3D Soft-Tissue, 2D Hard-Tissue and Psychosocial Changes Following Orthognathic Surgery

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Dedication

This work is dedicated to Mr. Younis Hajeer and Mrs. Moyasser Al-Haj Issa, my father and mother, who provided me with the opportunity to receive my education and who instilled in me a profound respect for the continuing pursuit of knowledge and the importance of hard working to achieve my dreams.

Summary

Background: Despite the three-dimensional (3D) nature of dentofacial deformities, assessment of orthognathic treatment outcome has been performed using lateral and frontal cephalograms as well as standardised photographs. A 3D imaging system (C3D®), based on the principles of stereophotogrammetry, has been developed for use in the assessment of facial changes following orthognathic surgery. Patients' perception of their facial appearance before and after orthognathic surgery has been evaluated using standardised questionnaires, but few studies have tried to link this perception with the underlying two-dimensional cephalometric data. Comparsions between patients' subjective opinions and 3D objective assessment of facial morphology have not been performed.

Aims: (1) To test the reliability of the 3D imaging system; (2) to determine the effect of orthognathic surgery on the 3D soft-tissue morphology; (3) to assess skeletal changes following orthognathic surgery; (4) to evaluate soft-tissue to hard-tissue displacement ratios; (5) to ascertain the impact of orthognathic surgery on patients' perception of their facial appearance and their psychosocial characteristics; (6) to explore the effect of dentofacial deformity, sex and age on the psychosocial characteristics; (7) to evaluate the extent of compatibility between the cephalometric and the three-dimensional measurements and (8) to determine if the magnitude of facial soft-tissue changes affects the perception of facial changes at six months following surgery.

Materials and Methods: Ethical approval was obtained from the related Local Area Ethics Committees. From the 107 orthognathic patients screened, seventy-five Caucasian patients were included in the study. Forty-six patients were diagnosed as skeletal Class III and twenty-four as skeletal Class II. The average age was 23.4 years (range=17–40 years) and the female-male ratio was 3:1. For the facial morphometric analyses, three subgroups were evaluated: subgroup A, Class III patients treated by maxillary advancement and mandibular setback; subgroup B, Class III patients treated by maxillary advancement alone and subgroup C, Class II patients treated by maxillary impaction and mandibular advancement. Patients were assessed at four times: within one week before surgery (T1), one month following surgery (T2), three

months following surgery (T3) and six months following surgery (T4). 3D images were captured and psycho-social questionnaires were completed at each assessment time. The questionnaires evaluated patients' motivation for surgery, perception of their facial appearance, personality characteristics and postsurgical satisfaction.

Accuracy of the C3D® system was established by comparing linear measurements taken directly from a dummy head with those taken indirectly through a software-based Facial Analysis Tool (FAT). Reproducibility of landmark identification was assessed by repeated digitisation of facial landmarks on ten randomly selected 3D facial models of orthognathic patients. The accuracy of the volumetric calculation algorithms was tested in vitro and in vivo by comparing the volumes of added facial explants obtained by water displacement with those obtained indirectly using 3D models (via the FAT).

In the main study, 3D facial models of orthognathic patients were built and exported to the FAT. Twenty-eight anthropometric landmarks were identified on-screen and their x-, y- and z- coordinates were obtained. Conventional and geometric morphometric analyses were performed to evaluate soft-tissue surgical change and the soft-tissue relapse. Superimposition of each couple of models was accomplished by partial Ordinary Procrustes Analysis and x-, y- and z- displacements of landmarks were obtained. A novel landmark-based facial asymmetry analysis was performed. Volumetric assessment at four facial regions was undertaken in subgroup A.

Lateral cephalograms were obtained at three times: within one month before surgery (T1), within one week after surgery (T2) and at six months following surgery (T3). These records were used to assess skeletal changes, skeletal relapse and soft-tissue to hard-tissue displacement ratios.

Results and Conclusions: C3D imaging system was proved to be accurate with high reproducibility. The reproducibility of landmark identification on 3D models was high for 24 out of the 34 anthropometric landmarks ($SD \leq 0.5$ mm). One volumetric algorithm in the Facial Analysis Tool had an acceptable accuracy for the assessment of volumetric changes following orthognathic surgery (mean error= 0.314 cm^3). The error of the cephalometric method was low and the simulation of mandibular closure proved to be reproducible. 2D soft-tissue measurements were compatible with 3D measurements in terms of distances, but angular measurements showed significant differences ($p<0.05$).

Significant 3D-based soft-tissue changes were observed in subgroups A, B and C following surgery. Significant increase in alar base width was detected in the three subgroups ($p<0.01$), wheras the mouth width had a significant decrease in subgroup A only ($p<0.01$). Relapse was observed between one month and three months for some facial landmarks. For the majority of comparisons, the relapse between three months and six months was insignificant ($p>0.05$). In subgroup A, mandibular setback was stable, whereas in subgroup C mandibular advancement relapsed significantly. In subgroup A, maxillary advancement relapsed significantly, whereas the horizontal relapse in subgroups B and C was insignificant. Significant soft-tissue to hard-tissue displacement ratios were found in the anteroposterior direction and to a lesser extent in the vertical direction.

