to each other; the upper moved 66% of the surgical change and the lower 64%. The mean values and percentile proportions are summarised in Table 5.8.

n=4			
Mean maxillary advancement with impaction		0 + impaction	
Mean mandibular setback		4.75±0.96 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0	0	n.a.
Paranasal	0	0	n.a.
Subnasale	0.05	0.10	n.a.
Subalar	0.10	0.12	n.a.
Supracommissural	0	0	n.a.
Upper vermilion	0.55	0.21	n.a.
Lower vermilion	3.25	0.53	68
Subcommissural	2.35	0.44	49
Labiomental groove	3.93	0.79	83
Chin	4.58	0.99	96

Table 5.7- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class III cases that underwent a maxillary impaction and a setback by bilateral sagittal split osteotomy.

n=14			
Mean maxillary advancement with impaction		2.99±0.27 mm + impaction	
Mean mandibular setback		2.86±1.23 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	0.86	0.86	29
Paranasal	2.35	0.46	79
Subnasale	2.43	0.51	81
Subalar	2.36	0.46	79
Supracommissural	1.36	0.46	45
Upper vermillion	1.96	0.46	66
Lower vermillion	1.84	1.06	64
Subcommissural	1.32	0.93	46
Labiomental groove	2.57	1.22	90
Chin	2.76	1.28	97

Table 5.8- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class III cases that underwent a maxillary impaction, 3-mm maxillary advancement and a bilateral sagittal split osteotomy.

In the 6-mm advancement group (n=27), the results were similar. The actual mean maxillary advancement was 5.91±0.24 mm and the mandibular setback was 2.74±1.02 mm. Subnasale, paranasal and subalar regions were the most affected points overlying the maxilla, 80, 75 and 75% respectively. The effects of surgical change decreased to 44% in the supracommissural regions. The nasal tip reflected 33% of the maxillary advancement. In the mandible, the chin kept to the mandibular shift by 98%. The labiomental groove closely followed this region adjacent to it, by showing 91% of the mandibular surgical change. Subcommissural regions were affected less, 47%. The upper

vermilion moved 57%, and the lower moved 65% of the surgical change.

These mean values and percentile proportions are summarised in Table 5.9.

n=27			
Mean maxillary advancement with impaction		5.91±0.24 mm + impaction	
Mean mandibular setback		2.74±1.02 mm	
	Mean (mm)	S.D.	% movement
Nasal tip	2.00	1.01	34
Paranasal	4.44	0.65	75
Subnasale	4.70	0.72	80
Subalar	4.40	0.54	75
Supracommissural	2.59	0.64	44
Upper vermilion	3.34	0.76	57
Lower vermilion	1.77	0.81	65
Subcommissural	1.28	0.63	47
Labiomental groove	2.50	1.02	91
Chin	2.69	1.05	98

Table 5.9- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class III cases that underwent a maxillary impaction, 6-mm maxillary advancement and a bilateral sagittal split osteotomy.

The final group had 9-mm advancement of the maxilla (n=5) which was an actual mean maxillary advancement of 8.97±0.31 mm and a mean mandibular setback of 2.80±1.30 mm. Subnasale, and paranasal and subalar regions were again the most affected areas overlying the maxilla, 75, 74 and 72% respectively. The projection of surgical change to soft tissues decreased in the supracommissural regions to 45%. The nasal tip projected 34% of the maxillary advancement. In the mandible, the chin displayed all of the surgical

change. The labiomental groove reflected 90% of the mandibular movement. Subcommissural regions were affected less, 46%. The upper vermilion moved 49% of the surgical change, whereas the lower projected 71% of the surgical change. The mean values and percentile proportions are summarised in Table 5.10.

n=5			
Mean maxillary advancement with impaction		8.97±0.31 mm + impaction	
Mean mandibular setback		2.80±1.30 mm	
	Mean (mm)	S.D.	% movement
Nasai tip	3.00	0.35	33
Paranasal	6.60	0.42	74
Subnasale	6.70	0.27	75
Subalar	6.50	0.50	72
Supracommissural	4.00	0.79	45
Upper vermilion	4.40	0.65	49
Lower vermilion	2.00	0.87	71
Subcommissural	1.30	0.45	46
Labiomental groove	2.52	1.14	90
Chin	2.80	1.30	100

Table 5.10- The mean±S.D. soft tissue changes and their percentile proportions to bony surgical change for bimaxillary Class III cases that underwent a maxillary impaction, 9-mm maxillary advancement and a bilateral sagittal split osteotomy.

Figure 5.4, 5.5 and 5.6 show comparison of the percentile changes between groups of different treatment plans.

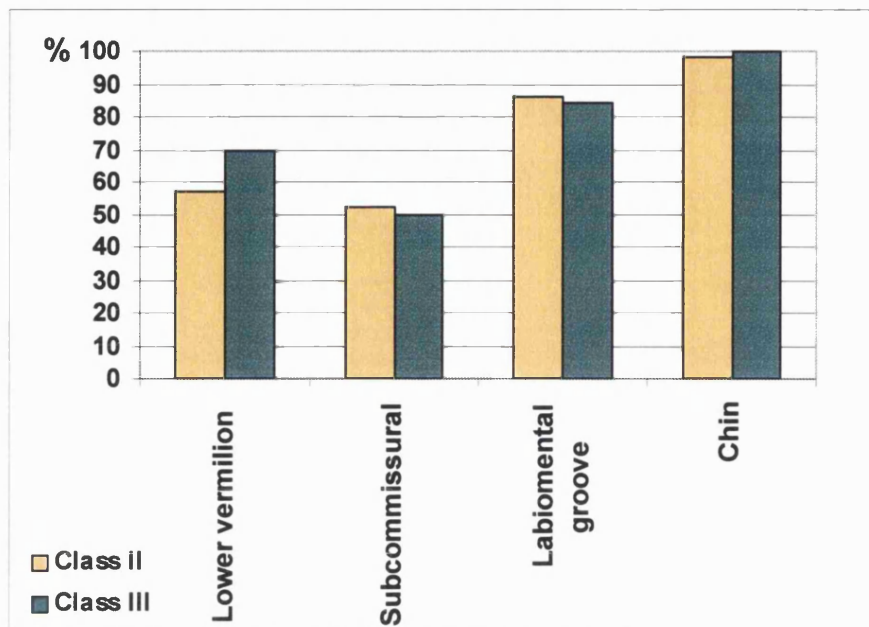


Figure 5.4- The comparison of percentile soft tissue changes between single jaw Class II and III cases.

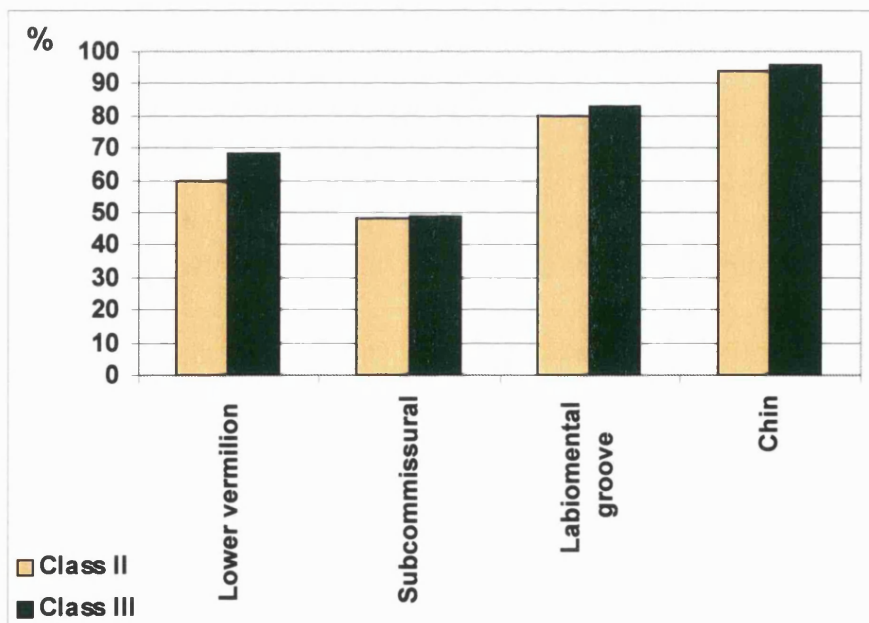


Figure 5.5- The comparison of percentile soft tissue changes between bimaxillary Class II and III cases that underwent a maxillary impaction and a mandibular procedure.

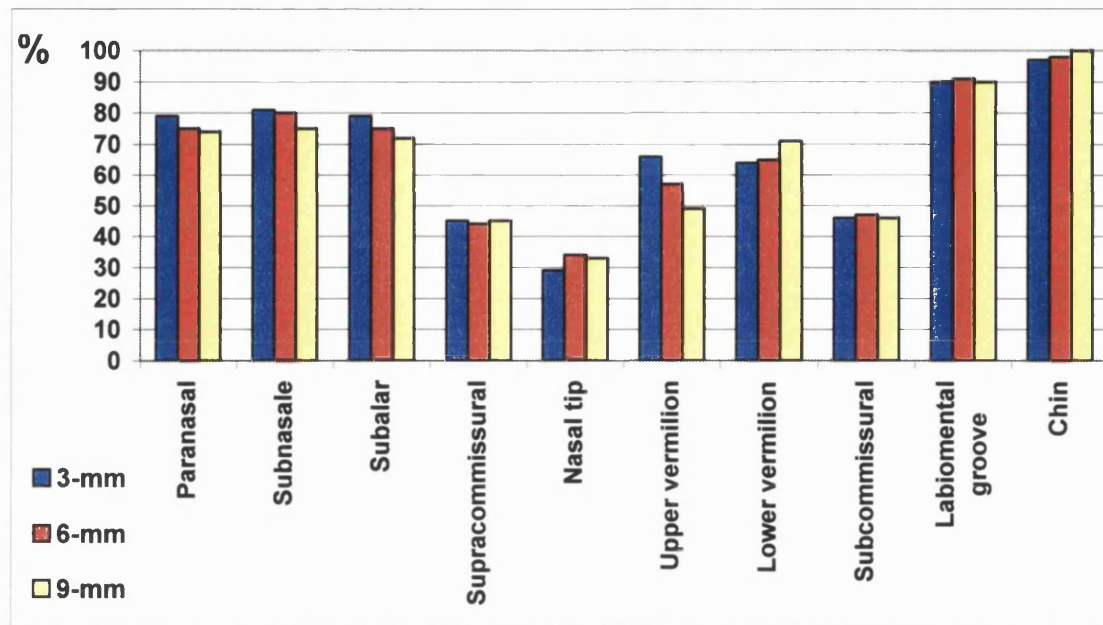


Figure 5.6- The comparison of soft tissue changes (% of the skeletal change) in Class III cases undergoing 3-mm, 6-mm and 9-mm advancement and impaction with a mandibular setback.

Using the thin-plate splines analysis, the directions of movements of the landmarks on the lateral profile outline were observed. Samples of thin-plate splines graphic changes are demonstrated in Figure 5.7. The landmarks associated to the areas not affected by the surgery (landmarks 1,2 and 3) show the unaffected grid in the upper third of the face for both figures. Both grid systems show the change around the nasal tip (landmark 4), subnasale (landmark 5), the lips (landmarks 6,7,8 and 9) and the chin (landmarks 10 and 11). The direction of curves of the grid lines shows the direction of movements of the soft tissue landmarks for Class II and III cases.

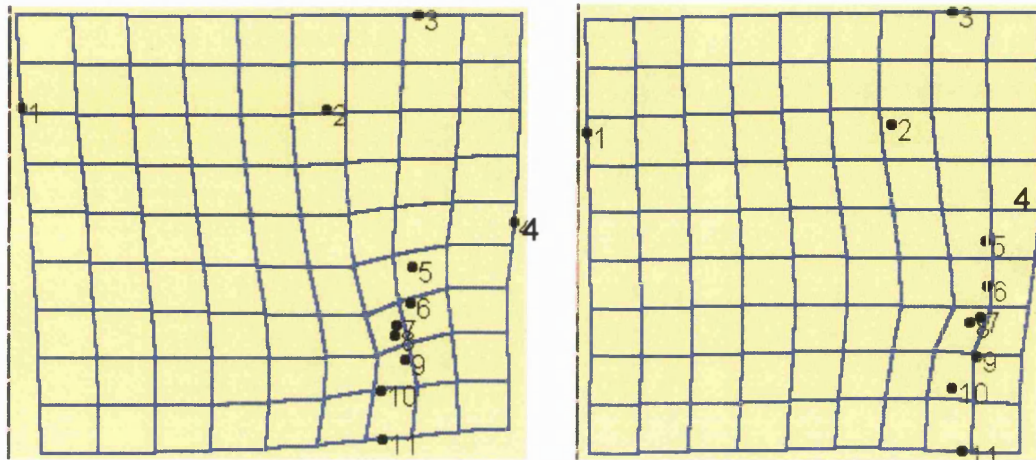


Figure 5.7- The thin-plate splines graphical analysis obtained after the superimposition of pre and postoperative optical surface scans' lateral profiles. The image on the left represents the change in a Class II case, and the image on the right represents the change in a Class III case. The landmarks associated to the areas not affected by the surgery (landmarks 1,2 and 3) show the unaffected grid in the upper third of the face for both figures. Both grid systems show the change around the nasal tip (landmark 4), subnasale (landmark 5), the lips (landmarks 6,7,8 and 9) and the chin (landmarks 10 and 11). The direction of curves of the grid lines shows the direction of movements of the soft tissue landmarks for Class II and III cases.

Among Class II patients (n=47), the movement of the maxillary reference points were insignificant except five patients who had a maxillary horizontal forward shift.

Genioplasty introduced increased change in the results so 4 patients were excluded and the remaining 38 patients were analysed for the points corresponding the mandible. The stomion point on the lower lip moved forward and up in 19, forward only in 10, forward and down in 9 cases. On labrale inferius, 22 cases moved forward and upward, 8 moved solely forward, 6 forward and downward. Two of the cases showed no change on this landmark. The major vector was a forward and upward component for the

labiomental groove and pogonion (15 cases for labiomental groove and 18 for pogonion). At the labiomental groove, 15 cases moved solely forward while 14 moved in the same direction as the pogonion. The pogonion moved forward and downward in 6 cases while the labiomental groove moved forward and downward in 8 cases. These results are summarised in Table 5.11.

Landmark	Direction of movement	n
Stomion inferius		19
		10
		9
Labrale Inferius		22
		8
		6
	unchanged	2
Labiomental groove		15
		15
		8
Pogonion		18
		14
		6

Table 5.11- The direction of movements for landmarks on the soft tissue profile for Class II cases (n=38).

Among the Class III patients (Table 5.12) who had a maxillary advancement and impaction with a mandibular setback (n=46), the nasal tip moved forward and up in a majority of cases (n=33). In 7 cases, it moved straight forward, and remained immobile in 6 cases.

The direction of movement for subnasale was forward and up in 27 cases and forward and down in the other 7. Ten of the cases though moved straight forward and only 2 remained immobile. From subnasale downwards on the upper lip, the downward component of the movement became stronger.

Labrale superius moved straight forward in 35 cases, forward and down in 9. The other two remained constant. On the upper lip stomion, 22 moved forward with a downward vector while 21 moved straight forward, and 3 remained unchanged.

The movement of the stomion point on the lower lip was more complicated. Eleven moved forward and down, and 9 solely forward. This landmark also showed backward movement in 23 cases; 14 with an upward and 9 with a downward vector. In 3 cases, the stomion inferius remained unchanged. Below this landmark, backward movement was the major vector. With labrale inferius, 22 cases moved backward and downward, 9 moved solely backward, and 11 backward and upward. Four of the cases showed no change of this landmark. The labiomentental groove and pogonion displayed the least complicated movement. The major vector was backward with and upward component (21 cases for labiomentental groove and 23 for pogonion). On the

labiomental groove 18 cases moved solely backward while 17 moved the same direction for pogonion. On the pogonion 6 moved backward and downward while 7 moved similarly for labiomental groove. These results are summarised in Table 5.12.

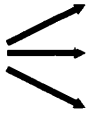
Landmark	Direction of movement	n
Nasal tip	 unchanged	33 7 6
Subnasale	 unchanged	27 10 7 2
Labrale superius	 unchanged	35 9 2
Stomion superius	 unchanged	21 22 3
Stomion inferius	 unchanged	9 11 14 9 3
Labrale Inferius	 unchanged	11 9 22 4
Labiomental groove	 unchanged	21 18 7
Pogonion	 unchanged	23 17 6

Table 5.12- The direction of movements for landmarks on the soft tissue profile for Class III cases (n=46).

Figure 5.8 shows the range of the percentile values for all patients.

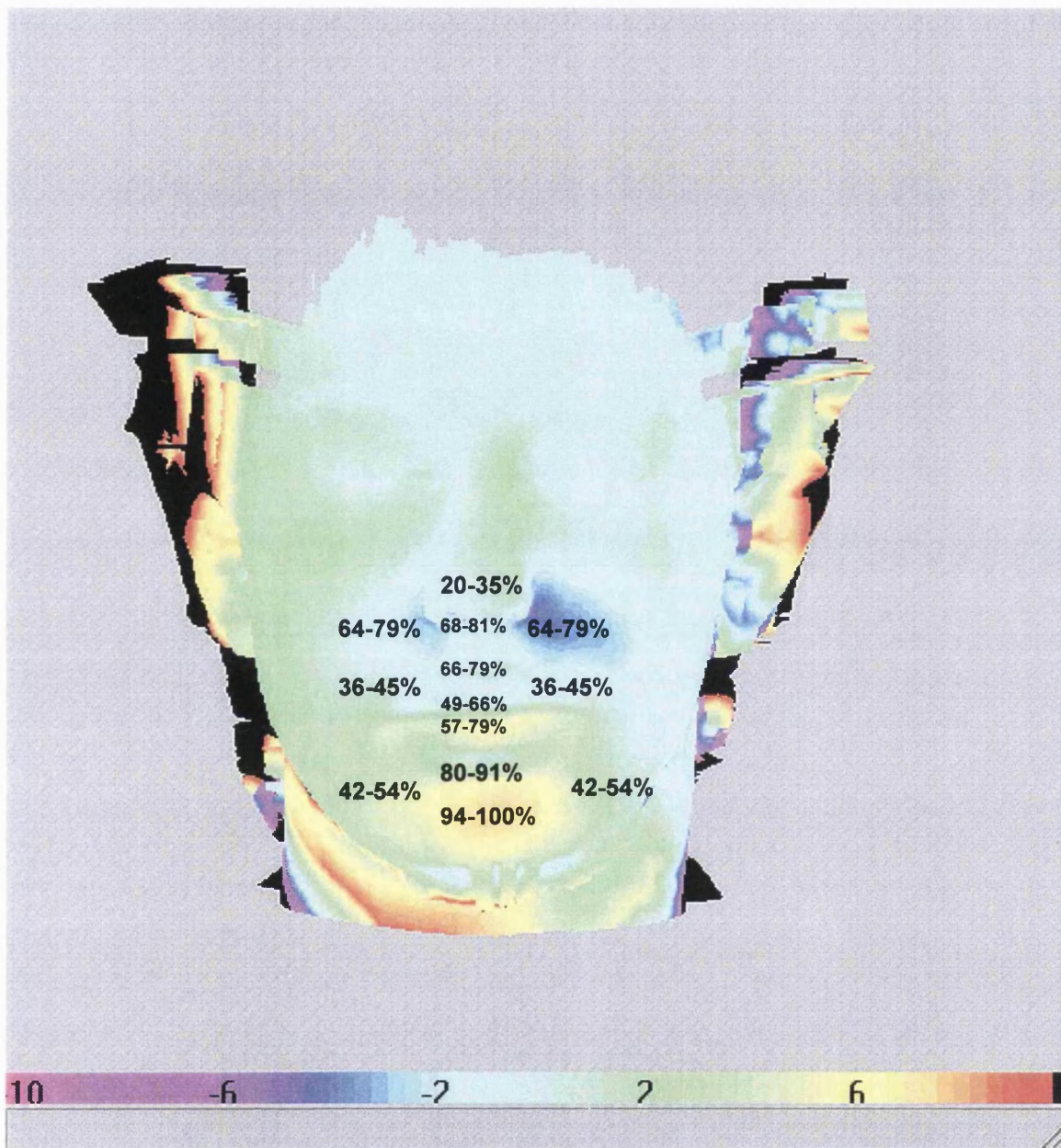


Figure 5.8- The range of percentile values for soft tissue change after orthognathic surgery.

5.5 Discussion

This study showed the effects of orthognathic surgery on the facial soft tissue mask after the correction of Class II and III facial deformities. These changes differed in various regions of the face in all patients. Other researchers have not investigated many of the areas investigated in this study, e.g. paranasal regions, supracommissural and subcommissural regions. This has only been possible with the use of a reliable three-dimensional imaging tool.

The lips in particular were investigated in greater detail in this study. It was possible to differentiate the soft tissue responses for the upper and the lower lips and the vermilion borders in detail by the optical surface scanner. The chin was also investigated in greater detail particularly in relation to the labiomental groove.

Soft tissue changes were studied by many researchers in the last century, but often reporting contradictory findings. Bell and Dann (1973) reported a change of 70% for the upper lip movement relative to upper incisor movement, which was 66-79% for this study. Lines and Steinhauser (1974) and Hack *et al.* (1993) suggested a ratio of 60% though in the latter study they suggested that this ratio would decrease to 50% over the long term of five years. On the other hand, the results of Carlotti *et al.* (1986) were higher with a ratio of 90% and later Schendel and Carlotti (1991) suggested this ratio improvement was due to the use of V-Y closure of the vestibular incision. Our study was able to investigate the upper lip in greater detail by giving results of different sections of the upper lip; e.g. the subalar, subcommissural and

supracommissural regions and the vermillion with the help of the 3D optical surface scanner.

The anatomical and morphological nature of the upper lip probably determines the soft tissue movement in relation to the repositioning of the underlying skeletal structure. The upper lip hangs like a muscular curtain attached to the anterior nasal spine at the subnasal region which may explain why that region follows the hard tissue much closely (80%) compared to lateral areas of the upper lip, the supracommissural regions (45%), and the unbound end at the upper lip vermillion, especially at the stomion (65%). In addition, the amount of change depends on factors like the elasticity of the upper lip, its proximity and contour of the alveolar bone, and the volume of the potential space at the fornix of the alveolar sulcus. The important extraneous factor is the relation to the lower lip to form a lip seal. The influence of these factors is shown in Figure 5.9 where the preoperatively existing concave outline of the upper lip straightens followed by maxillary advancement.

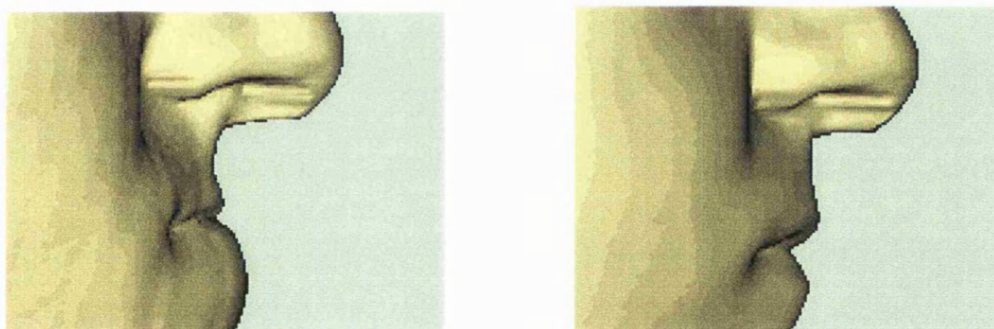


Figure 5.9- Optical surface scans showing the preoperatively existing concave outline of the upper lip which straightened after maxillary advancement and formation of a lip seal.

Figure 5.9 demonstrates how the differential effect of the maxillary advancement works towards the correction of the concave outline of the upper lip. Subnasale and subalar region advanced more than the upper lip vermilion. The position of the upper lip in relation to the lower lip was altered by the bimaxillary procedure allowing an increase in the vertical height and a better lip support by the upper incisors, so the previous drape of the upper lip with the concave outline compensated for the formation of a lip seal. As the soft tissues projected the skeletal change more on subnasale and subalar region than the lateral parts of the upper lip (supracomissural regions), the mid upper lip gained volume altering the flat appearance.

This decreasing effect of the maxillary movement on the lateral parts of the upper lip and the soft tissue mask of the middle third of the face is an important finding. This can be explained by the semi-circular shape of the maxilla and the muscle attachments. The magnitude of the maxillary advancement is planned at the central part of the bone corresponding to the maxillary incisors. When this semi-circular bone is advanced by a certain magnitude at this point, the other bilateral points on the circumference of the circle move less, in other words, the degree of projection of the advancement on soft tissues decreases gradually towards the back (Figure 5.10). This is also applicable to the mandible since the mandibular bone resembles a semi-circle as well. For these reasons use of an accurate 3D imaging tool for the evaluation of soft tissues is especially important for the lips. This finding was supported by McCance *et al.* (1992 a) and Techalerpaisarn and Kuroda (1998).

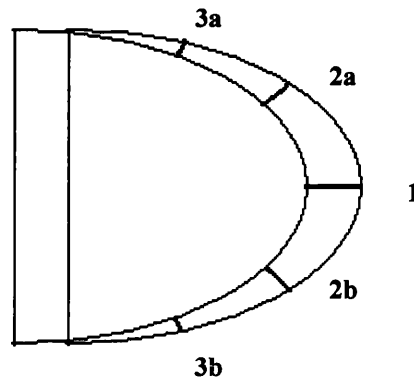


Figure 5.10- When a semi-circular shaped bone is advanced at point 1, the other points on the circumference of the circle bilaterally (2a, 2b, 3a, 3b) move relatively less, in other words, the degree of projection of the advancement on soft tissues decreases gradually towards the back.

An additional factor is the muscle attachments. The fibres of orbicularis oris muscle attach to the upper and lower jaws near the midline, well away from the alveolar margin. The mucous membrane of the lips is firmly attached to these deep fibres (McMinn, 1994). This firm attachment of the incisive and mental slips of the orbicularis oris muscle to the bone near the midline and the mucous membranes of the lips enables the upper lip on the midline and the soft tissue pogonion to follow the advancement more closely than the lateral parts, which are relatively loose (Figure 5.11).

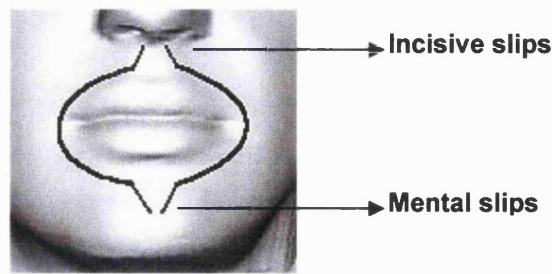


Figure 5.11- The incisive and mental slips of the orbicularis oris muscle are the deepest fibres, which are attached to the bone near the midline, well away from the alveolar margin and the mucous membrane of the lips is also firmly attached to them.

Dann *et al.* (1976) reported the ratio for nasal tip advancement of 20-35% similar to this study. Rosen (1988), on the other hand, found the nasal tip advancement insignificant. Lee *et al.* (1996) suggested that the nasal tip changes occurred but disappeared by the end of first year.

The paranasal regions, bilaterally, correspond to the attachment of levator anguli oris muscle at the canine fossa, and the attachments of the nasalis muscle (Figure 5.12) (McMinn, 1994). These firm attachments help to explain the up to 80% reflection of the maxillary advancement to the soft tissues in the paranasal regions (Figure 5.13). Previous studies did not mention the soft tissue response at the paranasal regions. Widening of the alar base was discussed previously, especially when cinch suture technique is not used. Most of those studies evaluated the facial profile outline or the clinical alar base width, but not the paranasal region.



Figure 5.12- The attachments of levator anguli oris and nasalis muscles in the paranasal region (left), and the soft tissue change in the region after maxillary advancement compared to the adjacent soft tissues (right).

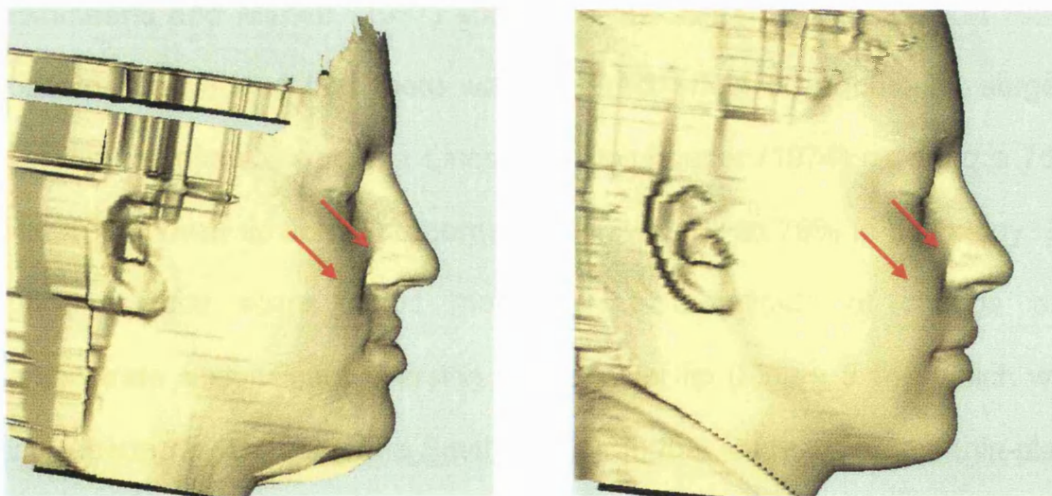


Figure 5.13- The preoperative (left) and postoperative (right) optical surface scans showing the change in the paranasal regions, indicated by the red arrows.

The amount of the reflection of the mandibular movement to the soft tissues of the lower facial third was found to be greater. This study reported a 100% ratio around the soft tissue pogonion, which was supported by many other researchers. This can be explained by the close proximity of the soft tissue pogonion to the underlying bone because of the muscle attachments, the mentalis muscle and the mental slips of the orbicularis oris muscle (Figure 5.11). The semi-circular shape of the mandible, like the maxilla, is again another effect on the decreasing degree of projection of the mandibular procedure gradually towards the lateral parts of the mandible (Figure 5.10).

Mommaerts and Marxer (1987) supported the same ratio at the soft tissue pogonion and added that there was no direct effect of mandibular surgery over labrale inferius, whereas Lines and Steinhauser (1974) reported a 75% ratio at the lower lip vermilion border, which was 57 to 79% in this study. 3D optical surface scans could measure the magnitude of change and demonstrate a significant eversion of the lower lip (Figure 5.14), which was also reported by Hershey and Smith (1974). In this study, using the thin-plate splines analysis, the forward movement of stomion inferius was shown while labrale inferius was moving backward (Figure 5.14a), displaying the eversion of the lower lip and increasing the lower vermilion border in many Class III cases. This was due to the relaxation of the lower lip after the tension caused by the lower teeth and the alveolar bone was eliminated with a mandibular setback, and eventually eliminating lip incompetence and forming a better lip seal.

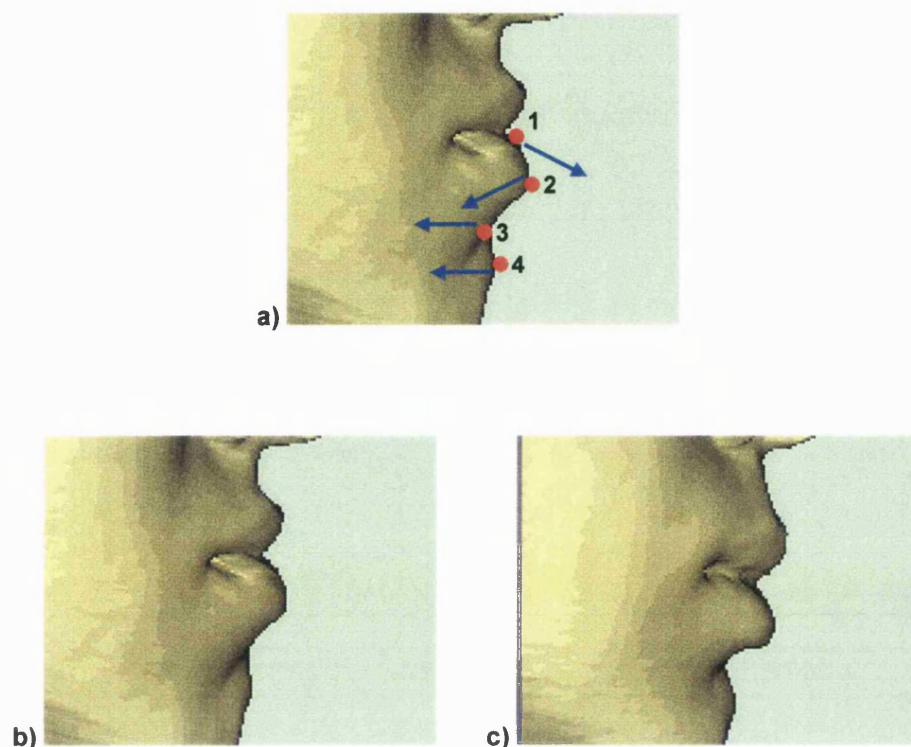


Figure 5.14- The eversion of the lower lip after mandibular setback: a) The direction of the shift of the landmarks; 1- stomion inferius, 2- labrale inferius, 3- labiomentall groove, 4- soft tissue pogonion, b) the preoperative, and c) the postoperative optical surface scans.

The positions of the lips are determined mostly by themselves more than the underlying bone. Other studies reported a 67% ratio at the lower lip vermilion, which was as low as 38% according to Quast *et al.* (1983). The range of change at the labiomentall groove in this study was 80-91%, close to Hershey and Smith's (1974) 80% change.

The directions of the movements of the soft tissue points were clearly shown in this study using thin-plate splines, and they had vertical components as well as the main horizontal vector. Many researchers stated that the vertical component of change only followed a vertical movement of the underlying bone, as with the impaction of the maxilla or the autorotation of the mandible. Although maxillary impaction did not introduce a significant difference in soft tissue change, the thin-plate splines revealed the vertical vectors caused by these procedures. It is difficult to determine the amount of autorotation of the mandible, but this study reported the deviations in the direction of movements, again, using thin-plate splines. Since vertical changes did not make a significant difference to the overall result, we evaluated the magnitudes of movements regardless, but used these components of movement to explain the shift of some individual landmarks as in Figure 5.14.

In conclusion, the soft tissue changes following the shift of the underlying skeletal structures after orthognathic surgery depend on various factors including; muscle attachments, proximity of the soft tissues to the underlying bone, the geometrical shape of the bones, soft tissue elasticity, thickness, surgical technique and the magnitude of surgical movement, hence it can be difficult to predict. However, there is a general trend as discussed in this study for the direction and amounts of facial soft tissue changes in the middle and lower facial thirds.

This study has highlighted the regions of the face significantly affected by the osteotomy movements and illustrated that soft tissue changes are quantifiable.

CHAPTER VI

THE EFFECT OF ORTHOGNATHIC SURGERY ON THE UPPER AND LOWER LIP VERMILION WIDTH

6.1 Introduction

Lips are an important component of the facial complex, and can be grossly affected by the movement of the maxilla and the mandible but the degree of change is influenced by several factors. The surgical movements of facial bones produce lip movements which can be predicted, whereas the contraction of surgical incisions and alteration in muscle tone have unknown effects.

The literature review revealed no controlled study of lip vermillion width changes following orthognathic surgery. The difficulties are current imaging techniques for recording lip changes, which are crude, although clinical measurement techniques of soft tissues are sensitive. Therefore a better understanding of the relationship between hard tissue movement and overlying soft tissue response is essential in order to improve the desired soft tissue outcome after orthognathic surgery.

6.2 Aims

The aims of this study were to analyse the upper and lower lip vermillion widths for Caucasian, Afro-Caribbean and Oriental controls, and to investigate the upper and lower lip vermillion width changes after orthognathic surgery in skeletal Class II and III patients.

6.3 Patients and methods

Sixty subjects were recruited for the first part of this study to measure the upper and lower lip vermillion widths in order to set up a normative data. Three groups of twenty control subjects representing Caucasians, Afro-Caribbeans and Orientals were formed. These control subjects were chosen randomly from the members of public. In the Caucasian group, 11 were males and 9 were females. 13 of these had Class I, 3 had Class II / division 1 and 4 had Class III dentoskeletal relationship. The Afro Caribbean group had 12 male and 8 female subjects, 11 of which were dentoskeletally Class I, 2 were Class II / division 1 and 7 were Class III. In the Oriental group, 7 males and 13 females took part. Fourteen of these were Class I, 1 was Class II / division 2 and 5 were Class III dentoskeletally.

For the second phase, thirty-seven non-cleft patients undergoing orthognathic surgery were included. Nineteen of these were Class II / division 1 and eighteen were Class III dentoskeletally. Nine of the 19 Class II patients underwent 4 to 6-millimetre maxillary impaction along with forward advancement of the mandible by sagittal split osteotomy. Five of these had 4-millimetre and 4 had 6-millimetre impactions. Seven underwent only mandibular advancement of the mandible by sagittal split osteotomy. The other three underwent a 3-millimetre advancement two of which were 4-millimetre impactions and one 8-millimetre downfracture of the maxilla as well as the mandibular procedure. Sixteen of the 18 Class III patients underwent maxillary advancements; 2 had 3-millimetre, 12 had 6-millimetre and 2 had 9-millimetre, which were accompanied by a set back of the mandible with

bilateral sagittal split osteotomy for a Class I skeletal relationship. One of the 3-millimetre advancement, 6 of the 6-millimetre advancement and 1 of the 9 millimetre advancement cases had 2 to 4-millimetre impaction. Two remaining cases underwent 4-millimetre maxillary impaction without any maxillary advancement.

The vermillion width of each subject in both phases of the study was measured from labrale superius (upper vermillion margin) to the stomion (free margin of the lip) on highest point of cupid's bow on the upper lip, and from stomion to labrale inferius (lower vermillion margin) on the lower lip at the midline when the lips were relaxed (Figure 6.1). The patients were asked to sit upright and lick their lips followed by a swallowing action and gaze in the horizon with their lips in relaxed position for the reproducibility of measurements. All measurements were taken during the preoperative work-up and six months postoperatively after the swelling of soft tissues had settled down using a Vernier calliper. The measurements were repeated three times and the means of these measurements were used for the final evaluation. The paired student t-test was used for comparing the changes.

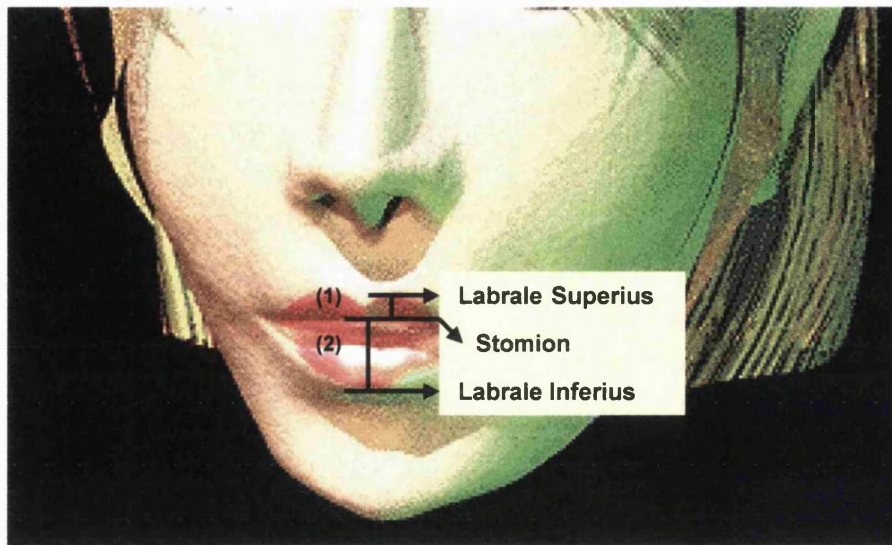


Figure 6.1- The localisation of landmarks; a) labrale superius, b) stomion, c) labrale inferius clinically. The upper vermilion width (1) was measured from labrale superius to the stomion on cupid's bow, and the lower vermilion width (2) was measured from the stomion to labrale inferius at the midline.

6.4 Results

6.4.1 The control group

The values recorded after measuring upper and lower lip vermilion widths and the upper to lower lip vermilion width ratios are in Table 6.1. The mean upper to lower lip vermilion ratio for Caucasians was 0.73 ± 0.11 . This ratio for Afro-Caribbeans and Orientals were 0.76 ± 0.07 and 0.76 ± 0.08 respectively (Figure 6.2). The mean bivermilion widths (total vermilion width=sum of upper and lower vermilion widths when the lips are relaxed) were calculated for Caucasians, Afro-Caribbeans and Orientals and these values were 17.1 ± 2.99 mm, 23.3 ± 1.45 mm and 15.6 ± 1.94 mm respectively (Figure 6.3). The differences between the upper and lower lip vermilion width ratios between the three groups were statistically insignificant ($p > 0.05$). The difference

between the mean bivermilion widths of Afro-Caribbeans was significantly broader than Caucasians and Orientals ($p < 0.05$).

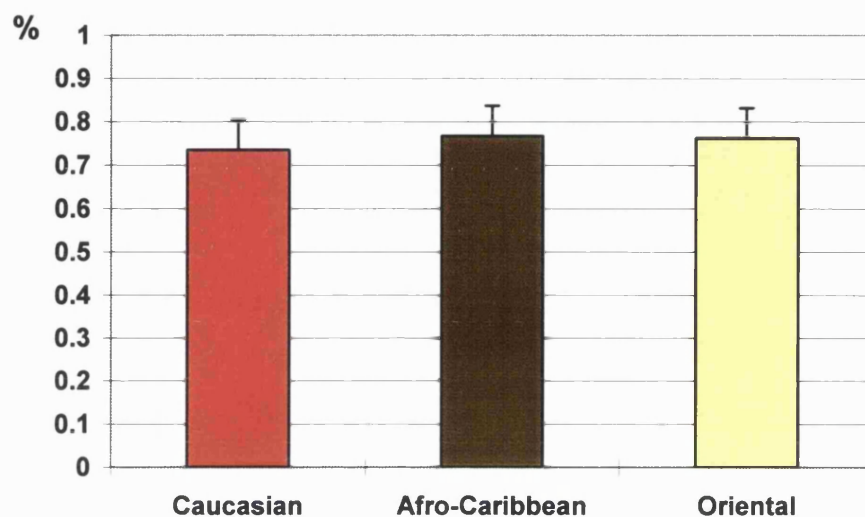


Figure 6.2- The means and standard deviations of upper to lower lip vermilion width ratios for Caucasian, Afro Caribbean and Oriental control subjects. (n=60) ($p > 0.05$)

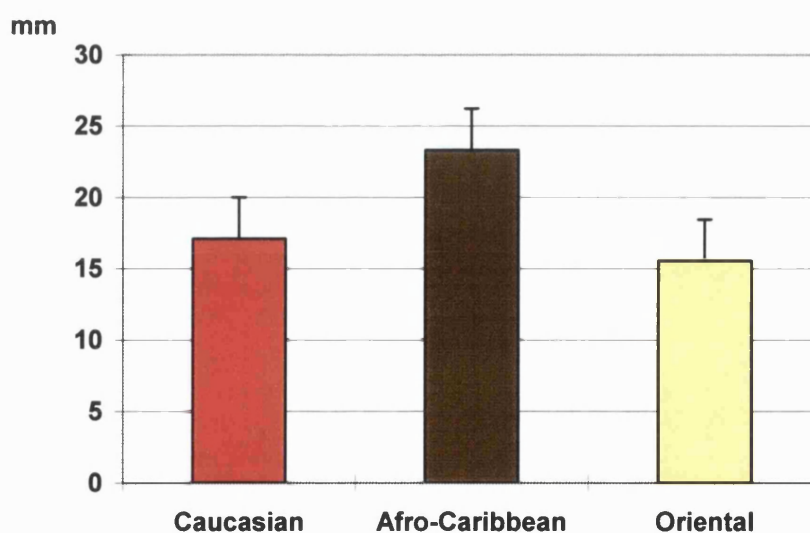


Figure 6.3- The mean and standard deviation of bivermilion width measurements for Caucasian, Afro Caribbean and Oriental control subjects. (n=60)

a) Caucasian group

	upper vermillion width (mm)	lower vermillion width (mm)	vermillion ratio	gender	skeletal relationship
1	8	11	0.72	M	Class I
2	7	10	0.7	M	Class I
3	7	10	0.7	F	Class I
4	6	9	0.66	F	Class I
5	7	11	0.63	M	Class I
6	8	11	0.72	M	Class I
7	6	8	0.75	F	Class I
8	7	10	0.7	F	Class I
9	6	9	0.66	F	Class I
10	7	10	0.7	F	Class I
11	5	9	0.55	F	Class I
12	6	6	1	F	Class II / div 1
13	6	9	0.66	M	Class I
14	8	11	0.72	M	Class III
15	8	10	0.8	M	Class III
16	9	11	0.81	M	Class III
17	8	10	0.8	F	Class II / div 1
18	10	16	0.62	M	Class III
19	8	10	0.8	M	Class II / div 1
20	7	7	1	M	Class I

b) Afro-Caribbean group

	upper vermillion width (mm)	lower vermillion width (mm)	vermillion ratio	gender	skeletal relationship
1	10	14	0.71	F	Class I
2	10	13	0.76	M	Class I
3	9	13	0.69	F	Class I
4	9	13	0.69	M	Class III
5	11	13	0.84	M	Class III
6	10	11	0.91	M	Class I
7	10	13	0.76	M	Class I
8	10	14	0.71	M	Class III
9	11	14	0.78	M	Class I
10	9	12	0.75	F	Class I
11	10	14	0.71	M	Class III
12	12	14	0.86	M	Class II / div1
13	9	13	0.69	M	Class III
14	10	14	0.71	M	Class I
15	11	13	0.85	M	Class I
16	9	13	0.69	F	Class II / div1
17	10	14	0.71	F	Class III
18	10	13	0.77	F	Class I
19	12	14	0.86	F	Class III
20	9	13	0.69	F	Class I

c) Oriental group

	upper vermillion width (mm)	lower vermillion width (mm)	vermillion ratio	gender	skeletal relationship
1	7	10	0.7	F	Class I
2	9	12	0.75	M	Class I
3	7	9	0.77	F	Class I
4	6	8	0.75	F	Class I
5	7	9	0.77	M	Class I
6	6	7	0.85	M	Class I
7	6	9	0.66	F	Class III
8	7	10	0.7	M	Class I
9	6	8	0.75	F	Class I
10	6	9	0.66	M	Class I
11	6	7	0.66	F	Class I
12	7	10	0.7	F	Class III
13	7	7	1	F	Class I
14	8	10	0.8	F	Class II / div 2
15	6	7	0.86	M	Class III
16	7	9	0.77	F	Class I
17	6	8	0.75	F	Class I
18	7	9	0.77	F	Class III
19	7	10	0.7	F	Class I
20	6	9	0.66	M	Class III

Table 6.1- The upper and lower vermillion widths, upper to lower vermillion width ratios of 60 control subjects.