Increased self-esteem, reduced anxiety and reduced depression were among the findings in the three subgroups as well as in Class II and Class III groups. Different trends of facial appearance perception were observed between subgroups A, B and C. Class II patients were significantly different from Class III patients in some psychosocial measures. Females, compared with males, had significantly less self-esteem at all assessment times and were more anxious at T1 and T2. Patients' perception of facial changes was not generally affected by the magnitude of z-displacements of facial landmarks assessed in 3D. Satisfaction was high among all subgroups despite the presence of residual anteroposterior skeletal discrepancies at T4 in subgroups B and C.

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Publications, Oral Presentations and Posters

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Oral presentations at scientific meetings

- '3D facial changes following orthognathic surgery – a preliminary report' presented at the Annual Meeting of the Scottish Society of Oral and Maxillofacial Surgery. Kilmarnock, Scotland, on the 8th of November 2001.

- '3D facial soft-tissue changes following orthognathic surgery: Class II and Class III deformities' presented to the 78th European Orthodontic Conference, Sorrento, Italy, 4th – 8th June 2002. **This Lecture was selected for the Houston Award Competition.**

- 'Applications of 3D imaging in Orthodontics, Oral and Maxillofacial Surgery' presented at the Orthodontic Technicians' programme at the 17th British Orthodontic Conference, Glasgow, Scotland, 22nd - 25th September 2002.

- '3D facial soft-tissue changes following orthognathic surgery in Class III patients' presented as a 'Free Topic Lecture' to the 17th British Orthodontic Conference, Glasgow, Scotland, 22nd - 25th September 2002.

- '3D facial soft-tissue changes following orthognathic surgery in Class II patients' presented to the IXth International Symposium on Dentofacial Development and Function, Istanbul, Turkey, 13th - 16th October 2002.

- 'Facial changes in Class III dentofacial deformities following orthognathic surgery' presented at the Annual Meeting of the Scottish Society of Oral and Maxillofacial Surgery, Perth, Scotland, 31st of Oct. and 1st of November 2002.

- '3D imaging of the face and teeth and its applications in Orthodontics' presented to the Annual Conference of the Orthodontic Technicians Association, London, England, 7th – 9th March 2003.

- 'Three-dimensional assessment of facial soft-tissue asymmetry of dentofacial deformities' has been accepted and will be presented to the Annual Scientific Meeting of the British Association of Oral and Maxillofacial Surgeons, Glasgow, Scotland, 11th – 13th June 2003.

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- 'Three-dimensional facial changes following orthognathic surgery – a preliminary report' was presented on the 1st of Oct. 2001 at the 16th British Orthodontic Conference, Harrogate, England, 30th September - 3rd October 2001. **This poster won the Gunter Russell Prize.**

- 'Three-dimensional facial soft-tissue changes following orthognathic surgery in Class II dentofacial deformities – linear and angular measurements' presented to the Scottish NHS Research Day meeting, Aberdeen, Scotland, 6th of September 2002.

- 'Motivational patterns of Class II and Class III orthognathic patients: a prospective assessment' presented to the 17th British Orthodontic Conference, Glasgow, Scotland, 22nd - 25th of September 2002.

- 'Three-dimensional assessment versus patients' perception of facial soft-tissue changes following orthognathic surgery' presented to the 17th British Orthodontic Conference, Glasgow, Scotland 22nd - 25th of September 2002.

- 'A prospective investigation on anxiety and depression levels of orthognathic patients' has been accepted and will be presented to the Annual Scientific Meeting of the British Association of Oral and Maxillofacial Surgeons, Glasgow, Scotland, 11th – 13th June 2003.

- 'Three-dimensional soft-tissue changes following orthognathic surgery in Class III patients: linear and angular measurements' has been accepted and will be presented to the 81st General Session of the International Association of Dental Research, Göteborg, Sweden, 25th – 28th June, 2003.

Declaration

This thesis is the original work of the author

Chapter One

Literature Review

1 Background and Literature Review

1.1 Orthognathic surgery

1.1.1 Definition of orthognathic surgery and its aspects

Orthognathic surgery is the correction of severe dentofacial deformities either by surgery alone or in combination with orthodontics. The past three decades have produced increasing sophistication in diagnosis and planning for orthognathic patients, improvements in related orthodontic mechanics and techniques and significant advances in anaesthesia and surgical approaches. Orthognathic surgery is now capable of repositioning one or both jaws, moving the chin in all three planes of space and repositioning dentoalveolar segments.

Impaired mastication, speech problems, temporomandibular joint dysfunction and psychological effects may be associated with a dentofacial deformity[1-3] and each may be addressed successfully with orthognathic correction[1,4].