6.4.2 Class II subjects

Figure 6.4 shows the pre and postoperative means and 95% confidence intervals for the upper and lower vermillion widths (mm) of Class II subjects that underwent mandibular advancement with or without maxillary impaction. The changes in these patients were not significant ($p>0.05$). When the Class II subjects who underwent maxillary impaction and mandibular advancement were separated from the rest of the group, there was still no significant change on the upper and lower lip vermillion widths ($p>0.05$). Despite the insignificance, the minute change on the upper and lower vermillion widths were same as the change occurred in the group who did not undergo maxillary impaction. When the subjects who had a 3-millimetre maxillary

advancement as well as the mandibular osteotomy were included in the analysis, there was still no change.

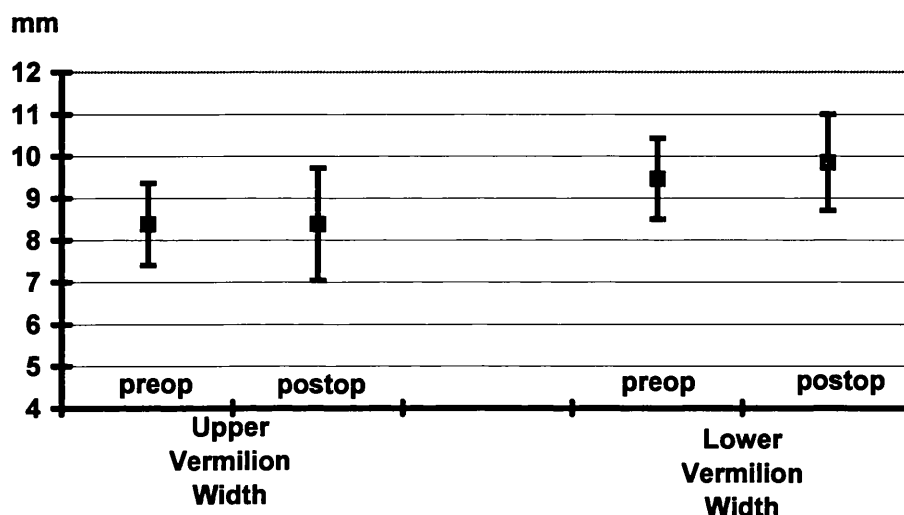


Figure 6.4- The mean and 95% confidence intervals of upper and lower vermillion width measurements for Class II subjects pre and postoperatively (mm).

6.4.3 Class III subjects

Class III subjects who underwent 3-millimetre advancement of the maxilla along with mandibular set-back with bilateral sagittal split osteotomy did not show significant changes in upper and lower vermillion widths ($p > 0.05$), whereas, subjects who had 6-millimetre advancement and the mandibular procedure showed a significant change in their upper vermillion widths ($p < 0.05$). The change was an increase of 17-18% of the upper vermillion width. The change in the lower vermillion was insignificant ($p > 0.05$). A significant 11-13% increase in the upper vermillion width was found amongst the Class III subjects who underwent maxillary impaction as well as 6-millimetre maxillary advancement and the same mandibular procedure.

Figure 6.5 shows that the change in the upper vermilion width for all Class III subjects was statistically significant ($p < 0.05$) but there wasn't a significant change in the lower lip (Table 6.2).

The changes were greater in lip vermilions that were narrower than 15 mm in the Class III group. The Class II subjects with narrow vermilions showed 5% decrease of the upper vermilion width, which was statistically insignificant. The broader Class II vermilions though showed the same tendency of change as the whole Class II group.

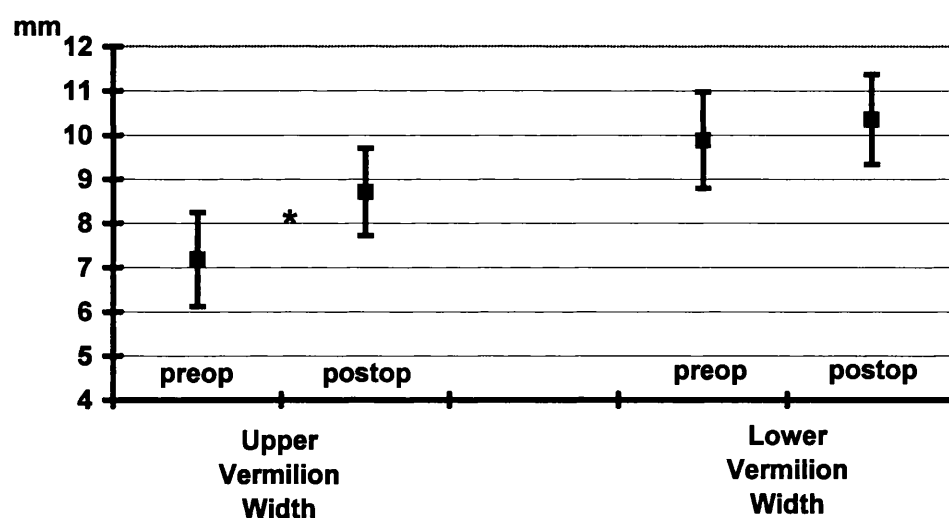


Figure 6.5- The mean and 95% confidence intervals of upper and lower vermilion width measurements for Class III subjects pre and postoperatively (mm). (* $p = 0.02$)

Class II	preoperative	postoperative
Upper vermillion width	8.38±1.80	8.38±2.47
Lower vermillion width	9.46±1.78	9.85±2.12
Class III		
Upper vermillion width	7.18±2.30	8.71±2.14
Lower vermillion width	9.88±2.37	10.35±2.21

Table 6.2- The means $\pm$ SD for pre and postoperative upper and lower vermillion widths of Class II and Class III subjects.

The change of upper vermillion width was irregular in the Class II group (5 decreased, 4 increased, 7 remained same) but the mean showed an insignificant decrease of 4%. This change was more regular among Class III subjects (9 increased, 3 remained the same) and the mean showed a marked increase of 18%.

The change of lower vermillion width at the midline was irregular in the Class II group (8 decreased, 3 increased, 5 remained same) and the mean showed a slight decrease of 3%. The irregularity of this change was similar for Class III subjects, but they mostly tended to increase (6 increased, 2 decreased, 4 remained the same) and the mean showed a less increase than the other widths, an insignificant 4%.

6.5 Discussion

This study showed that in Class III cases the surgery had a significant effect on upper vermillion width, whereas in Class II cases the lips were not significantly affected and the changes were unpredictable. Advancement of the maxilla and advancement or setback of the mandible had direct effects on vermillion width, whereas maxillary impaction and down fracture did not have a significant affect. Another important finding is that patients with narrower vermilions were affected more. The reason that the effect of surgery on upper lip vermillion is significant may be that the upper lip is usually narrower and less bulky than the lower. The orthognathic surgery procedure did not have significant effect on the lower vermillion.

There are very few studies in literature assessing the lips after orthognathic surgery. The existing studies either included lips within a general evaluation of facial profiles or assessed either the upper or the lower lip after a single jaw procedure. As the results of these studies differ greatly, it is almost impossible to compare them for a better evaluation of the lips together. Furthermore, profile evaluations were favoured and frontal assessment of lips was performed by a limited number of researchers. Most of these studies evaluated the ratio of movement of the upper and/or the lower lip to the movement of the hard tissues lying underneath and rotational movements of lips resulting in change in the vermillion width was not observed.

For this study, the clinical measurements were taken two days before and six months after the operation. This was reported to be a sufficient time after the

surgery for the soft tissues to settle down by Stella *et al.* (1989) and Dann *et al.* (1976).

Oliver (1982) investigated the changes in lip broadness and strain with orthodontic treatment and surgery and reported that the lip broadness was an important factor to influence the change, broader vermilions being able to absorb changes more easily than narrow ones, which is supported by this study. Furthermore, the narrower parts of the vermilions were even more affected than the broader parts; for example, the change in the upper vermillion width was more distinct at the midline than the broader lateral parts. Gjorup and Athanasiou (1991) reported similar results. According to Freihofer (1976), increased vermillion broadness (>17 mm) produced a less predictable correlation between soft and hard tissue changes. In this study, the changes in the vermilions in the range of 10-15 mm were more predictable than the vermilions broader than 15 mm.

Adaptation of the lip posture is also dependent on their resting positions on teeth and pressures due to position. Proffit and Phillips (1988) studied the pressures following different applications of orthognathic surgery and stated the decrease in resting pressures of the upper and lower lip respectively after maxillary advancement by Le Fort I and mandibular advancement by sagittal split osteotomy. This decrease in the resting pressure was affecting the lip posture after orthognathic surgery.

Previous studies were done on cross-sectional evaluations based on cephalographs, whereas for this study, direct clinical measurements were taken ruling out the error of an imaging technique in the results.

The effect of surgery on the lip depends on many factors, these include the thickness of the tissues overlying bony segments, the magnitude of movements and accompanying vertical vectors of movement, lip posture and strain, position of the teeth supporting soft tissues, and the surgical technique.

Stella *et al.* (1989) suggested that the mass of soft tissue content in thick lips assisted in absorbing a larger amount of maxillary advancement, helped by the effect of “dead space” especially in maxillary retrognathic patients where usually an air pocket exists between the maxillary dentoalveolar structures and upper lip labial mucosa.

Burstone (1967) emphasised the effect of the interlabial gap, which is described as the space between upper and lower vermilions at rest, stating that the effect of surgery on the lips was greater where the preoperative interlabial gap was wider. This is closely related to the attempt to produce an oral seal. Patients seeking the help of orthognathic surgery with Class II and III skeletal relationships may have incompetent lips and may tend to compensate for their skeletal deformity creating a pseudo lip seal (Lines and Steinhauser, 1974). When the skeletal deformity is corrected, the relocation of the lip does not need a forced lip seal, and may result with greater change in the posture and size of the lips (Mommaerts and Marxer, 1987).

The surgical technique is another important factor in the postoperative lip posture, including the vermilion width. For example the incision for a LeFort I osteotomy is known to shorten the lip with a loss of vermilion (Ingersoll *et al.*, 1982).

The inability to locate the inner surface of the lower lip accurately may add up on the results of the surgery in the postoperative period. The position of the upper incisors to the lower lip has significant influence on posture of the lips indirectly (Albrechtsen and Larson, 1997), which can be altered with orthognathic surgery (Figure 6.6).

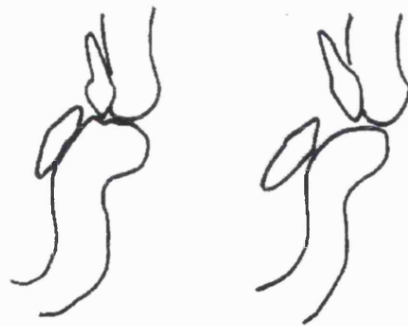


Figure 6.6- The interference of the upper incisors to the location of lower lip.

6.6 Conclusion

- The increase in the lip vermilion width was significant and predictable in upper lips of Class III patients.
- The change was more significant in lips with a bivermilion width (upper vermilion width + lower vermilion width) narrower than 15 mm for Class III patients. Broadness of the lips was found to be an important factor.
- Upper lip vermilion width was affected significantly whereas the lower lip vermilion width was not.
- Other indirect factors affecting the vermilion width of lips after orthognathic surgery included presence of increased interlabial gap prior to surgery, strain of lips due to incompetence and change in the position of incisors by orthodontic treatment.

CHAPTER VII

THE ROLE OF TRAINING ELASTICS AND THE OCCLUSAL WAFER AFTER ORTHOGNATHIC SURGERY

7.1 Introduction

In addition to clinically planned and surgically executed skeletal changes that were expected to correct the facial deformity, orthognathic surgery has other biological sequels. These include muscle atrophy, denervation, scar contraction at surgical site, decreased muscle mass, myofibrosis and morphological alterations of the condyle. During the postoperative period the clinician and the patient may also face some complications due to decreased muscle extensibility and strength, hypomobility, increased fatigability, internal derangement of the TMJ and alterations to the efficiency and the length of masticatory muscles.

With the introduction of bone plates and screws and the elimination of prolonged intermaxillary fixation, the probability of these clinical squeals is decreased. Nevertheless a rehabilitation protocol is important for patients after orthognathic surgery to regain neuromuscular function and reduce the discomfort of any undesired consequence. This rehabilitation protocol apart from strict oral hygiene usually involves the use of:

- a. The occlusal wafer
- b. Training elastics
- c. Range-of-motion exercises
- d. Therapeutic devices (which may be required in patients unresponsive to initial stages of the protocol.)

Osteotomy wafers (Figure 7.1) are used in orthognathic surgery as an intermediate guide for repositioning the mobilised maxilla relative to the intact

mandible, and as an aid to achieving and maintaining the planned final occlusion (Irving *et al.*, 1984). Bimaxillary cases principally require an intermediate wafer, which relates the mobilised maxilla during temporary intermaxillary fixation to the unchanged mandible. This is helpful in stabilising the maxilla whilst it is plated into its definitive position. The final wafer relates the osteotomised mandible to the fixed maxilla, both during the insertion of bicortical screws, and when the occlusion is not sufficiently stable for temporary or permanent fixation. A third role is the establishment of postoperative proprioception. After rigid fixation of the mandible, the wafer may be wired to the maxilla, or less frequently to the mandible, to provide postoperative proprioceptive guidance for up to 2 weeks. The wafer may thus help the patient to occlude into the planned occlusion, with or without the help of elastics, by overriding the patient's preoperative proprioceptive drive (Bamber and Harris, 1995). This combination may also help to eliminate the difference between the anaesthetized centric relation and active centric occlusion in addition to the overcorrection in the immediate postoperative period (Bamber *et al.*, 1999). But there is no controlled study reported in the literature assessing effective contribution of occlusal wafers and training elastics in postoperative rehabilitation.

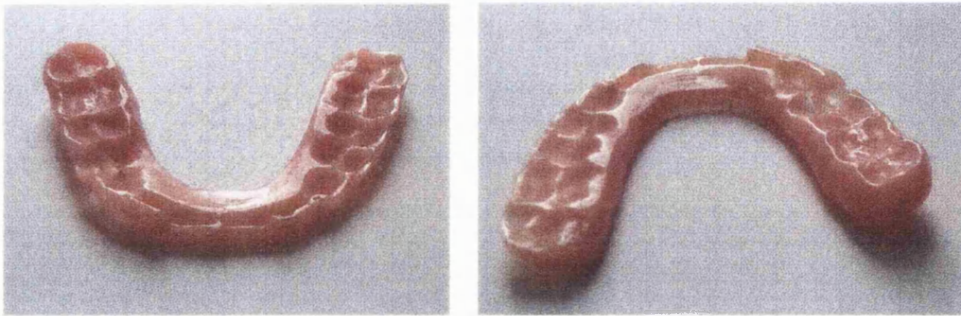


Figure 7.1- An occlusal wafer.

Orthodontists commonly use training elastics postoperatively to control the occlusion and facilitate direct closure and maximum interdigitation of the teeth.

There are very few studies about the role of occlusal wafers and the rationale of the application of training elastics. Lindorf and Steinhauser (1978) describing their technique for bimaxillary procedures stated that the use of intermediate and final wafers permitted the precise surgical achievement of the correction of jaw deformities. Ripley *et al.* (1982) developed a two-piece composite wafer that served as an intermediate and a final wafer in one for bimaxillary procedures. They suggested this allowed a rapid progression from maxillary stabilisation to mandibular surgery as it eliminated the exchange of wafers. They also thought the lugs were good application points for skeletal suspension. They claimed the stability offered by this wafer minimised the necessity for applying intraosseous wires. The same year, Ellis (1982) suggested another alternative modification for wafer design similar to the one introduced by Ripley *et al.* (1982). He claimed the same advantages as Ripley for his modification.

Jacobs and Sinclair (1983) focused on the use of orthodontic mechanics by elastics postoperatively after removal of the wafer but did not mention their use during the time the wafer was in, but that could be because their patients underwent intermaxillary fixation.

In the beginning of the rigid fixation of bony segments, the role of wafers was not only limited to be a simple interocclusal wafer to provide stability during fixation and to accommodate limited jaw function with minimal occlusal interference. Fridrich and Williamson (1989) modified the wafers by increasing their thickness in order to avoid breakage during function, whereas Schwestka *et al.* (1990) introduced the 'sandwich splint' to improve the reproduction of pre and postoperative vertical dimensions from model surgery to actual operation. Quick release wafers were introduced to allow the reduction of operating time and precise tooth positioning with postoperative orthodontics (Seward and Foreman, 1972; Lee, 1991). Block and Hoffman (1987) developed a removable wafer to improve patients' postoperative oral hygiene.

Chemello *et al.* (1994) in their study examining the long-term stability of orthognathic surgery procedures stated that the removal of the wafer in the postoperative period causing the autorotation of the mandible superiorly influenced the change of vertical height after the operation.

Bamber and Harris (1995) evaluated the effects of wafer thickness on the postoperative result. They showed, contrary to expectations, that there was

no advantage in using the thin and fragile wafer, and in major vertical moves the thicker wafer was more accurate. They also suggested overcorrection of the anteroposterior position to anticipate musculoskeletal relapse inducing forces, and use of immediate postoperative training elastics and the final wafer for 2 weeks to overcome the difference between the anaesthetised centric relation and active centric occlusion by 'proprioceptive' training.

7.2 Aim

The overall aim of this study was to investigate the role of the occlusal wafer and training elastics in the postoperative period of orthognathic surgery.

7.3 Patients and methods

One hundred and eleven patients undergoing orthognathic surgery consented for this study but patients whom the orthodontist thought needed the training elastics for the best outcome of their treatment in the postoperative period but randomly included in either group B or C were excluded from the study later (n=11). The remaining 100 patients were randomised into three groups for contrasting wafer and training elastic application during the 2 weeks following the surgical procedure. These randomisation groups were;

1. Group A: Patients to wear the final occlusal wafer and training elastics for 2 postoperative weeks.
2. Group B: Patients to wear the final occlusal wafer but without training elastics for 2 postoperative weeks.
3. Group C: Patients to wear neither a final occlusal wafer nor training elastics for the same period postoperatively.

The patients included are summarised in Table 7.1.

	Class II	Class III	n=100		
Group A	12	21	F	23	33
			M	10	
Group B	17	16	F	21	33
			M	12	
Group C	17	17	F	20	34
			M	14	
Total	46	54	100		

Table 7.1- The summary of patients included in the trial

Intermediate wafers were used for all patients. Final wafers were used to position the jaws in the final set-up but was removed before extubation for patients in Group C. Training elastics were applied to all patients in Group A and were kept for 2 weeks following the surgical procedure. Likewise, no training elastics were applied to patients of Groups B and C. They were applied after the 2-week period for those who needed the guidance applied by the forces of these elastics. Patients whom the orthodontist thought needed the training elastics for the best outcome of their treatment in the postoperative period but randomly included in either group B or C were excluded from the study (n=11). The final number of patients included in the randomisation was 100.

In order to evaluate the role of occlusal wafers and training elastics, overjet and overbite measurements and observations of the occlusion were done twice before the surgical procedure, 3 weeks, and one day before the admission to the ward. Postoperatively, the overjet measurements were

recorded the day the patient was discharged from the ward (T1), the day the wafer and training elastics were removed (T2) (or the end of 2nd postoperative week for patients who were not wearing them, i.e. patients in randomisation Group C), and six months after the surgical procedure (T3). SPSS statistical software package (SPSS for Windows, Release 10.0.5, Standard Version, © SPSS Inc. 1989-1999, 444 N. Michigan Ave, Chicago, Illinois 60 611) was used for the statistical analysis. In order to allow easy reach and to avoid interference for the accuracy of the measurement of overjet, the wafer was cut away in the central incisor region, exposing the central incisors for clinical measurements and observations (Figure 7.1). The observations included the ability to bite into the indentation of the wafer, presence of anterior or posterior open-bites, and possible external factors avoiding a successful bite, e.g. pain, infection or problems with the fitting of the wafer.

7.3 Results

The mean preoperative and postoperative overjet measurements taken at T1, T2 and T3 for Class II and Class III subjects in Groups A, B, and C are shown in Figure 7.2.

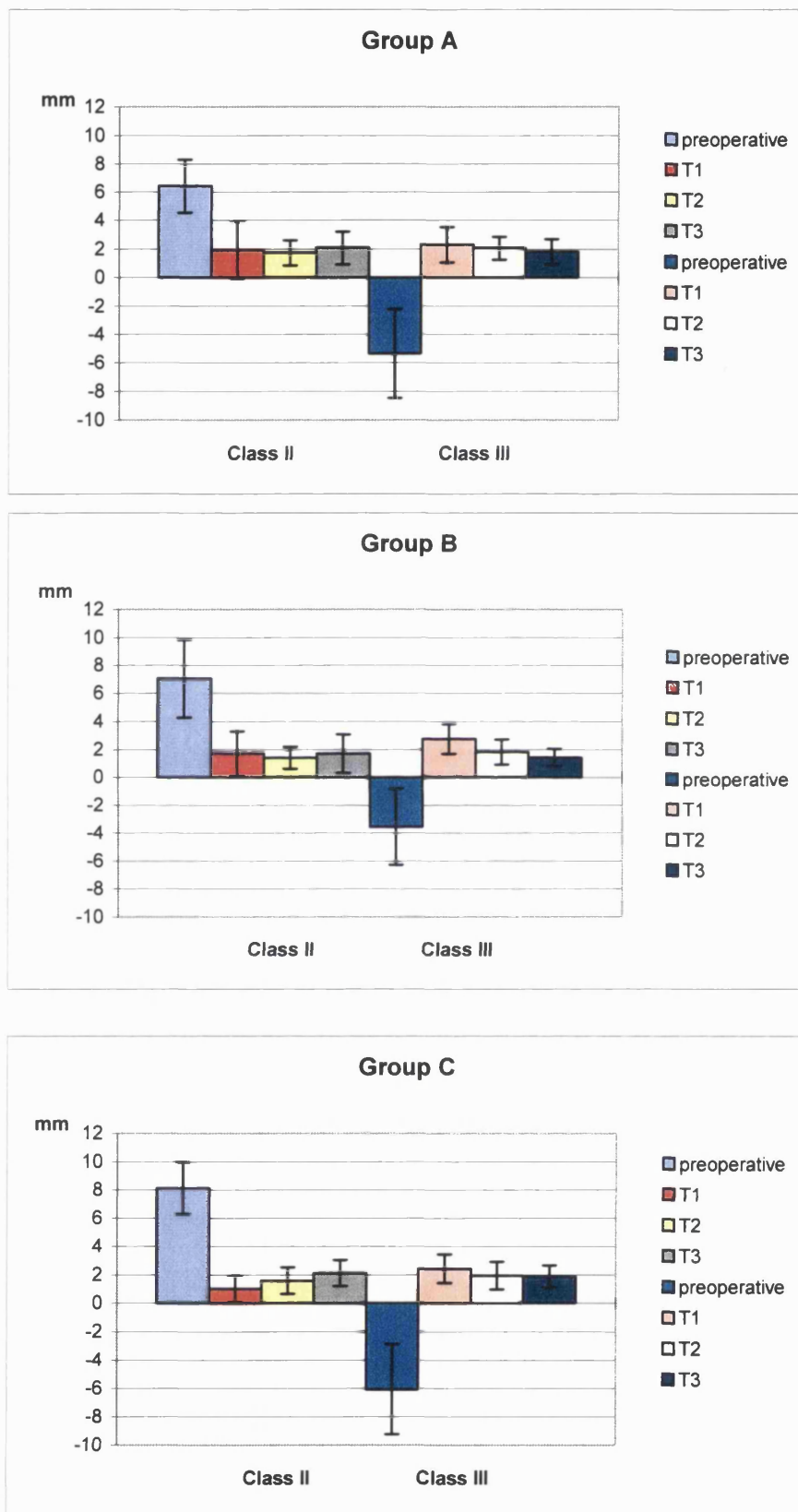


Figure 7.2- The mean and SD preoperative and postoperative overjet measurements (mm) taken at T1, T2 and T3 for Class II and Class III subjects in Groups A (wafer and elastics), B (wafer), and C (nil).

In the first 2 postoperative weeks 64% of the subjects' overjet readings showed a change less than or equal to 2 millimetres. Thirty percent were Class II and 34% Class III preoperatively. Twenty five percent of the subjects didn't show any change in this period. Ten percent of these with no change in their overjet were in Group A, 8% in Group B and 7% in Group C. Most of the subjects who showed more than 2-millimetre change of overjet postoperatively, which were 11% of the total, were in Group B, i.e. were wearing just wafers but no elastics. The postoperative change in overjet between T1 and T2 in three randomisation groups are summarised in Table 7.2 and Figure 7.3.

%	Group A		Group B		Group C		Total
	Class II	Class III	Class II	Class III	Class II	Class III	
No change	33	29	29	19	12	29	25
≤ 2 mm	59	61	59	62	76	65	64
> 2 mm	8	10	12	19	12	6	11

Table 7.2- The postoperative change in overjet between T1 and T2 in three randomisation groups.

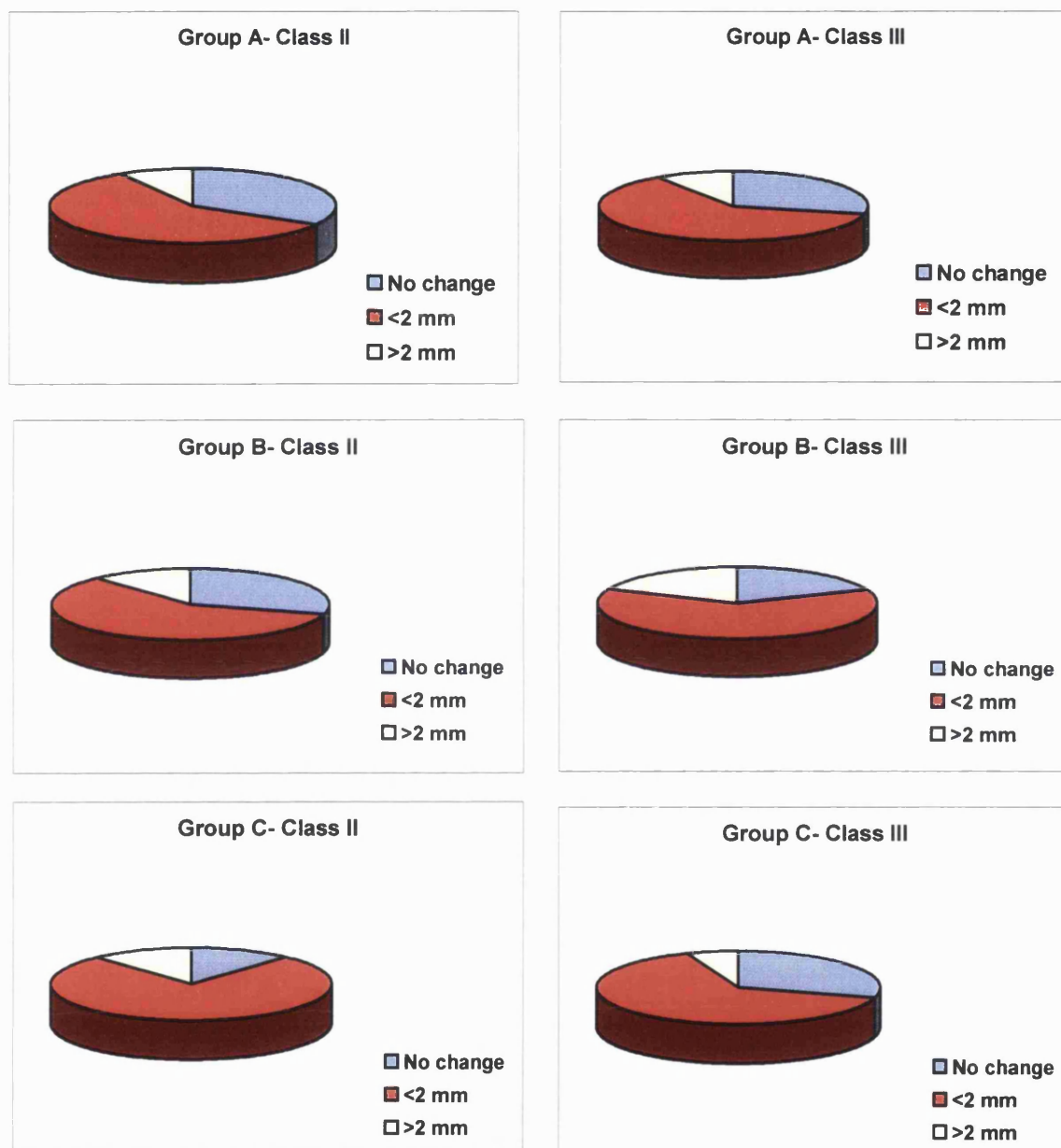


Figure 7.3- The postoperative changes in overjet between T1 and T2 in three randomisation groups.

The mean change in overjet in the 6-month postoperative period was highest in Group B for both Class II and III subjects. The Class II subjects in Group C followed this closely. Group A and Class III subjects in Group C displayed the least change in their overjet postoperatively.

The change in overjet was more in the first 2 weeks (T1-T2) compared to the following 5 months (T2-T3) for all groups. In all groups, this difference was greater among Class III subjects, more prominent in Group A. These results are summarised in Table 7.3 and Figure 7.4.

mm	Group A	
	Class II	Class III
T1-T2	0.93±1.16	1.00±0.95
T2-T3	0.50±0.67	0.24±0.44
T1-T3	1.17±1.19	1.14±1.01
	Group B	
	Class II	Class III
T1-T2	1.12±1.27	1.19±0.83
T2-T3	0.59±1.00	0.50±0.63
T1-T3	1.53±1.33	1.44±1.03
	Group C	
	Class II	Class III
T1-T2	1.06±0.75	0.82±0.73
T2-T3	0.53±0.94	0.29±0.47
T1-T3	1.35±0.93	0.88±0.93

Table 7.3- The means $\pm$ standard deviations (mm) of postoperative change of overjet between T1 (just before the patient is discharged from the ward), T2 (2 weeks postoperatively) and T3 (6 months postoperatively)

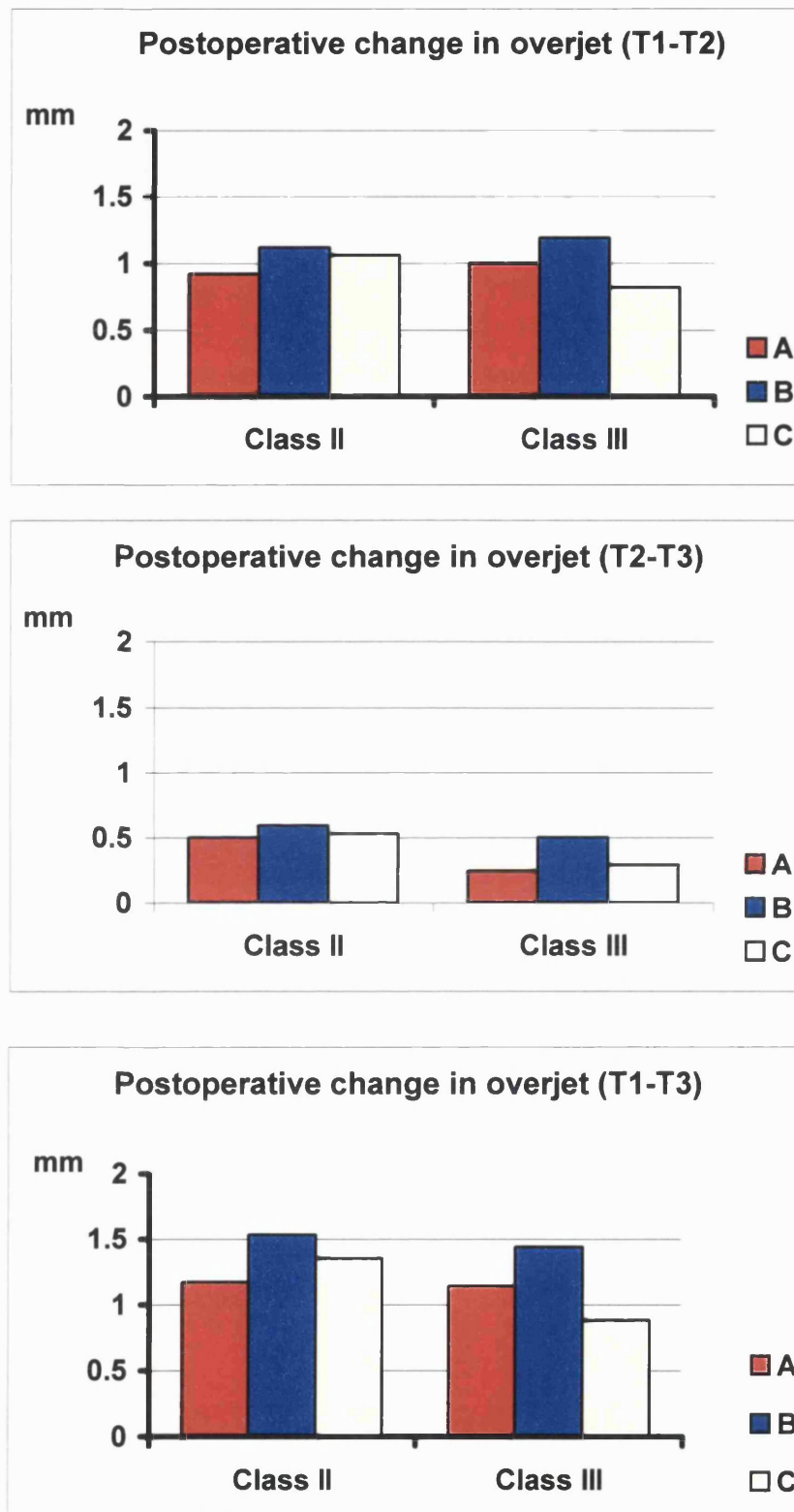


Figure 7.4- The means of postoperative change of overjet between T1 (just before the patient is discharged from the ward), T2 (2 weeks postoperatively) and T3 (6 months postoperatively). a) T1-T2, b) T2-T3, c) T1-T3.

Student t test was performed to compare the means of overjet measurements for each group. The results of these statistical analyses are summarised in Table 7.4.

p	Group A		
	Class II	Class III	All
T1-T2	N.S.	N.S.	N.S.
T2-T3	N.S.	0.02	N.S.
T1-T3	N.S.	N.S.	N.S.
	Group B		
	Class II	Class III	All
T1-T2	N.S.	0.004	0.023
T2-T3	N.S.	N.S.	N.S.
T1-T3	N.S.	0.001	0.050
	Group C		
	Class II	Class III	All
T1-T2	N.S.	N.S.	N.S.
T2-T3	0.034	N.S.	N.S.
T1-T3	0.002	N.S.	N.S.

Table 7.4- The p values after comparing means of overjet measurements taken at different times (T1, T2, T3) for all groups (N.S.= Not significant)

These values showed that the difference between the mean overjet measurements of Class III cases in Group B while they were wearing the occlusal wafer (T1-T2) and Class II cases in Group C after 2 postoperative weeks (T2-T3) were statistically significant. The difference between the mean overjet measurements of Class III members of Group A between T2 and T3 was also statistically significant.

When means of overjet measurements taken at T1, T2 and T3 were compared between Groups A, B and C, the difference was statistically insignificant.

7.4 Discussion

The mean change in overjet in the six-month postoperative period (T1-T3) was highest in Group B, which was closely followed by Class II subjects in Group C. Group A and Class III subjects of Group C displayed the least change of overjet postoperatively (Figure 7.4). When statistical tests were applied, there was a significant change of overjet for Class III subjects of Group B within the first 2 postoperative weeks (T1-T2) but not for the following 5 months of the postoperative period (T2-T3). The same significance of change was found for the same group in the whole six-month period (T1-T3). Although Class II subjects did not show a statistically significant change of overjet, when the whole Group B was evaluated statistically, significant change was found for T1-T2 and T1-T3 (Table 7.4).

The change of overjet was significant mainly amongst Class III subjects in Group B, whereas Class II subjects remained more stable, 29% showing no change and 59% less than 2-millimetre change during the first 4 weeks postoperatively (Table 7.2). The highest percentage of cases that did not experience any change in their overjet during the same period was in Group A. Also only a low percentage of the cases in Group A (8% for Class II, 10% for Class III) showed more than 2-millimetre change. These were not considered to be extraordinary findings since this group received the guidance of both occlusal wafer and training elastics. On the other hand, percentage of Class II subjects in Group B and Class III subjects in Group C showing no change in their overjet measurements were close to the percentage in Group A (Table 7.2). In the freely floating Group C, 76% of Class II cases and 65% of Class III cases showed less than 2-millimetre change, which was contrary to expectation (Table 7.2) (Figure 7.3). This was an observation many clinicians may find favourable since the first few weeks postoperatively is the period most relapse is expected to take place and in this group where no guidance of occlusal wafers and training elastics were present, majority of the subjects showed a magnitude of change in overjet which would not grossly influence the expected postoperative result.

The cases that were included in this study were overcorrected. Preoperatively Class II cases were overcorrected to an edge-to-edge incisor relationship to allow for the natural immediate relapse, and to eliminate the difference between the anaesthetised centric relation and active conscious upright centric occlusion. One would expect the immediate postoperative overjet

readings (T1) should be close to zero for those edge-to-edge cases. The findings of this study support this for the mean T1 overjet measurements of Group C Class II patients. In Groups A and B, the mean immediate postoperative overjet measurements (T1) are approximately 2 millimetres (Figure 7.2). Although occlusal wafers worn by subjects in Groups A and B were expected to offer additional guidance into this overcorrected occlusion, the subjects often could not bite into the occlusal wafer according to the measurements and clinical observations. This finding makes it worth questioning the guidance role of the occlusal wafer. The similarity of T1 readings of Groups A and B may also suggest the presence of training elastics do not make a great change at this early stage.

Another important clinical observation was the relief on patients' face when the occlusal wafer was removed at the end of 2 weeks. Not surprisingly, patients found it more comfortable to occlude after the removal of occlusal wafers. This can be seen as a decrease in the T2 overjet measurements of Class II cases of Groups A and B, which are taken after the removal of occlusal wafers (Figure 7.2). The slight increase in the T3 overjet measurements of the same cases, which are taken 6 months postoperatively, suggests the settling of occlusion during this period.

Despite these observed short-term variations, the overall result of all cases in three groups had similar successful outcome. This is also supported by the statistically insignificant difference between the mean overjet measurements of Groups A, B and C taken at T1, T2 and T3. These similarities suggest that

the use of occlusal wafers and training elastics did not make a significant difference to the final outcome, which was satisfactory in all three groups, including Group C. The patients in Groups A and B found the occlusal wafers quite difficult to cope with and very discomforting especially during a period when patients are suffering from other discomforting factors. They also pointed out to the difficulties the wafers and elastics introduced while trying to maintain a good oral hygiene, which is very important in the early postoperative period when the oral mucosa is healing and can be prone to infection. The theoretical value of providing proprioceptive guidance is probably more comforting for the surgeon than the patient. However, it does provide a visible means of clinical assessment.

7.5 Conclusion

According to the findings of this investigation the use of occlusal wafers and training elastics as a routine do not lead to a significant difference in the postoperative occlusion. On the contrary, occlusal wafers may interfere in patients' adaptation to their new occlusion and may add extra discomfort rather than offering guidance in the early postoperative period.

On the other hand, postoperative rehabilitation is known to be crucial for patients to regain neuromuscular function and reduce the discomfort so postoperative range-of-motion exercises gain more importance to reprogram muscles to the new occlusion enhancing postoperative proprioception.

The results of this study are based on overjet measurements only. However, a more thorough investigation is suggested to determine the role of occlusal wafers and training elastics and to the follow-up the occlusion in the early postoperative period with possible use of 3-dimensional intraoral imaging. The difficulty that the investigators faced was the lack of a 3-dimensional imaging system that would take detailed records of the occlusion, discarding the obscurity that is caused by the wafer.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

8.1 Summary and conclusions

Facial appearance has a great impact on one's self-esteem, behaviour, and social and professional interactions. Many may feel uncomfortable by the fact that physical attractiveness makes difference to one's quality of life. Therefore, people who are not happy with their facial appearance often seek help of surgical procedures for the correction of their disfigurement.

The diagnosis of facial deformity, treatment planning, surgical prediction and the evaluation of the outcome of orthognathic surgery are just as challenging as the actual surgical procedure.

This study programme;

- a) evaluated the concept of facial aesthetics; reviewing the differences between three ethnic groups, i.e. Caucasians, Afro-Caribbeans, and Orientals using a multiracial panel.
- b) sought solutions to the questions that arise before and after orthognathic surgical correction of facial disharmony, using a three-dimensional imaging tool, the Optical Surface Scanner.
- c) used a novel morphometric analysis, Thin-Plate Splines, for the accurate quantitative evaluation and better graphical visualisation of the facial soft tissue changes.
- d) investigated postoperative rehabilitation with the occlusal wafer and training elastics to restore proprioception. Also observed the effect of overcorrection on the final occlusion.

8.1.1 Review of ethnic facial aesthetics

- a) The evaluation of the facial soft tissue components showed that although the multi-dimensional judgment of attractiveness may differ from one individual to another, the concept of facial beauty was to a great extent shared by all.
- b) The normal ranges for facial symmetry, alar base width and the vermilion border ratio were found to be strong markers of facial beauty.
- c) In most beautiful faces, the chin coincided with the facial plane. This is a vertical line drawn from glabella perpendicular to the Frankfort plane. Given this position of the chin, the mid-face was anterior to the facial plane. The homogenised conformity of the world culture was reflected by the panel in this study, which although formed of three independent ethnic groups, appeared to share a common basis for the assessment of facial beauty. The Caucasian facial features were perceived more familiar, standard, and beautiful, therefore, as the aesthetic norm.

Communication technology, the media, and their availability around the globe provide daily reinforcement of commercially selected facial aesthetics. Peck and Peck (1970) suggested that the more frequently we observed a particular facial pattern, the more likely we perceived it as “correct”. The presentation of Caucasoid facial patterns in the media determines people's notions of beauty.

8.1.2 Validation of the optical surface scanner

Although the assessment of facial aesthetics and diagnosis of facial deformity must be mainly based on experienced clinical observation, the aid of an improved imaging tool with the paramount advantage of capturing the three-dimensional details of the face accurately is crucial to support the clinical diagnosis and help the treatment plan for the correction of the deformity. Conventionally two-dimensional radiological and photographic techniques have been used for this purpose and have often proved to be inadequate. The optical surface scanning system developed by Linney and his co-workers (Linney *et al.*, 1993) has been used regularly over the last decade for recording facial soft tissues three-dimensionally. With the anticipation that the optical surface scanner could be a reliable tool for the preoperative assessment, diagnosis, treatment plan, prediction and postoperative evaluation of the outcomes of orthognathic surgery, this programme of study aimed to validate its application.

- a) The optical surface scanner was compared to conventional cephalography - there were no significant geometrical differences between these methods.
- b) However, the optical surface scanner was a reliable tool for three-dimensional assessment, and diagnosis of the facial deformity, and should replace the cephalograph for soft tissue analysis for the following reasons:

- i. Optical surface scans are substantially easier to analyse than radiographs, and can be viewed from any preferred angle.
 - ii. The surface scan is not subject to magnification, and therefore gives precise measurements enabling superimposition and the determination of the changes following surgery.
 - iii. Linear measurements of the optical surface scanner are identical with clinical measurements.
 - iv. As a non-contact procedure, the system avoids any distortion of the soft tissue surfaces being measured.
 - v. This scanner is free of harmful radiation, so repeated investigations for long-term follow-up are without potential morbidity.
- c) The disadvantages of the scanning procedure are:
- i. The need for patients to keep a constant position and relaxed facial posture during the recording period of 10 seconds.
 - ii. The standardisation of head inclination is essential to capture all the required landmarks. For instance, head inclination could obscure subnasal and alar measurements. Therefore, this study tested and showed that these errors could be eliminated by using a spirit level to set the patient's Frankfort plane horizontal against a headrest, together with a narrow vertical beam of laser light initially on the facial midline to achieve the optimum head/facial posture. The use of a headrest as a support stabilised the head position avoiding movement.

8.1.3 The evaluation of facial soft tissue changes after orthognathic surgery

In orthognathic surgery, as in every surgical intervention, surgical planning based on a reliable prediction of outcome depends on the data from accurate and reproducible postoperative measurements. This study programme showed;

- a) the optical surface scanner could capture soft tissue changes and measure the linear, area and volumetric differences after the surgical correction of Class II and III facial deformities. The facility of these measurements is eminently suitable for clinical practice.
- b) Thin-Plate Splines proved to be a highly accurate morphometric tool, which showed the direction and degree of vector movement of any chosen landmark. Its invaluable application was that of an accurate complimentary research tool.
- c) Many regions of the face, which had not been previously investigated, e.g. paranasal regions, supracomissural and subcomissural regions (angles of the mouth) were accessible for measurement using the optical surface scanner. This enabled the lips to be investigated in detail, differentiating the responses of the upper and the lower vermilion borders.
- d) The medial region of the upper lip was found to follow closely the movements of the underlying hard tissue, presumably due to the muscle attachments into and lateral to the anterior nasal spine. An additional determining factor is the semi-circular contour of the

underlying dentoalveolar surface. This would explain the limited movement of the more lateral supracomissural and subcomissural regions. An additional important influence on the labial contour is the postoperative facilitation to establish a comfortable lip seal. Hence, the optical surface scans showed differential maxillary soft tissue advancement. It is of interest to note that this advancement did not alter the nasolabial angle, which was presumably maintained by the forward and upward displacement of the collumella by the septum. This was seen in the projection of the nasal tip, which moved 20-35% of the maxillary advancement.

- e) Changes in the chin were studied particularly in relation to the labiomentall groove and the lower lip. The magnitude of projection of the mandibular movement to the soft tissues of the lower facial third was found to be greater. As has been established, the pogonion moves as a 1:1 ratio compared to the underlying skeletal change. However, the labiomentall groove moved 80-90% of the skeletal change reflecting the opening of the groove with advancement. The lower lips showed 60-70% conformity of movement of the mandible both with advancements and setbacks. Eversion of the lip is a movement by which the lip is rotated outwards revealing more vermilion. The three-dimensional surface scans confirmed the eversion of the lower lip with a mandibular setback. This was seen with the Thin-Plate Splines analysis clearly showing the forward movement of stomion inferius and simultaneous backward movement of labrale inferius exposing increased lower vermilion. With advancement, there

was a corresponding inversion of the lower lip. However, there was not a significant Thin-Plate Splines change in these landmarks in the mandibular advancement of the Class II cases, i.e. minimal change in the exposed vermillion. With maxillary advancement, the exposed upper vermillion increased significantly. Thin-Plate Splines analysis showed labrale inferius moving forwards with simultaneous downward movement of stomion superius.

- f) As with the maxilla, the subcomissural regions (the areas below the angle of the mouth) showed decreased changes again presumably due to the lack of influence of the underlying mandible due to its contour.

Optical surface scans of the soft tissues in conjunction with cephalometric analysis are routinely used in our unit for preoperative surgical assessment, planning and postoperative review of orthognathic surgery, and their use is very likely to increase with wider availability of various surface scanners in the market.

8.1.4 The role of training elastics and the occlusal wafer after orthognathic surgery

In addition to clinically observed changes that were planned to correct the facial deformity, orthognathic surgery has other biological consequences, including decreased muscle extensibility and strength, hypomobility, and increased fatigability. A rehabilitation protocol involving the use of an occlusal wafer, training elastics with exercises is thought to be important for patients after orthognathic surgery to regain neuromuscular function, reduce the discomfort of any undesired consequence, guide the patient into the new occlusion facilitating direct closure and maximum interdigitation of the teeth, and help to reprogram the muscles, enhancing postoperative proprioception. The last section of this programme investigated the role of the occlusal wafer and training elastics in the first two postoperative weeks by their randomised application to three groups.

- a) The findings of this investigation indicated that routine use of occlusal wafers and training elastics did not lead to a significant difference in the postoperative occlusion. On the contrary, many patients reported additional discomfort caused by occlusal wafers. Hence, the theoretical value of providing proprioceptive guidance was concluded to be more comforting for the surgeon and the orthodontist than the patient. However, it is believed to provide a visible means of clinical assessment.
- b) This part of the study also confirmed that despite routine overcorrection, i.e. a planned edge-to-edge wafer occlusion for

mandibular advancement and a Class II / division 1 wafer occlusion for mandibular setbacks, all cases were observed to achieve a final Class I incisor relationship. We are unsure whether this is a result of neuromuscular and facial restraint or true proprioceptive adaptation determined by the occlusion.

In summary, this programme evaluated the concept of facial aesthetics in relation to the perception of beauty by individuals and sought solutions to the questions that arise for the correction of facial disfigurement with orthognathic surgery by using a three-dimensional imaging tool, the optical surface scanner with the help of a novel morphometric analysis, the thin-plate splines, for accurate evaluation of the problem and better visualisation of facial soft tissue changes with graphic and quantitative presentations which helped the explanations of the surgical outcomes, and investigated the devices used for early postoperative rehabilitation, the occlusal wafer and training elastics for their role in proprioception.

It is anticipated that the results of this work will contribute significantly in diagnosis of facial deformity, planning of orthognathic surgery and its outcome.

8.2 Suggestions for further research

This programme of study used the optical surface scanner as a reliable 3D imaging tool. The developments in 3D imaging techniques will continue with the advancement of technology and it would be advisable to test and use these new tools as they become available.

This study investigated the role of occlusal wafers and training elastics based on clinical overjet measurements. However, a more thorough investigation, possibly using a three-dimensional intraoral imaging tool is suggested. The difficulty faced in this study was the lack of such a system, which would take detailed records of the occlusion obscured by the occlusal wafer itself.

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APPENDICES

A.1 Information sheet and consent form for the patients participating in the study

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Fax: 0171 915 1259
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EVALUATION OF FACIAL SOFT TISSUE CHANGES

INFORMATION SHEET

Please read this information carefully and ask if you don't understand or would like more information.

The type of surgery you are considering, is known as "Orthognathic Surgery". Its purpose is to improve:

- a) the alignment of your teeth, the way they meet
- b) the relationship between your upper and lower jaws
- c) your facial appearance.

For surgery, each patient's operation has to be planned individually, in order to determine, which method of treatment is best for you. A number of investigations need to be carried out, which include, a full examination of your face and mouth, special x-rays of your face and jaws, impressions to make casts of your teeth and photographs of your face and mouth.

Using this information, a team of orthodontists and surgeons will decide the treatment options for you.

The assessment and investigations will continue after your operation, as a part of the follow-up period, to see the result of the operation and determine whether it was to your and the surgical team's satisfaction.

During this period, a research will be taking place, trying to find out the affects of this surgery, mainly performed on facial bones, on your facial features as you see them in your daily life. If you volunteer to participate, it will involve some measurements with a conventional ruler, on your face, routine clinical photographs and a “laser scan”. A laser scan is not much different than a conventional photograph, but will give us the advantage of evaluating your face in 3D on a computer screen. It is not like an x-ray, i.e. does not have radiation.

We will also be trying different treatment options on you. You may be wearing a wafer, which is a piece of plastic with slots to accommodate the teeth on the opposite jaw, and elastics. Both of these are routinely used for guiding you into your “new bite” after the operation. If you wear either or both of them, they will help you in that way, but if you don’t, your own teeth will find your new bite. These evaluations will take place during your routine visits to our clinics and will not require any additional visits or any significant loss of time for you.

We will be very pleased if you would participate, during your treatment, and the results of this investigation will help us a lot to evaluate whether we achieved our goals in your treatment, which will be beneficial to future patients, undergoing same type of surgery. You will be kept informed of all relevant facts as the research progresses.

You have no obligation to participate and may withdraw at any time without giving a reason, and this will not interfere at all with the progress of your treatment.

Mr. M. Soncul

Dr. M.A. Bamber

Professor M. Harris

Department of Oral and Maxillofacial Surgery
Professor Malcolm Harris Tel 0171 915 1056
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EVALUATION OF FACIAL SOFT TISSUE CHANGES

CONSENT FORM

Please read this form carefully and ask if you don't understand or would like more information.

Form of consent to participate in research associated with clinical treatment.

CONSENT BY THE PATIENT

I understand that this study is trying to assess the accuracy and stability of osteotomy operations and I have been asked to help by allowing to take some clinical pre and postoperative records, when I am in the hospital and also in follow-up appointments. The nature of the study and my involvement has been explained to me.

I.....(full name)

of.....(address)

hereby fully and freely consent to participate in the above research project.

I understand and acknowledge that the investigation is designed to promote medical knowledge.

I understand that I may withdraw my consent at any stage during the investigation. I acknowledge the purpose of the investigation and accept any risks involved from the procedures (if any). The nature and purpose of such procedures has been detailed to me in an information sheet and has been explained to me by:

Dr/Mr/Ms.....

Signed.....Date...../...../.....

DECLARATION BY THE INVESTIGATOR

I confirm that I have provided an information sheet and explained the nature and effect of the procedures to the volunteer and that his/her consent has been given freely and voluntarily.

Signed.....

Name.....

Department of Oral and Maxillofacial Surgery
Professor Malcolm Harris Tel 0171 915 1056
Dr Anwar Bamber Tel 0171 915 1226
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e-mail: A.Bamber@eastman.ucl.ac.uk

EVALUATION OF FACIAL SOFT TISSUE CHANGES

CONSENT FORM

Please read this form carefully and ask if you don't understand or would like more information.

Form of consent by healthy volunteer to participate in research associated with clinical treatment.

CONSENT BY THE VOLUNTEER

I understand that this study is trying to assess the accuracy and stability of osteotomy operations and I have been asked to help by allowing to take some clinical records as a healthy volunteer.

The nature of the study and my involvement has been explained to me.

I.....(full name)

of.....(address)

hereby fully and freely consent to participate in the above research project about *the evaluation of facial soft tissue changes*.

I understand and acknowledge that the investigation is designed to promote medical knowledge.

I understand that I may withdraw my consent at any stage in the investigation. I acknowledge the purpose of the investigation and accept any risks involved from the procedures (if any). The nature and purpose of such procedures has been detailed to me in an information sheet and has been explained to me by:

Dr/Mr/Ms.....

Signed.....Date...../...../.....

DECLARATION BY THE INVESTIGATOR

I confirm that I have provided an information sheet and explained the nature and effect of the procedures to the volunteer and that his/her consent has been given freely and voluntarily.

Signed.....

Name.....

A.2 Data for Chapter 3

Ranking of subjects

Ranking of Subjects by Panels											
Sub no	gender	eo	layca	laybl	layor	surca	surbl	suror	ortca	ortbl	ortor
41	1	1	2.50	1.00	3.00	2.00	3.00	1.00	4.00	2.00	3.00
42	1	1	5.00	2.00	2.00	4.00	5.00	3.00	1.00	3.00	2.00
43	1	1	4.00	4.00	5.00	3.00	2.00	6.00	3.00	5.00	4.00
44	1	1	8.00	8.00	6.00	6.00	7.00	4.00	8.00	8.00	7.00
45	1	1	2.50	6.00	4.00	5.00	1.00	5.00	6.00	4.00	5.00
46	1	1	6.00	5.00	7.00	7.00	8.00	8.00	5.00	6.00	6.00
47	1	1	1.00	3.00	1.00	1.00	1.00	2.00	2.00	1.00	1.00
48	1	1	7.00	7.00	8.00	8.00	8.00	7.00	7.00	7.00	8.00
17	1	2	6.00	6.00	5.00	4.00	6.00	6.00	6.00	8.00	6.00
18	1	2	2.00	1.00	1.00	1.00	1.00	4.00	1.00	3.00	1.00
19	1	2	1.00	4.00	3.00	6.00	2.00	3.00	3.00	1.00	2.00
20	1	2	4.00	5.00	6.00	5.00	5.00	1.00	5.00	5.00	5.00
21	1	2	7.00	7.00	7.00	7.00	8.00	8.00	8.00	6.00	7.00
22	1	2	3.00	3.00	2.00	2.00	3.00	5.00	4.00	2.00	3.00
23	1	2	8.00	8.00	8.00	8.00	7.00	7.00	7.00	7.00	8.00
24	1	2	5.00	2.00	4.00	3.00	4.00	2.00	2.00	4.00	4.00
9	1	3	5.00	5.00	4.00	3.00	4.00	3.00	2.00	4.00	4.00
10	1	3	1.00	1.00	1.00	1.00	2.00	1.00	1.00	2.00	2.00
11	1	3	3.00	4.00	6.00	7.00	3.00	4.00	5.00	6.00	6.00
12	1	3	7.00	6.00	5.00	5.00	7.00	6.00	6.00	5.00	5.00
13	1	3	2.00	2.00	2.00	2.00	1.00	2.00	3.00	1.00	1.00
14	1	3	4.00	3.00	3.00	4.00	5.00	5.00	4.00	3.00	3.00
15	1	3	6.00	7.00	7.00	6.00	6.00	7.00	7.00	7.00	7.00

Sub no	gender	eo	layca	laybl	layor	surca	surbl	suror	ortca	ortbl	ortor
16	1	3	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
33	2	1	7.00	4.00	6.00	5.00	4.00	6.00	5.00	4.00	6.00
34	2	1	1.50	2.00	2.00	2.00	3.00	1.00	2.00	2.00	1.00
35	2	1	5.00	7.00	5.00	7.00	7.00	7.00	7.00	8.00	7.00
36	2	1	4.00	5.00	4.00	6.00	6.00	5.00	4.00	6.00	4.00
37	2	1	6.00	6.00	7.00	3.00	2.00	4.00	6.00	1.00	5.00
38	2	1	1.50	1.00	1.00	1.00	1.00	2.00	1.00	3.00	2.00
39	2	1	8.00	8.00	8.00	8.00	8.00	8.00	8.00	7.00	8.00
40	2	1	3.00	3.00	3.00	4.00	5.00	3.00	3.00	5.00	3.00
25	2	2	3.00	3.00	2.00	3.00	1.50	3.00	3.00	3.00	2.00
26	2	2	5.50	5.00	6.00	5.00	6.00	7.00	5.00	4.00	5.00
27	2	2	5.50	7.00	7.00	7.00	8.00	6.00	6.00	7.00	6.00
28	2	2	1.00	1.00	1.00	1.00	1.00	1.00	1.50	1.00	3.00
29	2	2	8.00	8.00	8.00	8.00	7.00	5.00	8.00	6.00	7.00
30	2	2	4.00	4.00	3.00	4.00	4.00	4.00	4.00	5.00	4.00
31	2	2	2.00	2.00	4.00	2.00	3.00	2.00	1.50	2.00	1.00
32	2	2	7.00	6.00	5.00	6.00	5.00	8.00	7.00	8.00	8.00
1	2	3	6.00	5.00	5.00	5.00	5.00	5.00	6.00	5.00	4.00
2	2	3	4.50	6.00	6.00	3.00	4.00	6.00	2.00	2.00	6.00
3	2	3	8.00	8.00	8.00	8.00	8.00	7.00	8.00	8.00	7.00
4	2	3	4.50	4.00	1.00	4.00	6.00	2.00	5.00	6.00	3.00
5	2	3	1.00	3.00	4.00	6.00	2.00	3.00	3.00	4.00	5.00
6	2	3	2.00	1.00	3.00	2.00	1.00	4.00	1.00	3.00	2.00
7	2	3	3.00	2.00	2.00	1.00	3.00	1.00	4.00	1.00	1.00
8	2	3	7.00	7.00	7.00	7.00	7.00	8.00	7.00	7.00	8.00

Ranking of Subjects by Malaysian Panel										
Sub no	gender	eo	malay1	malay2	malay3	malay4	malay5	malay6	malay7	malay 8
1	2	3	6	4	6	5	6	5	2	6
2	2	3	4	1	2	3	4	1	5	4
3	2	3	8	8	8	8	8	8	8	8
4	2	3	5	6	5	6	2	6	1	5
5	2	3	2	5	3	4	5	3	3	2
6	2	3	3	2	1	2	1	2	6	3
7	2	3	1	3	4	1	3	4	4	1
8	2	3	7	7	7	7	7	7	7	7
9	1	3	2	3	4	4	2	4	3	2
10	1	3	3	1	3	3	3	1	2	3
11	1	3	6	5	5	7	4	5	5	6
12	1	3	5	8	2	5	5	8	4	5
13	1	3	1	2	1	2	1	3	1	1
14	1	3	4	6	7	1	6	2	6	4
15	1	3	7	4	5	6	7	6	7	7
16	1	3	8	7	8	8	8	7	8	8
17	1	2	4	3	8	7	6	6	7	4
18	1	2	2	1	3	3	3	2	1	2
19	1	2	1	2	1	1	2	3	2	1
20	1	2	6	5	5	2	4	4	5	6
21	1	2	7	8	6	6	8	8	6	7
22	1	2	3	6	4	5	5	1	3	3
23	1	2	8	7	7	8	7	7	8	8
24	1	2	5	4	2	4	1	5	4	5
25	2	2	2	2	1	2	2	1	3	2
26	2	2	6	4	7	5	5	8	7	6
27	2	2	5	6	5	4	7	7	4	5

Sub no	gender	eo	malay1	malay2	malay3	malay4	malay5	malay6	malay7	malay 8
28	2	2	1	1	2	1	1	3	1	1
29	2	2	8	7	8	7	6	6	6	8
30	2	2	4	3	3	6	4	4	5	4
31	2	2	3	5	4	3	3	2	2	3
32	2	2	7	8	6	8	8	5	8	7
33	2	1	6	6	4	6	4	4	7	6
34	2	1	1	1	2	2	2	2	2	1
35	2	1	5	7	7	5	7	6	8	5
36	2	1	4	5	5	7	6	3	4	4
37	2	1	7	3	6	4	5	7	3	7
38	2	1	2	2	1	1	3	1	1	2
39	2	1	8	8	8	8	8	8	6	8
40	2	1	3	4	3	3	1	5	5	3
41	1	1	2	2	3	2	1	3	1	2
42	1	1	4	5	5	1	2	1	2	4
43	1	1	3	3	2	4	4	5	4	3
44	1	1	7	6	8	7	7	8	8	7
45	1	1	8	4	6	6	8	7	7	8
46	1	1	5	8	4	8	6	4	6	5
47	1	1	1	1	1	3	3	2	3	1
48	1	1	6	7	7	5	5	6	5	6

Key		
subno	Subject Number	
gender	Gender	1=male / 2=female
eo	Ethnic Origin	1=Caucasian 2= Afro-Caribbean 3=Oriental
layca	Lay Caucasian	
laybl	Lay Afro-Caribbean	
layor	Lay Oriental	
surca	Surgeon Caucasian	
surbl	Surgeon Afro-Caribbean	
suror	Surgeon Oriental	
ortca	Orthodontist Caucasian	
ortbl	Orthodontist Afro-Caribbean	
ortor	Orthodontist Oriental	
malay1,2,...,8	Malaysian Panel Members	

A.3 Data for Chapter 4

A.3.1 Measurements on optical surface scans and cephalographs

Upper Incisor Exposure (mm)							
preoperative					postoperative		
subject	clinical	cephalograph	lasergraph		clinical	cephalograph	lasergraph
1	6	6	4		2	2	1
2	0	1	0		1	1	1
3	3	4	2		4	5	4
4	4	3	3		6	5	5
5	2	2	2		3	4	3
6	10	8	7		4	5	4
7	3	3	3		3	2	2
8	3	4	3		4	5	4
9	3	5	4		6	6	6
10	3	2	3		3	3	3
11	6	4	7		6	6	7
12	4	8	6		2	5	3
13	4	4	5		2	2	2
14	2	2	2		1	0	2
15	6	7	7		6	7	7
16	12	7	8		6	7	6
17	3	3	3		3	2	2
18	2	2	2		1	0	2
19	3	4	3		4	5	4
20	4	4	5		2	2	2
21	2	2	2		1	0	2
22	3	4	4		2	2	3
23	3	3	3		3	2	2
24	6	4	5		3	2	3
25	3	4	3		4	5	4
26	4	4	5		2	2	2
27	2	2	2		1	0	2
28	3	3	3		3	2	2
29	3	2	3		3	3	3
30	4	4	5		2	2	2

Nasolabial Angle (degrees)					
subject	preoperative			postoperative	
	cephalograph	lasergraph		cephalograph	lasergraph
1	96	96		101	101
2	82	82		90	89
3	99	99		90	91
4	111	110		120	119
5	101	102		105	107
6	89	88		90	90
7	116	114		120	119
8	115	114		118	117
9	106	111		106	118
10	95	97		98	100
11	101	113		107	117
12	94	97		100	97
13	99	100		101	104
14	94	95		83	85
15	106	112		108	114
16	100	87		104	93
17	88	88		92	91
18	95	99		101	101
19	84	86		89	92
20	102	102		105	104
21	96	94		99	99
22	90	93		97	98
23	99	101		99	99
24	89	90		88	90
25	91	90		90	90
26	103	103		106	105
27	116	114		119	117
28	90	93		97	98
29	95	97		98	100
30	99	100		100	97

Nasofacial Angle (degrees)					
subject	preoperative			postoperative	
	cephalograph	lasergraph		cephalograph	lasergraph
1	37	36		37	36
2	39	39		40	41
3	34	35		35	35
4	37	37		37	37
5	41	40		40	40
6	36	36		34	36
7	39	38		38	38
8	39	37		38	37
9	32	33		33	33
10	37	37		37	37
11	34	36		37	37
12	38	36		37	36
13	42	42		42	42
14	32	33		33	33
15	39	39		39	38
16	34	35		35	35
17	36	36		37	36
18	41	40		41	41
19	32	34		32	32
20	34	34		36	35
21	37	36		37	36
22	30	29		30	30
23	42	42		43	42
24	34	37		36	27
25	31	32		33	32
26	37	37		36	37
27	39	39		39	39
28	33	35		33	34
29	38	37		37	37
30	31	32		33	32

Nasomental Angle (degrees)					
subject	preoperative			postoperative	
	cephalograph	lasergraph		cephalograph	lasergraph
1	132	131		131	131
2	119	117		125	125
3	120	123		127	127
4	121	121		122	122
5	126	128		128	128
6	131	129		130	129
7	134	131		128	129
8	114	115		122	122
9	121	123		126	128
10	121	121		125	128
11	121	122		121	124
12	123	123		123	122
13	141	138		136	132
14	127	127		126	125
15	128	128		128	128
16	122	122		124	122
17	137	134		129	130
18	139	141		132	132
19	125	127		130	130
20	122	122		122	122
21	127	128		127	128
22	121	122		125	125
23	124	124		121	124
24	122	123		124	122
25	132	130		128	125
26	131	131		126	129
27	114	116		119	122
28	141	139		135	135
29	132	132		130	127
30	127	124		125	124

Labiomental Angle (degrees)					
subject	preoperative			postoperative	
	cephalograph	lasergraph		cephalograph	lasergraph
1	152	152		150	150
2	135	135		140	139
3	141	142		143	143
4	147	147		148	148
5	163	160		163	162
6	134	134		140	139
7	155	155		155	155
8	136	136		140	139
9	159	158		156	156
10	135	135		141	140
11	142	143		144	144
12	144	143		144	143
13	128	128		134	135
14	138	139		140	140
15	141	141		144	144
16	146	145		146	145
17	139	139		142	142
18	142	143		142	142
19	129	130		141	139
20	151	151		151	150
21	146	146		146	146
22	133	133		136	136
23	137	136		139	139
24	146	146		145	146
25	142	140		142	142
26	133	133		137	136
27	148	148		148	148
28	139	140		140	140
29	144	144		144	144
30	142	142		144	144

subject	Nasal Tip (mm)	
	cephalograph	lasergraph
1	2	3
2	3	2
3	2	2
4	2	2
5	3	2
6	1	2
7	0	0
8	2	1
9	2	1
10	2	1
11	4	3
12	1	1
13	2	2
14	-2	-1
15	1	0
16	4	3
17	2	3
18	0	0
19	1	3
20	2	2
21	1	0
22	1	2
23	0	0
24	1	1
25	1	2
26	2	1
27	1	0
28	0	0
29	2	1
30	2	2

A.3.2 Data for the measurement of head position change

Bending energy for change in head position (g.cm ² /sec ²)					
	Subject A	Subject B	Subject C	Subject D	Subject E
1:02	0.01162	0.0193	0.00389	0.0033	0.01088
1:03	0.0205	0.03657	0.00542	0.00422	0.00173
1:04	0.01327	0.01455	0.00743	0.01312	0.01095
1:05	0.00608	0.02373	0.01768	0.02171	0.01087
1:06	0.02225	0.01898	0.0163	0.01802	0.00126
1:07	0.01338	0.01789	0.01507	0.03952	0.00971
1:08	0.01939	0.03364	0.00963	0.02362	0.00525
1:09	0.03413	0.02243	0.01733	0.014	0.00134
1:10	0.0101	0.06786	0.0306	0.01835	0.00116
1:11	0.01805	0.03261	0.02077	0.00194	0.01556
1:12	0.02517	0.02843	0.01272	0.00444	0.0025
2:03	0.01919	0.0078	0.00263	0.0068	0.01411
2:04	0.01115	0.00356	0.00852	0.01932	0.0163
2:05	0.01738	0.0048	0.01319	0.03026	0.0057
2:06	0.01266	0.01036	0.00808	0.0213	0.01058
2:07	0.01829	0.0068	0.01151	0.03754	0.0071
2:08	0.02827	0.0059	0.00896	0.0237	0.00548
2:09	0.03662	0.00616	0.00729	0.0221	0.0124
2:10	0.00778	0.02311	0.02209	0.02311	0.0132
2:11	0.02177	0.00897	0.01312	0.0035	0.02259
2:12	0.02595	0.00651	0.00942	0.01216	0.01137
3:04	0.00575	0.00551	0.01011	0.01013	0.00759
3:05	0.00741	0.00373	0.00846	0.01885	0.00913
3:06	0.01409	0.01281	0.00908	0.01701	0.00318
3:07	0.00369	0.0077	0.00771	0.04917	0.00734
3:08	0.00314	0.00603	0.00936	0.02725	0.00471
3:09	0.0048	0.00596	0.00764	0.00666	0.00405
3:10	0.00831	0.01922	0.01663	0.01501	0.00199
3:11	0.00505	0.0106	0.00956	0.00618	0.0093
3:12	0.01444	0.01036	0.0082	0.00536	0.00553
4:05	0.00871	0.00186	0.01415	0.00289	0.01516
4:06	0.00906	0.00499	0.01095	0.00363	0.04299
4:07	0.00619	0.00293	0.01005	0.0314	0.02558
4:08	0.01081	0.00683	0.00188	0.01306	0.00733
4:09	0.01731	0.00379	0.01445	0.0071	0.04383
4:10	0.00523	0.02703	0.02216	0.00925	0.04747
4:11	0.00486	0.01033	0.02196	0.01717	0.01434
4:12	0.01893	0.00841	0.00428	0.01664	0.04962
5:06	0.0143	0.00447	0.01109	0.00479	0.05021
5:07	0.00213	0.00386	0.00434	0.03634	0.02331
5:08	0.00541	0.00384	0.01344	0.01617	0.00808
5:09	0.01672	0.00393	0.00765	0.01061	0.05541
5:10	0.00794	0.02282	0.00398	0.01166	0.05918
5:11	0.01047	0.01094	0.01201	0.03094	0.03789
5:12	0.02265	0.00959	0.00923	0.02475	0.05395
6:07	0.01007	0.00332	0.00905	0.02356	0.00794
6:08	0.01894	0.00654	0.00793	0.00453	0.00528
6:09	0.03622	0.00562	0.00355	0.01498	0.00065

	Subject A	Subject B	Subject C	Subject D	Subject E
6:10	0.01526	0.02607	0.01096	0.00804	0.00137
6:11	0.02307	0.01554	0.00733	0.0205	0.01788
6:12	0.04929	0.0129	0.00467	0.0255	0.00125
7:08	0.00278	0.0046	0.00739	0.00955	0.0057
7:09	0.01192	0.00184	0.00866	0.05234	0.00999
7:10	0.0085	0.01891	0.0055	0.0386	0.01061
7:11	0.00843	0.00839	0.01203	0.03623	0.00631
7:12	0.02429	0.00705	0.00435	0.05748	0.01289
8:09	0.00774	0.00416	0.0114	0.03199	0.02014
8:10	0.01197	0.01319	0.01693	0.01555	0.02796
8:11	0.00677	0.01019	0.01734	0.02436	0.02532
8:12	0.02033	0.00843	0.00121	0.04044	0.02026
9:10	0.01663	0.01367	0.00976	0.00856	0.00269
9:11	0.0111	0.00487	0.00488	0.0206	0.01745
9:12	0.0122	0.0035	0.0129	0.0138	0.00113
10:11	0.00468	0.00775	0.01517	0.02402	0.0167
10:12	0.01054	0.0078	0.01308	0.02548	0.00375

A.3.3 Data for landmark identification error

Bending energy for landmark identification ($\text{g.cm}^2/\text{sec}^2$)		
	Frontal	Lateral
1:02	0.00202	0.00163
1:03	0.00361	0.00318
1:04	0.0045	0.00332
1:05	0.00765	0.00301
1:06	0.00733	0.00244
1:07	0.01031	0.00264
1:08	0.01605	0.00447
1:09	0.00509	0.00448
1:10	0.00631	0.00245
2:03	0.00142	0.00228
2:04	0.00131	0.00219
2:05	0.00416	0.00194
2:06	0.00349	0.00104
2:07	0.00505	0.00263
2:08	0.01141	0.00455
2:09	0.00259	0.0029
2:10	0.0028	0.00176
3:04	0.00176	0.00108
3:05	0.00486	0.00074
3:06	0.00381	0.00167
3:07	0.00536	0.00088
3:08	0.01063	0.00106
3:09	0.00199	0.00061
3:10	0.002	0.00024
4:05	0.00223	0.00179
4:06	0.00343	0.00253
4:07	0.00239	0.00079
4:08	0.00801	0.00099
4:09	0.00202	0.0006
4:10	0.00118	0.00104
5:06	0.00334	0.00115
5:07	0.00568	0.00103
5:08	0.00713	0.00173
5:09	0.00263	0.00104
5:10	0.00292	0.00081
6:07	0.0051	0.00221
6:08	0.00466	0.0042
6:09	0.00148	0.00231
6:10	0.0034	0.00145
7:08	0.00647	0.00063
7:09	0.00563	0.00053
7:10	0.00256	0.00089
8:09	0.00717	0.00069
8:10	0.0073	0.00122

A.4 Data for Chapter 5

Measurement of soft tissue changes with optical surface scanner

Class II - Soft Tissue Changes										
	Nasal tip	Para nasal	Sub nasale	Sub alar	Supra Comm.	Upper Verm.	Lower Verm.	Sub Comm.	Labio Mental groove	Pg
1	.00	.00	.00	1.00	.50	1.00	3.50	2.50	5.50	6.00
2	.00	.00	.00	.50	.00	1.00	2.50	2.00	3.00	4.00
3	.00	.00	.00	.50	.00	1.00	3.50	3.00	5.00	6.00
4	.00	.00	.00	1.00	.50	1.00	4.00	3.50	6.00	6.00
5	.00	.00	.00	1.00	.50	1.00	4.00	4.50	7.00	7.50
6	.00	.00	.50	1.50	.50	1.50	5.00	4.00	7.00	8.00
7	.00	.00	.00	1.00	.50	1.50	4.50	4.00	8.00	8.00
8	.00	.00	.00	.50	.20	.80	5.00	5.00	8.00	8.00
9	.00	.00	.00	.50	.20	.50	4.00	4.50	7.00	8.00
10	.00	.00	.00	.80	.50	.80	5.00	5.00	6.00	8.00
11	.00	.00	.20	.50	.20	.80	4.00	3.50	6.00	6.00
12	.00	.00	.20	.50	.00	1.00	3.50	4.50	6.00	8.00
13	.00	.00	.00	.00	.00	.20	5.00	4.00	7.00	8.00
14	.00	.00	.20	.50	.20	1.00	4.50	4.00	6.50	7.50
15	.00	.00	.00	.40	.00	.80	4.00	3.00	6.00	6.50
16	.00	.00	.00	.30	.00	1.00	5.00	4.00	6.00	8.00
17	.00	.00	.00	.00	.00	.00	1.00	1.00	2.00	2.00
18	.00	.00	.00	.20	.00	.50	1.00	.50	1.50	2.00
19	1.00	1.60	2.00	2.00	1.00	1.80	3.00	2.00	4.00	4.50
20	.60	2.00	1.80	2.00	1.50	1.50	1.50	.60	1.50	1.50
21	1.20	3.80	4.50	3.80	2.00	3.00	3.00	1.50	3.00	4.00
22	.50	2.00	2.00	2.00	1.00	1.00	1.50	.80	1.80	2.00
23	1.00	4.00	4.00	4.00	2.00	3.00	2.00	1.00	1.50	1.80
24	.30	.50	.20	.30	.00	.80	2.50	3.00	5.00	6.00
25	.30	.60	.30	.50	.30	1.20	3.50	3.00	6.00	7.00
26	.20	.30	.30	.30	.00	.60	2.50	2.00	5.00	6.00
27	.20	.20	.00	.30	.00	1.00	3.00	1.70	4.00	5.50
28	.20	.20	.20	.50	.00	1.00	4.50	4.00	7.00	7.00
29	.00	.00	.40	.20	.00	.50	3.50	3.00	5.00	6.00
30	.50	.50	.20	.50	.20	.50	4.00	2.50	4.50	6.00
31	.00	.20	.40	.20	.00	.50	2.50	2.50	4.00	4.50
32	.20	.20	.40	.20	.00	.40	5.00	4.00	6.00	8.00
33	.50	.20	.40	.20	.00	1.00	4.00	2.50	6.00	6.00
34	.20	.00	.20	.20	.00	.50	5.00	3.50	7.00	7.50
35	.30	.40	.40	.20	.20	1.00	2.20	2.00	4.50	5.00
36	.20	.20	.30	.20	.00	1.00	4.00	4.00	5.00	6.00
37	.00	.00	.20	.00	.00	.30	3.00	3.50	6.50	7.50
38	.20	.50	.50	.30	.20	1.20	5.00	4.50	6.00	6.50
39	.30	.30	.50	.30	.00	1.00	3.50	2.00	5.00	6.00
40	.30	.80	.30	.20	.20	.50	4.00	3.20	4.80	5.50
41	.00	.50	.20	.50	.30	.50	5.50	3.00	6.00	8.00
42	.50	.30	.30	.40	.20	1.00	4.00	3.00	5.00	6.00
43	.50	.20	.30	.40	.00	.80	5.00	3.50	5.00	6.00
44	.00	.00	.20	.30	.00	.50	4.00	3.00	4.50	6.00
45	.00	.20	.20	.20	.00	.80	3.00	3.20	5.50	5.50
46	.20	.20	.00	.20	.00	1.00	4.20	2.80	4.50	6.00
47	.00	.20	.00	.20	.00	.70	3.70	3.20	3.50	5.50

Class III – Soft Tissue Changes										
	Nasal tip	Para nasal	Sub nasale	Sub alar	Supra Comm.	Upper Verm.	Lower Verm.	Sub Comm.	Labio Mental groove	Pg
1	.00	.00	5.00	5.00	.00	1.50	4.00	3.00	5.00	6.00
2	.00	.00	.00	2.00	.00	1.00	4.50	2.50	5.50	6.00
3	.00	.00	.00	.00	.00	.50	4.20	3.00	5.00	6.00
4	.00	.00	2.00	2.00	.00	.80	4.00	3.20	5.00	6.00
5	.00	.00	.00	.00	.00	.50	2.00	1.80	2.20	3.00
6	2.00	2.50	3.00	2.50	1.50	2.50	1.00	.50	3.00	3.00
7	2.00	2.00	3.00	2.00	1.00	2.50	4.50	4.00	5.80	6.00
8	.00	2.00	2.00	2.00	1.00	1.00	1.30	1.00	1.50	2.00
9	1.00	2.00	2.00	2.00	1.00	2.00	1.80	1.00	2.50	2.50
10	.00	3.00	2.00	3.00	2.00	2.00	1.50	1.00	2.20	2.50
11	.00	2.00	2.00	2.00	1.00	2.00	3.00	2.00	3.50	3.80
12	1.00	3.00	3.00	3.00	2.00	2.00	1.20	1.00	2.00	2.00
13	.00	2.00	2.00	2.00	1.00	1.00	3.00	2.50	3.50	4.00
14	2.00	2.50	3.00	2.50	1.50	2.50	2.40	1.00	3.50	3.80
15	1.00	3.00	3.00	3.00	2.00	2.00	1.50	1.00	2.00	2.00
16	2.00	2.00	3.00	2.00	1.00	2.00	1.80	1.00	2.00	2.00
17	1.00	2.00	2.00	2.00	1.00	2.00	.50	.50	1.00	1.00
18	.00	2.00	2.00	2.00	1.00	2.00	1.20	1.00	2.00	2.00
19	.00	3.00	2.00	3.00	2.00	2.00	1.00	1.00	1.50	2.00
20	3.00	4.00	5.00	4.00	2.00	3.50	3.00	2.00	4.00	4.00
21	1.00	4.00	5.00	4.00	2.00	2.00	1.00	.50	2.00	2.00
22	2.00	5.00	5.00	4.00	2.00	3.00	2.20	2.00	4.00	4.00
23	1.00	4.00	4.00	4.00	2.00	3.00	3.00	.02	3.50	4.00
24	3.00	5.50	5.00	5.00	4.00	3.00	1.00	1.00	2.00	2.00
25	1.00	5.00	4.00	4.00	3.00	3.00	1.00	.50	1.80	2.00
26	4.00	4.00	6.00	5.00	3.00	4.00	1.50	1.20	1.50	1.80
27	3.00	5.20	6.00	5.00	3.00	4.00	3.00	2.00	3.50	4.00
28	1.00	4.00	4.00	4.00	3.00	3.00	1.80	1.00	2.00	2.00
29	1.50	5.00	4.00	5.00	2.00	2.00	1.00	1.00	1.50	1.50
30	1.00	4.00	4.00	4.00	3.00	4.50	1.40	1.00	2.00	2.00
31	2.50	4.20	5.00	5.00	3.00	3.00	2.20	2.00	3.50	4.00
32	1.00	4.00	4.00	4.00	2.00	4.50	2.80	2.00	3.50	3.80
33	1.00	4.00	4.00	4.00	3.00	3.80	2.00	1.50	2.80	3.00
34	3.00	5.00	6.00	5.00	3.00	4.00	1.00	.50	1.80	2.00
35	3.00	4.00	5.00	4.00	2.00	3.50	2.00	1.50	2.80	3.00
36	4.00	5.00	6.00	5.00	3.00	4.00	3.00	2.20	3.50	3.80
37	1.00	5.00	4.00	5.00	3.00	3.00	1.50	1.00	1.50	2.00
38	1.00	4.50	5.00	4.50	2.00	3.80	1.00	.50	.90	1.00
39	1.00	5.00	4.00	4.20	3.00	3.00	1.80	1.80	2.80	3.00
40	2.50	4.00	5.00	5.00	3.00	4.00	1.00	1.00	1.50	1.80
41	3.00	5.00	5.00	5.00	4.00	3.00	.80	1.00	1.80	2.00
42	1.50	3.00	4.00	3.00	2.00	2.00	1.00	1.00	2.00	2.00
43	1.50	5.00	4.00	4.20	2.00	3.60	.50	.50	.50	0.80
44	1.50	3.00	4.00	3.80	2.00	2.00	3.00	2.20	4.00	4.00
45	2.00	5.00	5.00	4.50	2.00	4.50	1.80	1.50	3.00	3.00
46	3.00	4.50	5.00	4.50	2.00	3.50	2.50	2.00	3.80	4.00
47	3.00	7.00	7.00	7.00	3.00	5.00	3.50	2.00	4.50	5.00
48	2.50	6.00	6.50	6.00	4.00	5.00	1.50	1.00	2.00	2.00
49	3.50	7.00	7.00	7.00	4.50	3.50	1.50	1.00	1.80	2.00
50	3.00	6.50	6.50	6.00	3.50	4.50	2.00	1.50	2.50	3.00
51	3.00	6.50	6.50	6.50	5.00	4.00	1.50	1.00	1.80	2.00
52	.00	.00	.20	.20	.00	.60	4.00	3.00	5.00	6.00

	Nasal tip	Para nasal	Sub nasale	Sub alar	Supra Comm.	Upper Verm.	Lower Verm.	Sub Comm.	Labio Mental groove	Pg
53	.00	.00	.00	.20	.00	.50	3.00	2.00	3.20	4.00
54	.00	.00	.00	.00	.00	.80	3.20	2.20	4.00	3.50
55	.00	.00	.00	.00	.00	.30	2.80	2.20	3.50	3.80

A.5 Data for Chapter 6

Measurement of vermillion width change

	Preoperative		Postoperative	
	upper lip vermillion width	lower vermillion width	upper lip vermillion width	lower vermillion width
1	6	7	5	6
2	5	9	4	8
3	8	10	8	11
4	5	8	5	8
5	7	11	7	11
6	8	11	10	13
7	7	12	6	11
8	5	12	7	9
9	7	10	8	11
10	6	10	6	9
11	5	7	7	8
12	4	6	3	7
13	10	12	10	11
14	7	10	7	10
15	5	9	5	10
16	9	12	9	12
17	6	9	5	8
18	6	10	7	10
19	8	11	7	10
20	12	14	12	14
21	3	7	7	11
22	4	7	4	6
23	10	10	12	12
24	6	12	7	10
25	7	10	7	10
26	6	9	7	10
27	3	7	6	9
28	9	12	8	10
29	6	11	9	13
30	6	9	7	10
31	7	11	8	11
32	7	13	10	14
33	7	10	7	11
34	7	11	8	11
35	6	10	6	10
36	4	5	5	6
37	4	10	5	11

A.6 Data for Chapter 7

Measurement of change in overjet after orthognathic surgery

	Overjet				
	Randomisation	preoperative	T1	T2	T3
1	C	7.00	2.00	2.00	2.00
2	B	7.00	1.00	2.00	2.00
3	B	4.00	4.00	1.00	.00
4	A	8.00	.00	2.00	2.00
5	B	5.00	7.00	4.00	5.00
6	C	8.00	2.00	2.00	2.00
7	B	2.00	1.00	1.00	2.00
8	A	7.00	2.00	2.00	2.00
9	C	8.00	2.00	2.00	2.00
10	B	6.00	2.00	1.00	3.00
11	C	7.00	.00	1.00	2.00
12	C	8.00	.00	1.00	1.00
13	B	-9.00	3.00	3.00	3.00
14	B	-8.00	3.00	2.00	1.00
15	C	-4.00	2.00	2.00	2.00
16	B	-2.00	3.00	3.00	3.00
17	A	-8.00	4.00	3.00	3.00
18	C	-8.00	3.00	2.00	2.00
19	C	-12.00	2.00	1.00	1.00
20	C	-7.00	2.00	1.00	.00
21	A	-7.00	3.00	3.00	2.00
22	A	-4.00	4.00	2.00	2.00
23	A	-2.00	1.00	1.00	1.00
24	A	.00	5.00	2.00	1.00
25	A	-4.00	1.00	1.00	1.00
26	B	-7.00	3.00	2.00	2.00
27	A	-4.00	2.00	1.00	1.00
28	B	-2.00	.00	3.00	2.00
29	B	-4.00	1.00	3.00	3.00
30	A	-2.00	1.00	3.00	3.00
31	B	-2.00	2.00	1.00	1.00
32	C	-8.00	1.00	2.00	2.00
33	B	-8.00	2.00	2.00	2.00
34	C	9.00	4.00	2.00	2.00
35	C	10.00	1.00	1.00	1.00
36	C	4.00	2.00	1.00	.00
37	A	7.00	.00	.00	1.00
38	C	9.00	3.00	2.00	4.00
39	B	7.00	.00	1.00	1.00
40	C	9.00	1.00	2.00	.00
41	B	7.00	5.00	.00	.00
42	B	11.00	3.00	1.00	1.00
43	C	8.00	2.00	2.00	2.00
44	A	2.00	1.00	1.00	1.00
45	C	6.00	2.00	2.00	5.00
46	B	8.00	.00	2.00	2.00
47	A	10.00	4.00	3.00	3.00
48	B	5.00	.00	1.00	3.00
49	C	1.00	1.00	1.00	1.00
50	A	7.00	.00	2.00	2.00

	Randomisation	preoperative	T1	T2	T3
51	C	-2.00	2.00	2.00	2.00
52	B	-2.00	4.00	3.00	2.00
53	B	-4.00	4.00	2.00	1.00
54	C	-2.00	3.00	3.00	2.00
55	B	-3.00	2.00	2.00	2.00
56	B	-1.00	2.00	1.00	1.00
57	A	-2.00	1.00	3.00	2.00
58	A	-8.00	3.00	1.00	1.00
59	A	-1.00	3.00	2.00	2.00
60	C	-8.00	1.00	1.00	1.00
61	A	-1.00	4.00	3.00	1.00
62	B	-6.00	4.00	2.00	2.00
63	B	-9.00	3.00	1.00	.00
64	A	-1.00	4.00	2.00	2.00
65	A	-3.00	2.00	.00	1.00
66	B	-4.00	2.00	1.00	1.00
67	C	8.00	2.00	2.00	4.00
68	B	6.00	2.00	3.00	3.00
69	A	7.00	2.00	2.00	2.00
70	A	10.00	2.00	1.00	1.00
71	A	8.00	.00	.00	3.00
72	C	10.00	.00	1.00	2.00
73	B	10.00	2.00	.00	2.00
74	A	11.00	2.00	3.00	3.00
75	A	4.00	.00	.00	.00
76	C	8.00	1.00	2.00	2.00
77	A	7.00	1.00	2.00	2.00
78	B	9.00	2.00	1.00	1.00
79	A	10.00	1.00	2.00	2.00
80	C	7.00	.00	2.00	2.00
81	C	6.00	.00	2.00	2.00
82	A	8.00	.00	2.00	3.00
83	B	9.00	.00	2.00	2.00
84	B	-9.00	2.00	1.00	1.00
85	A	-10.00	2.00	3.00	2.00
86	A	-2.00	2.00	2.00	2.00
87	B	-9.00	2.00	2.00	2.00
88	A	-4.00	3.00	4.00	4.00
89	C	-3.00	2.00	2.00	2.00
90	C	.00	3.00	2.00	2.00
91	C	-8.00	3.00	2.00	1.00
92	A	-5.00	4.00	1.00	1.00
93	A	-6.00	2.00	2.00	2.00
94	B	-4.00	.00	1.00	2.00
95	B	-10.00	1.00	.00	1.00
95	C	-3.00	4.00	3.00	2.00
97	C	-1.00	3.00	2.00	2.00
98	C	-5.00	3.00	2.00	2.00
99	C	-2.00	2.00	1.00	1.00
100	C	-5.00	3.00	3.00	3.00
Key					
T1		Day of discharge from the ward			
T2		End of 2 nd postoperative week- removal of wafer / elastics			
T3		6 th month postoperatively			

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ABSTRACTS

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1. Soncul M, Bamber MA (2000). The reproducibility of the head position for a laser scan using a novel morphometric analysis for orthognathic surgery. Int J Oral Maxillofac Surg 29: 86-90.
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The reproducibility of the head position for a laser scan using a novel morphometric analysis for orthognathic surgery

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Abstract. The aim of this study was to evaluate the reproducibility of the head position for a three-dimensional soft tissue laser scan (lasergraph) using thin-plate splines, for orthognathic surgery planning and follow-up. 60 laser scans of five subjects (12 scans per subject) were obtained at specified intervals. The head was positioned in the lateral view using a spirit level, an engineering device for setting horizontal surfaces, to adjust the Frankfort horizontal plane parallel to the ground. The projection of a narrow beam of longitudinal laser light was used to adjust the axial plane for the frontal view. These scanned images (lasergraphs) were digitised and the co-ordinates of the landmarks recorded. The digitised laser scans were compared using thin-plate splines analysis. The mean difference between the scans due to variations in head position was $0.0135 \pm 0.0109 \text{ g} \cdot \text{cm}^2/\text{sec}^2$ in the lateral view and $0.0090 \pm 0.0054 \text{ g} \cdot \text{cm}^2/\text{sec}^2$ in the frontal view. This represents an overall distortion error of less than 2% when following up the surgical change of a typical bimaxillary osteotomy case with 6 mm maxillary advancement and 3 mm mandibular set-back. It is concluded that facial laser scans (lasergraphs) with the Frankfort horizontal plane set using a head rest and spirit level, and the axial plane set using projection of a vertical laser light on the facial midline, are highly reproducible.

Key words: head position; optical laser scanner; morphometric analysis.

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The use of three-dimensional (3D) graphics for soft tissue evaluation in orthognathic surgery planning is setting new standards and has many advantages over conventional radiography. Recently, several techniques have been introduced for the morphometrics of the human face, the optical laser scanning system being one of the latest major developments⁹. This three-dimensional laser scan has also contributed towards the photorealistic simulation of the postoperative appearance of a patient⁷.

The optical laser scanning system

was designed at University College London Hospitals, where it is in regular use. All anatomical landmarks and facial structures are recorded within 0.5 mm, which meets the current clinical requirements of accuracy and reproducibility¹⁴ for orthognathic surgery assessment and planning. For a scan, the patient sits in a rotating chair, opposing the camera. A non-hazardous line of helium-neon laser light is projected on the face while the chair is rotated through 200 degrees for 15 seconds (Fig. 1). The distorted laser light reflecting the subject's facial anatomy is

recorded by the camera connected to the computer. The image is then saved in the computer and can be retrieved at a later date for further analysis. The hard copy of the lasergraph can be printed in full colour or black and white in any required view.

One of the major benefits of this system is the facility to manipulate the image in three dimensions. Thus, one can rotate the image on the computer screen in any direction and angle (Fig. 2) and select points on a standard or customised reference plane. Despite the many potential advantages of the system^{7,9} in

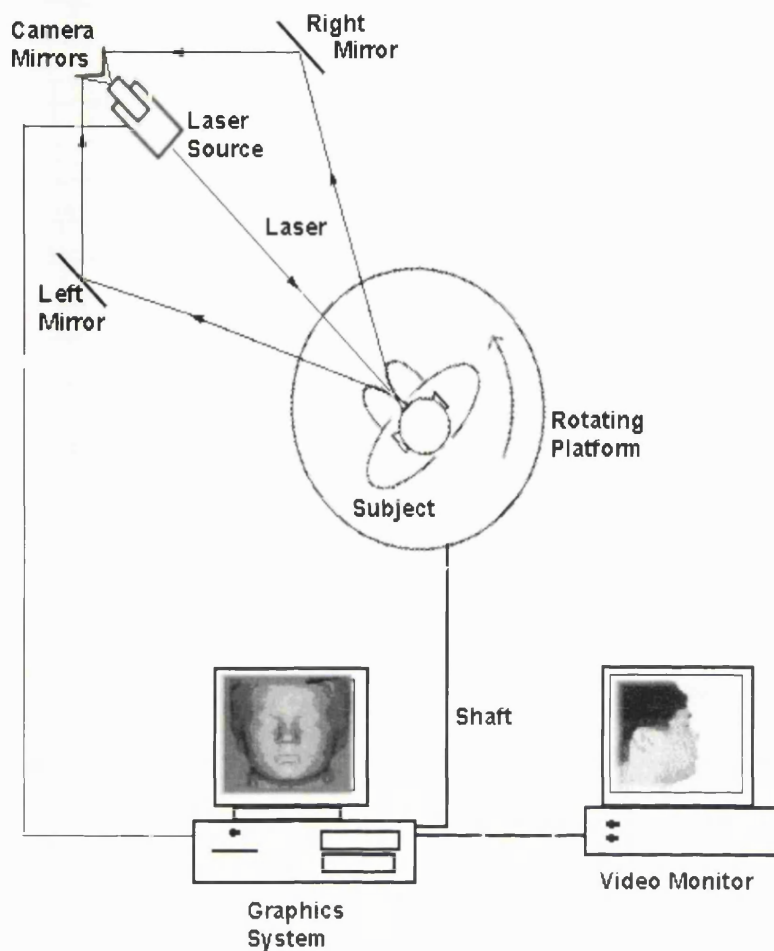


Fig. 1. The optical laser scanner system.



Fig. 3. The use of a spirit level to align the Frankfort plane parallel to the ground.

clinical applications, there is no agreed method of standardising head position for the optical laser scanner, which casts doubt upon the reproducibility of the achieved head position. It may even have erroneous effects on recorded soft tissue data for postoperative reviews. The three-dimensional surface that is presented to the projected laser light, and in turn recorded by the camera, is determined by the head position in any plane. Hence, it is possible that anatomic landmarks located in the areas of changing contour are affected by head inclination, thus influencing the accuracy of soft tissue change measurements. This may be mainly caused by obstruction of some landmarks by others due to an unsuitable head inclination.

There are no standardised methods reported for the quantitative evaluation of 3D facial soft tissue data. Hence, we have endeavoured to coerce the thin-plate splines transformations to validate the standardisation of the head position for laser scans. We believe that this would usefully supplement the conventional cephalometric analysis⁶.

The word "morphometrics" was first used by BLACKITH in 1965⁴, with the view of it being a standard application of multivariate analysis. It dealt with "size" and "shape" derived from biological forms. However, the synthesis of geometry, statistics and biology can be traced back as far as D'ARCY THOMPSON's "On Growth and Form" in 1917¹⁶. THOMPSON suggested that changes of biological form can be both modelled and described as mathematical smooth deformations. This concept formed the basis of "thin-plate splines".

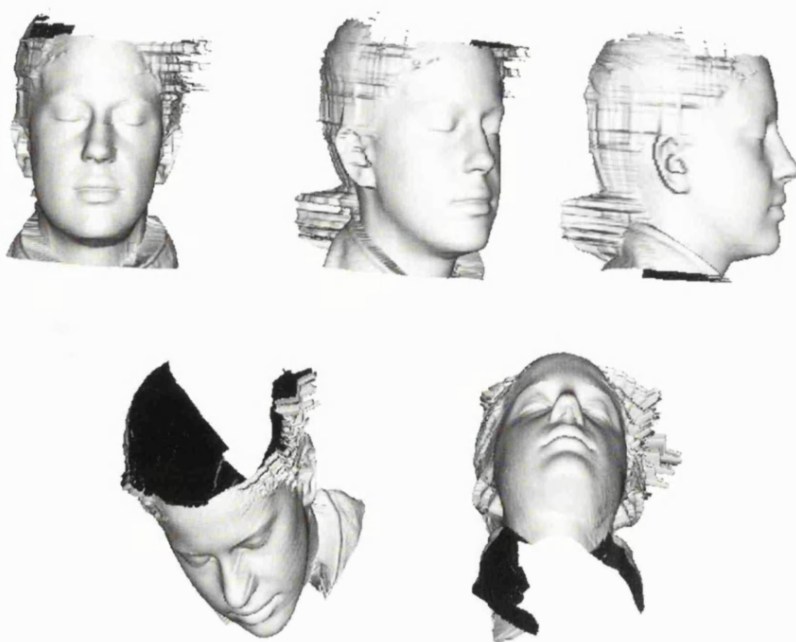


Fig. 2. The 3D lasergraph from various views.

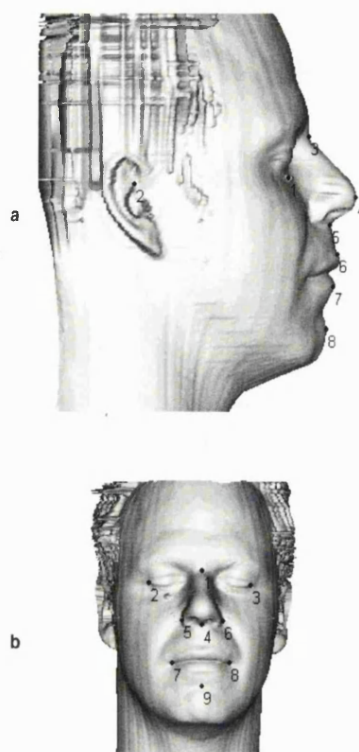


Fig. 4. a) Lateral view lasergraph showing landmarks used for this investigation: 1) Soft tissue orbitale, 2) Upper margin of tragus, 3) Soft tissue nasion, 4) Pronasale, 5) Subnasale, 6) Labrale superius, 7) Labrale inferius, 8) Soft tissue pogonion. b) Frontal view lasergraph showing landmarks used for this investigation: 1) Soft tissue nasion, 2) Right lateral canthus, 3) Left lateral canthus, 4) Subnasale, 5) Right alare, 6) Left alare, 7) Right cheilion, 8) Left cheilion, 9) Sublabiale.

The thin-plate spline is an interpolating function that can be used to describe shape change as a deformation of a structure, in this case the change in head position for a lasergraph.

This study aimed to test the reproducibility of the head position for lasergraphs by setting:

- the Frankfort horizontal plane parallel to the ground using a spirit level, an engineering device for setting horizontal surfaces, and
- the axial plane perpendicular to the ground in the frontal view, by reflecting a narrow laser light beam on the facial midline of the patient.

Material and methods

Sixty laser scans of five subjects (twelve scans each) were taken at random intervals of between 15 minutes and 24 hours. In the time between the scans, the subject was asked to walk around and relax. Three of the subjects were women and two were men; three had a

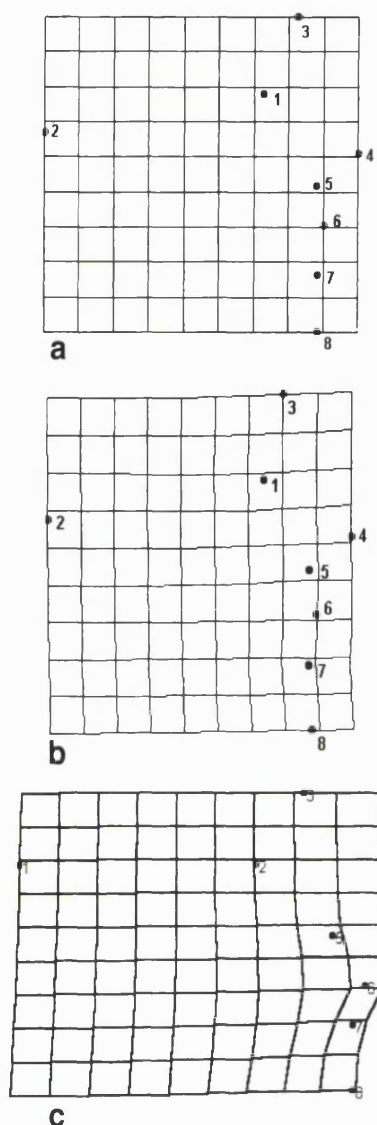


Fig. 5. a) A graphical output of thin-plate splines analysis after the digitisation of a pre-operative lasergraph. b) Graphical output of thin-plate splines analysis where the head position was intended to remain constant. The distortion of the image was caused by a slight change in the inclination of the head so that the digitised landmarks moved as a group. c) Graphical output of thin-plate splines analysis showing the change after bimaxillary surgery with 6 mm advancement of the maxilla and 3 mm set-back of the mandible.

Class I skeletal relationship, one had a Class II and one had a Class III; one subject had a facial asymmetry.

All the scans were taken by the same investigator, following a protocol for the use of an optical laser scanner⁸. The subject's head supported by the head rest was adjusted using a spirit level, an engineering device for setting horizontal surfaces. This consisted of a glass tube partially filled with alcohol and with air bubbles indicating perfect levelness to the three planes in space (Fig. 3). The head

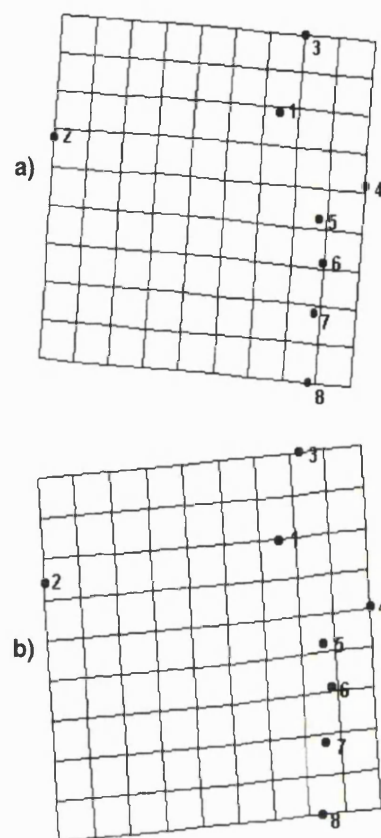


Fig. 6. a) Thin-plate splines analysis showing change in head position with chin moving inferiorly. b) Thin-plate splines analysis showing change in head position with chin moving superiorly. When the repeated lasergraphs were compared to each other, the slight changes in the head position were demonstrated as a rotation of the grid. The images compared here were otherwise identical, being free from magnification and individual movement of landmarks.

position was adjusted until the Frankfort horizontal plane was parallel to the ground. The axial plane of the head was adjusted and aligned perpendicular to the ground by shining the laser scanner source light longitudinally on the patient's facial midline¹. These scanned 3D images were saved on the host computer. For the digitisation process, an image was retrieved and an absolute lateral and frontal view of each subject's laser scan was obtained by rotating the 3D image on the screen (Fig. 2). This custom-designed software gives the same absolute frontal and lateral views repeatedly by default and the image manipulation process is calibrated and reproducible on the computer screen.

Using custom-designed software, the lateral and frontal view images were digitised for thin-plate splines (TpsDIG32 Version 1.1, a Windows 95/NT program developed by F. James Rohlf for geometric morphometric analysis). The anatomical landmarks digitised on each lateral profile and frontal view of the scan are illustrated in Figs. 4a and 4b.

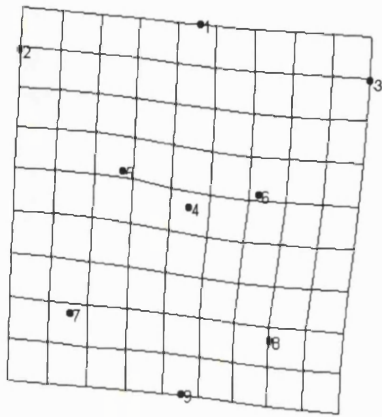


Fig. 7. The tilting of the head around the axial plane on the frontal view of lasergraphs was more visible graphically in thin-plate splines analysis.

These landmarks, which were difficult to localise on the laser scan, were clinically located and small self-adhesive balls were placed over them, as locators before scanning. The digitised lasergraphs (Fig. 5a) were then compared to each other using the thin-plate splines computer program. This analysis produced a report giving results in a quantitative and a graphical form (Fig. 5b). The graphical data were derived from a mesh diagram based on co-ordinates of digitised landmarks on the scans.

The quantitative data report of the thin-plate splines analysis was based on the "bending energy" required for the amount of deformation caused by alteration in the head position between scans. Bending energy is a metaphor borrowed from the mechanics of thin metal plates for use in morphometrics. It is the hypothetical energy that would be required to bend a metal plate. A deformation in the lasergraph (due to an osteotomy movement and/or a change in the head position) would be indicated by a change in the position of the baseline landmarks. The bending energy value for change in head po-

Table 1. The means and standard deviations of the bending energies ($\text{g} \cdot \text{cm}^2/\text{sec}^2$) for 5 subjects in lateral and frontal views

a) Lateral view

	Mean	SD
Subject A	0.012	0.011
Subject B	0.011	0.006
Subject C	0.019	0.013
Subject D	0.015	0.015
Subject E	0.014	0.009

b) Frontal view

	Mean	SD
Subject A	0.010	0.005
Subject B	0.013	0.006
Subject C	0.009	0.006
Subject D	0.007	0.004
Subject E	0.009	0.005

sition was calculated for every combination of 12 scans (66 comparisons in each view) for each subject, both in the lateral and the frontal views, 660 in total. These data were statistically analysed using parametric tests.

In order to calculate the landmark identification and digitisation method error, all the landmarks on a lasergraph were digitised ten times.

Results

Table 1 shows the mean bending energy, representing the change in head position, for each subject in both the lateral and the frontal view. 95% confidence intervals of the means are illustrated in Figs. 8 and 9.

Since the statistical analysis showed that there were no significant differences within and between subjects, all the data were integrated. The mean and standard deviation of the bending energy values for all comparisons for all

subjects were $0.0135 \pm 0.0109 \text{ g} \cdot \text{cm}^2/\text{sec}^2$ ($n=330$) for the lateral profile and $0.0090 \pm 0.0054 \text{ g} \cdot \text{cm}^2/\text{sec}^2$ ($n=330$) for the frontal view.

These bending energy values were compared with the bending energy value derived from a patient who had 6 mm advancement of the maxilla with 3 mm mandibular set-back, which was calculated to be $0.51055 \text{ g} \cdot \text{cm}^2/\text{sec}^2$ (Fig. 5c). The overall mean bending energy representing variation in head posture, including digitisation error, was thus less than 2% of this typical surgical change.

The mean value of bending energy representing the landmark identification and digitisation error of lasergraphs was $0.0018 \pm 0.0012 \text{ g} \cdot \text{cm}^2/\text{sec}^2$. This was not statistically significant.

The effect of a change in head position is illustrated in Figs. 6a and 6b. The surgical deformation as a result of osteotomy is more apparent when comparing the pre- and postoperative scans of a subject who has undergone orthognathic surgery (Fig. 5c). The change in head position in the axial plane (the frontal view of lasergraphs) was minimal, as illustrated by the thin-plate splines graphical analysis output (Fig. 7). The mean variations in the 12 scans from the five subjects showed no statistically significant differences between subjects in either plane (Table 1, Figs. 8 & 9).

Discussion

This study has shown that clinically significant error can be introduced into a laser scan due to variation in head position, unless a strict protocol is followed. A novel method of morphometric analysis is described which could prove to be a useful tool for clinical research.

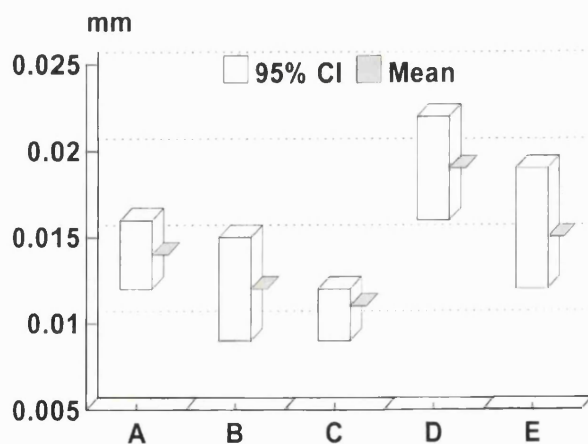


Fig. 8. 95% confidence intervals of the mean bending energies from 12 scans of 5 subjects (A-E) in the lateral view.

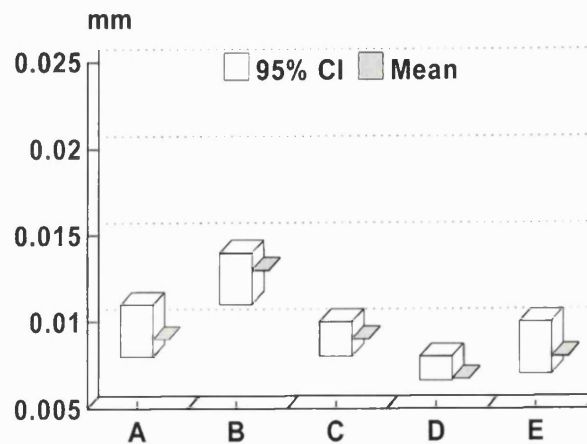


Fig. 9. 95% confidence intervals of the mean bending energies from 12 scans of 5 subjects (A-E) in the frontal view.

Despite being based on two-dimensional images, with the soft tissue recordings being limited to an outline of the lateral profile with poor resolution, the use of lateral skull cephalographs has for decades been the principal method for evaluating soft tissue change after orthognathic surgery. PIRTINIEMI *et al.*¹⁵ reported that although the head was positioned using a cephalostat, the geometric error due to head rotation in the cephalograph was up to 3.5 mm, which increased further in cases of facial asymmetry. In comparison, the errors in this lasergraph study due to head position were small and statistically insignificant. There is no other similar study reporting errors in soft tissue laser scans due to change in head position with which we can compare the results of this study. Additional advantages of this laser system are that 3D surface imaging data in a digital format can be analysed with greater accuracy in any desired view, and that laser scans can be conveniently stored by any computer system. If required, a print-out can be obtained in colour and black and white.

In the lateral profile, if the axis of rotation for the head was in the centre of the head's outline, then the bending energy for the change in head position would be zero, since the grid would rotate evenly around this centre point. The head is inclined on the neck, however, causing rotation in the grid (Figs. 6a & 6b) which can be easily measured by the thin-plate splines analysis. The head inclination has a direct effect on the 3D surface data that can be captured on the digitised image. Depending upon the head position, some soft tissue landmarks may disappear completely. For this reason, BUSH & ANTONYSHYN⁵ supported a downward inclination of the Frankfort plane for head position. However, this increased the error in some other landmarks.

LUNDSTROM *et al.*¹⁰ used the natural head position as a reproducible position for head inclination in their cephalometric study based on normal profiles. It is, however, difficult to achieve a reproducible natural head position in patients with abnormal and disharmonious profile outlines, facial asymmetry, and posturing habits¹¹. Earlier studies reporting the reproducibility of the natural head position in adults showed an error of 2°^{3,13}. In a separate study, LUNDSTROM & LUNDSTROM¹² reported that the natural head position as a

cephalometric reference for clinical purposes was not reproducible. Despite several investigations by many authors to find a reproducible head position, the Frankfort horizontal plane remains the most widely used reference plane for orthognathic surgery². This study showed that it can be reproduced with a simple technique of using a spirit level. The orientation of laser scans with the Frankfort horizontal plane also allows synchronisation of clinical assessment, lasergraphs, cephalographs and anatomically mounted models for orthognathic surgery planning.

There are no other cephalograph and lasergraph studies in the literature evaluating head position from the frontal view with which these results can be compared. All previous investigators used two-dimensional imaging tools, which only reproduced the lateral facial soft tissue profile for the analysis. This study, using a three-dimensional imaging tool, evaluated the head position in true lateral and frontal views; both these views are important for facial soft tissue analysis for surgeons and orthodontists.

The thin-plate splines analysis, using the mean bending energy, was thought to be more appropriate as a multivariate analysis for a three-dimensional image. The errors in the frontal view of laser scans were smaller than those in the lateral view, while the errors were clinically insignificant in both views. As a result of this study, it is advised to adjust the Frankfort horizontal plane parallel, and the frontal view axial plane perpendicular, to the true horizontal plane for a reproducible three-dimensional lasergraph.

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The optical surface scan as an alternative to the cephalograph for soft tissue analysis for orthognathic surgery

The aim of this study was to compare cephalographs and optical surface scanner images (lasergraphs) by measuring the lip-incisor relationship, the nasolabial angle, nasal tip projection, the nasofacial angle, the nasomental angle, and the labiomental angle in pre- and postoperative orthognathic surgery patients. The results showed that the methods were comparable, but the optical surface scan (lasergraph) could be used to greater advantage for pre- and postoperative assessment of soft tissue changes with orthognathic surgery, because of its clarity and 3-dimensional potential. (Int J Adult Orthod Orthognath Surg 1999;14:277-283)

Accurate recording and prediction of facial soft tissue changes after orthognathic surgery are important for surgeons and orthodontists. Conventional 2-dimensional radiologic and photographic techniques have been used for this purpose and have often proved to be inadequate. The use of traditional radiography also has limitations due to unjustified radiation doses from repeated examinations.

Other human face morphometry techniques that have been reported include Moire topography,^{1,2} stereophotogrammetry,^{3,4} morphoanalysis,⁵ and telecentric photography and photogrammetry.⁶ These are, again, all based on recording 2-dimensional photographic data. More recent systems include stereolithography⁷ based on computed tomographic (CT) scans, which also enables representation of complex anatomic structures in the form of models. Ultrasonography,⁸ based on the use of sound waves to reflect complex deeper structures for 3-dimensional images, has also been suggested. Currently, magnetic resonance imaging, an alternative to CT, is impracticable, as it is usually used on patients in the supine position.

The optical surface scanning system developed by Linney et al⁹ has been used regularly over the last decade for recording facial soft tissues, and recently its use for the measurement of the lip-incisor relationship was evaluated with good reproducibility.¹⁰ Its range of application has extended from surgical diagnosis and planning to prosthesis and implant design, clinical growth studies, forensic science, archaeology, psychology research, sculpture, and animation for advertising.

This optical surface scanning system (Fig 1) is based on the principle of triangulation. A beam of low-power semiconductor laser light is projected onto the subject's face and is distorted to reflect the contour of the surface anatomy. These reflections are then recorded by a camera situated adjacent to the laser projector. The subject sits on a rotating platform facing the camera and is rotated through 200 degrees in 10 seconds. Up to 258 profiles of the rotating subject are recorded in a scan. Specifically angled mirrors in the system enable the recording of additional views, so as

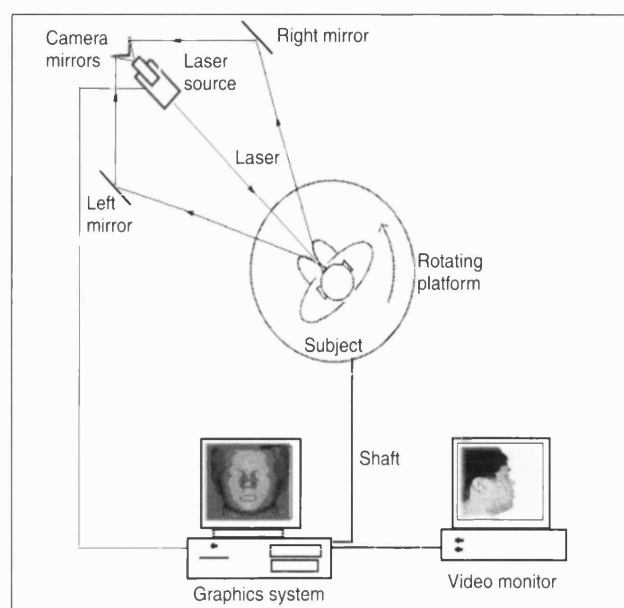


Fig 1 The optical surface scanner system.

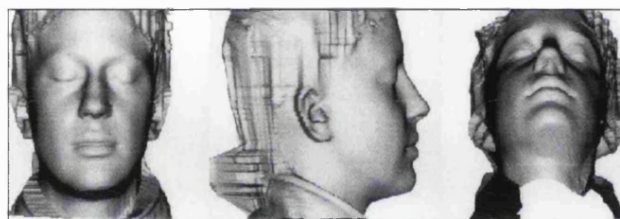


Fig 2 Various views of the optical surface scan (lasergraph).

to avoid the loss of data caused by the superimposition of prominent parts of the face, such as the nose, on neighboring facial structures. The angles at which these profiles are recorded may be programmed to yield finer sampling over areas of greater interest, where more detail is required. The recordings of the camera are sent to the transputer graphics system, which processes the video signals to form the scanned image on the video monitor (Fig 1).

Landmarks on the facial profile can be recorded within a 0.5-mm accuracy, which meets clinical requirements¹¹ for orthognathic surgery planning. The output image is presented on the monitor as a translation of the surface. This may be observed from any perspective (Fig 2), and measurements can be taken across the surface in 3 dimensions. However, there is a need to assess its accuracy and compatibility with conventional

cephalographs for its potentially wider clinical applications as systems based on similar principles are being marketed at reasonable costs.

The aims of this study were to compare conventional cephalographs and optical surface scanner images (lasergraphs) by measuring: (1) the upper lip-incisor exposure, (2) the nasolabial angle, (3) the nasal tip projection, (4) the nasofacial angle, (5) the nasomental angle, and (6) the labiomental angle in pre- and postoperative orthognathic surgery patients. The study was also intended to validate the apparent advantages of the optical surface scanner for orthognathic surgery.

Materials and methods

Thirty bimaxillary osteotomy patients consented to and were included in this study. The clinical upper lip-incisor exposure was measured after 3 minutes' re-

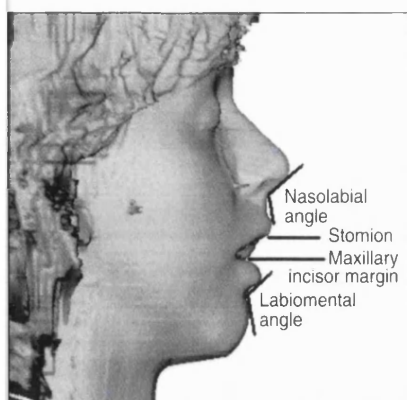


Fig 3 Maxillary incisor exposure and nasolabial and labiomental angles, as measured on an optical surface scan.

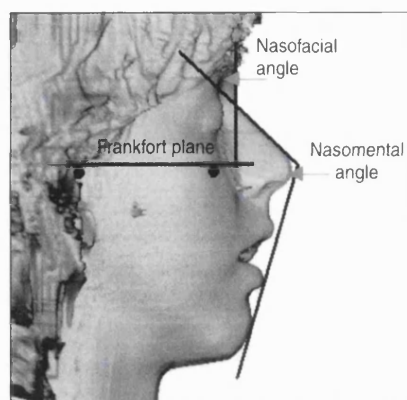


Fig 4 Nasofacial and nasomental angles on an optical surface scanner image.

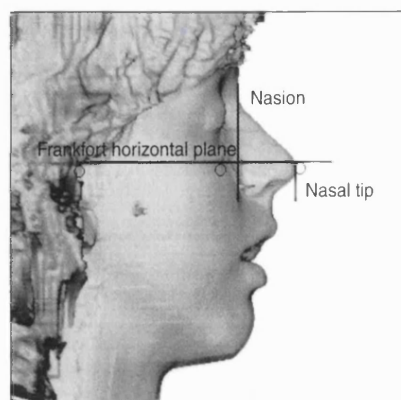


Fig 5 Nasal tip projection measurement on a scan.

pose, first during the preoperative workup, and again 6 to 8 weeks after surgery using a metric Vernier caliper, and on the cephalograph and the lasergraph. The nasolabial, nasofacial, nasomental, and labiomental angles and nasal tip projection are not accessible for reproducible clinical measurements, so they were measured only on optical surface scans and cephalographs, as described in Figs 3 to 5.

The lateral skull cephalographs were taken in the conventional manner with the patient's lips in repose. Optical surface scans were obtained similar to cephalographs, with the Frankfort plane horizontal (optical scanner designed and built by A. Linney et al, University of California at Los Angeles, Department of Medical Physics). To do this, the upper margin of the tragus and the orbitale were located manually, and markers were attached to the patient's skin. The head position was then adjusted using a spirit level until the Frankfort plane was horizontal.¹²

Using a 3-dimensional graphics display computer program, the authors retrieved the optical scanner image onto the screen; 2 reference points, 1 at stomion superius and the other at the maxillary incisor edge, were then marked and the maxillary incisor expo-

sure was determined by measuring the distance between these 2 points with the computer program (Fig 3). An optical surface scanner printout (lasergraph) was obtained, and the nasolabial angle was defined by the intersection of 2 lines; the first originated at subnasale, tangent to the lower border of the nose, and the second line, from subnasale to labrale superius, was recorded (Fig 3). The labiomental angle is formed by the intersection of 2 lines originating at the soft tissue B point; one is tangent to labrale inferius and the other is tangent to pogonion (Fig 3). The nasofacial angle was measured between a vertical line dropped from nasion perpendicular to the Frankfort plane and a line drawn tangent to the nasal dorsum (Fig 4). For the nasomental angle, a line from the nasal tip to pogonion was drawn and the angle between this line and the tangent to the nasal dorsum was recorded (Fig 4). The angular measurements were recorded on both cephalographs and optical surface scanner images using a protractor and a ruler.

A perpendicular line from nasion (N) to the Frankfort horizontal plane was drawn on the surface scans; the distance to the nasal tip was measured for the nasal tip projection, and changes after

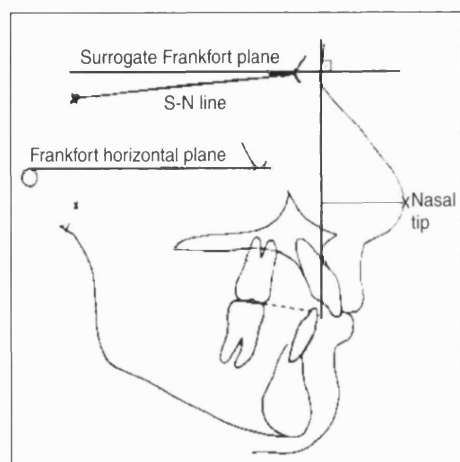


Fig 6 Nasal tip measurement on a cephalograph using a surrogate Frankfort plane.

the surgery were calculated (Fig 5). For cephalographs, a line from nasion was dropped perpendicular to the surrogate Frankfort plane (a reference plane 7 degrees above the sella-nasion [S-N] line); nasal tip measurements were taken (Fig 6), and changes with the surgery were calculated. The surrogate Frankfort plane was used instead of the original Frankfort plane, as it is derived from 2 unilateral reference points (S and N) and is reported to be more reproducible than the Frankfort plane.¹³ All measurements were repeated 3 times, and the mean of 3 measurements was used to calculate the pre- to postoperative changes. This change in the nasal tip projection was used to compare the cephalographs with the optical surface scans.

Results

The means and standard deviations of the clinical, cephalographic, and optical surface scan (lasergraphic) measurements of upper incisor exposure are presented in Table 1, and 95% confidence intervals of the mean are graphically illustrated in Fig 7a. Although there was a significant change between pre- and postoperative upper incisor exposure, the differences between the clinical, cephalographic, and surface scan measurements were not statistically significant ($P > 0.05$).

Table 1 Means and standard deviations of clinical, cephalometric, and lasergraphic evaluations of pre- and postoperative upper incisor exposure (in mm)

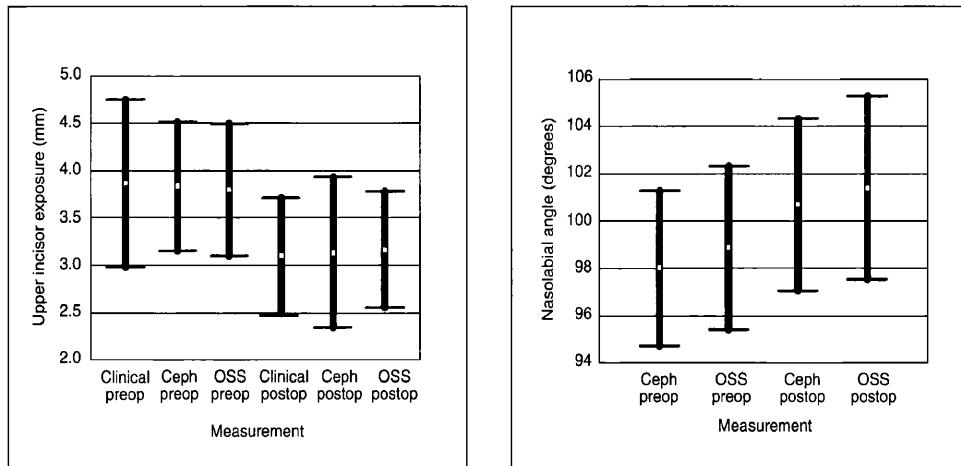
	Mean	SD
Clinical		
Preoperative	4.0	2.4
Postoperative	3.1	1.6
Cephalograph		
Preoperative	3.8	1.8
Postoperative	3.1	2.1
Lasergraph		
Preoperative	3.8	1.9
Postoperative	3.2	1.6

t test: $P > 0.05$.

Table 2 Mean and standard deviation of cephalometric and lasergraphic pre- and postoperative measurements of nasolabial angle, nasofacial angle, nasomental angle, and labiomental angle (in degrees)

	Preoperative		Postoperative	
	Cephalograph	Lasergraph	Cephalograph	Lasergraph
Nasolabial angle				
Mean	98.0	98.9	100.7	101.4
SD	8.8	9.3	9.8	10.4
<i>t</i> test	$P > 0.05$		$P > 0.05$	
Nasofacial angle				
Mean	36.2	36.3	36.5	36.0
SD	3.4	2.9	3.1	3.5
<i>t</i> test	$P > 0.05$		$P > 0.05$	
Nasomental angle				
Mean	126.5	126.4	126.5	126.6
SD	7.2	6.5	4.1	3.6
<i>t</i> test	$P > 0.05$		$P > 0.05$	
Labiomental angle				
Mean	142.2	142.1	144.2	143.9
SD	8.3	7.9	6.2	6.2
<i>t</i> test	$P > 0.05$		$P > 0.05$	

The means and standard deviations of the nasolabial, nasofacial, nasomental, and labiomental angles are presented in Table 2, and 95% confidence intervals of the mean are graphically presented in Figs 7b and 8. The differences between the surface scan and cephalograph measurements were statistically insignificant ($P > 0.05$).



Figs 7a and 7b The 95% confidence intervals of mean clinical, cephalometric (Ceph), and optical surface scan (OSS) for upper incisor exposure and nasolabial angle measurements preoperatively (preop) and postoperatively (postop), showing no difference between these methods.

Figs 8a to 8c The 95% confidence intervals of mean cephalographs (Ceph) and optical surface scans (OSS) for nasofacial angle, nasomental angle, and labiomental angle measurements, preoperatively (preop) and postoperatively (postop).

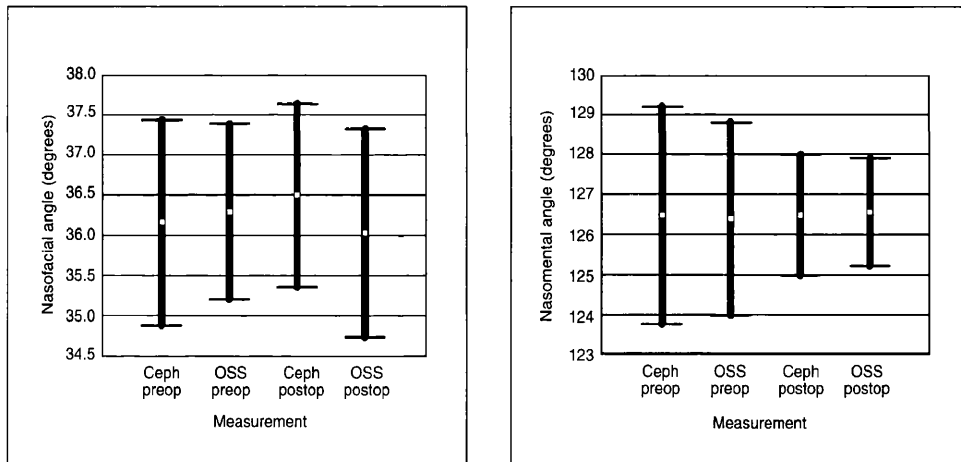


Fig 8a

Fig 8b

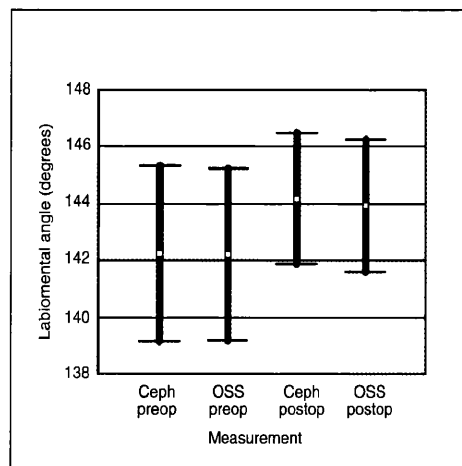


Fig 8c

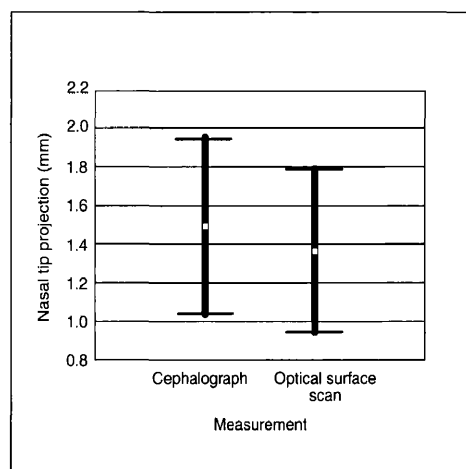


Fig 9 The 95% confidence intervals of mean nasal tip projection change after the surgery for cephalographs and optical surface scans.

The mean changes in nasal tip projection for both methods were 1.5 ± 1.2 mm for cephalographs and 1.4 ± 1.1 mm for surface scans. The difference between the 2 methods was not significant ($P = 0.5$), as can be seen in Fig 9, which shows the 95% confidence intervals of the means for this data.

Discussion and conclusion

Soft and hard tissue analyses for pre-operative surgical assessment and post-operative reviews have traditionally been done by measuring various angles and distances in 2 dimensions using craniofacial landmarks, planes, and contrived reference points on lateral cephalographs. Although useful, this method has inherent problems due to geometric complexity, magnification, the superimposition of craniofacial structures, distortion, and low resolution.^{14,15} For orthognathic surgery planning and postoperative follow-up, a technique capable of imaging low-density soft tissues with accuracy in all planes is required.

The results of this study showed that optical surface scans and cephalographs were comparable dimensionally, as there were no significant differences in measurements made with both of these methods. For the lip-incisor relationship, measurement accuracy was also comparable

to direct clinical measurements. Hence we believe that optical surface scans can complement the cephalograph in soft tissue analysis for orthognathic surgery planning and postoperative review.

The optical surface scan is substantially easier to examine and analyze than the cephalograph, and more importantly, the surface scan image is 3-dimensional and can be viewed immediately from any angle and position. Furthermore, the reference points on this image remain fixed as it is rotated. Measurements can be taken accurately across the surface as well as in a 2-dimensional linear manner, although this was not done in this protocol.¹⁶ It is also possible to focus on a particular surface section of the full image, such as the nasolabial region and lip relationships.

The surface scan is not subject to magnification, as the scale of the image is standardized by setting the appropriate number of pixels per millimeter. This gives precise measurements for superimposition and thus the determination of the changes following orthognathic surgery, monitoring of facial growth, or the growth of tumors. As a noncontact procedure, the system avoids any distortion of the soft tissue surfaces being measured. This system can display any view of the face in approximately 6 seconds,¹⁷ which is faster than previously reported 3-dimensional imaging systems. It is also possible to demonstrate soft tissue changes in 3 dimensions on the whole area of the face after surgery, whereas this is possible only in the midline with conventional cephalographs.

For long-term follow-up, the optical surface scan is entirely noninvasive, without the potential hazard of repeated exposure to ionizing radiation, and has the convenience of rapidly capturing an image that can be archived electronically. Images of the patients can also be stored on a hard disk drive or floppy disks, enabling further clinical evaluation and research at a later date.

However, the procedure requires the patient's cooperation to keep a constant position and relaxed facial posture, as any movement during the recording pe-

riod of 10 seconds will corrupt the image, resulting in motion artifacts. A separate study showed that using a headrest and a spirit level achieved a reproducible head position.¹² Also, the degree of irregularity of the surface reduces the high resolution of the scanned image. Furthermore, with the application of thin plate splines analysis,¹⁸ both area and volumetric changes in soft tissues can be calculated with greater accuracy, and with the introduction of this multivariate morphometric analysis, the main problem of the lack of clear statistical method for soft tissue changes is solved.

Optical surface scans of the soft tissues in conjunction with cephalometric analysis are routinely used in our department for preoperative surgical assessment, planning, and postoperative review of orthognathic surgery, and their use will very likely increase with wider availability of various surface scanners in the market. The number of university departments using optical scanners has also increased since they entered the imaging systems market. Nowadays, with wider availability, the cost has gone down to around 5,000 pounds. Considering the departments and practices performing orthognathic surgery on an average of 100 patients per year, the cost of the system per patient is minimal. The optical scanner serves other useful purposes for other patients' treatments, eg, facial swellings or facial prostheses. These 3-dimensional surgical simulations using surface scans would also serve to guide the surgeons and the patients.

In conclusion, the surface scan is comparable to a good-quality cephalograph for soft tissue profile assessment but has the additional advantages of being 3-dimensional, electronically storable, and noninvasive—advantages that supersede the traditional radiographic means of soft tissue analysis for postoperative follow-up.

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