1.1.2 Historical development of orthognathic surgery

A chronological historical overview of orthognathic surgery is given in Table 1.1. Orthognathic surgery, originated with Hullihen's mandibular procedure in 1849 in the USA[5]. Angle and Blair first described ostectomy of the horizontal ramus for the correction of mandibular prognathism[6] and Blair (1907) was the first to divide jaw deformities into five classes: mandibular prognathism, mandibular retrognathism, alveolar mandibular protrusion, alveolar maxillary protrusion and open bite[7].

Berger (1897) described a condylar osteotomy for the correction of prognathism while Babcock (1909) and Lindemann (1921) described an almost identical method to the one suggested earlier by Blair[8]. Between 1920 and 1940, some progress in orthognathic surgery was reported from the USA by Kazanjian[9]and Dingman (1944)[10]. Limberg (1928) also added some new operative procedures to the treatment of jaw deformities[11]. Between World War I and World War II, Pichler (1928), Wassmund (1935) and Hofer (1936) started to provide leadership in this field[8].

Development of orthognathic surgery halted until the early 1950s and then developed as a true specialty. Pichler founded the Vienna School of maxillofacial surgery [8] and was succeeded by his pupil Trauner who later moved to Graz. Trauner inaugurated several orthognathic surgical interventions and trained his successors Köle and Obwegeser. Wassmund established the German School in maxillofacial surgery [8]and developed the anterior maxillary osteotomy [12]. One of his pupils, Schuchardt (1955), developed the posterior maxillary osteotomy to correct open bite [10]. The main innovations of Köle were several new methods for changing the position of the alveolar process. He was the first to perform bimaxillary alveolar surgery for the correction of protrusion [13]. Obwegeser was the first to perform the 'intra-oral sagittal split of the mandible'[14]. This method was modified later by Dal-Pont (1961) and Hunsuck (1968)[15]. Converse (1952) in the USA was one of the innovators in orthognathic surgery during this period[10,16]but the USA lagged behind Europe in this field until the late 1970s[17-20].

Craniofacial surgery was first carried out using Le Fort III osteotomies by Gillies and Harrison[10,21] followed by Tessier[22]. Henderson and Jackson in Glasgow in 1973 were responsible for the development of the Le Fort II osteotomy for the correction of central midface deformity[23].

Rigid osteosynthesis principles were first applied to the fixation of a sagittal split osteotomy in 1974[8]. The first miniplate set was introduced in 1979[24] and these were modified by Steinhauser[25].

Some limitations of orthognathic surgery may be overcome by 'distraction osteogenesis', which is the 'mechanical induction of new bone between bony surfaces that are gradually pulled apart'[26]. This technique was developed from leg lengthening procedures of Ilizaroff in Russia (1989) and has been employed in the treatment of dentofacial deformities from the beginning of the 1990s[27].

Table 1.1	Historical overview of orthognathic surgery		
Author(s)	**Year**	**Place**	**Contribution to Orthognathic Surgery**
Hullihen	1849	USA	The first operation for correction of malocclusion and facial deformity by an anterior mandibular segmenta osteotomy
Cheever	1864	USA	The first to report an osteotomy technique in order to resect a nasopharyngeal mass in two patients (Cheever's operation)
Angle and Blair	1897	St.Louis, USA	The first described ostectomy of the horizontal ramus for the correction of a mandibular prognathism, 'St Louis operation'.
Berger	1897	Lyon, France	Description of a condylar osteotomy (condylectomy) for the correction of prognathism
Blair	1907	St. Louis, USA	One of the dominant leaders in the early orthognathic surgery. He described several methods of the correction of maxillofacial deformities. The first to divide jaw deformities into 5 classes. The first to realize the benefits of the cooperation between orthodontists and surgeons
Bruhn & Lindemann	1921	Germany	Description of a procedure similar to that mentioned by Blair (1907)
Limberg	1928	Russia	Proposal of some new operative procedures
Kostecka	1931	Prague,	Suggestion of a horizontal osteotomy with a Gigli saw as a 'blind procedure'.
Kazanjian **Dingman**	1932 1944	USA	New techniques and improvements for the correction of mandibular deformities
Pichler	1928	Vienna	The founder of the Vienna School of maxillofacial surgery
Axhausen	1934	Berlin, Germany	The first to mobilize and advance a malunited maxillary fracture by a Le Fort I osteotomy and an additional vertical osteotomy.
Wassmund	1935	Berlin, Germany	Started the German School of maxillofacial surgery Wassmund's procedure for the correction of maxillary protrusion (anterior maxillary osteotomy) Probably the first to perform a total maxillary osteotomy to correct an open bite case in 1927.
Hofer	1936	Linz	Used an intra-oral approach to accomplish a forward movement of the anterior maxillary segment
Gillies & Harrison	1942	London, UK	The first to perform a Le Fort III osteotomy.
Converse	1952	USA	Publication of several methods for corrections of jaw deformities. One of the first plastic surgeons who was interested in facial skeleton surgery as well as reconstructive procedures on the soft tissues.
Trauner	1955	Vienna → Graz, Austria	Inauguration of several orthognathic surgical procedures as well as teaching both Köle and Obwegeser
Schuchhardt	1955	Germany	The inventor of the posterior maxillary osteotomy (1955), so-called 'Schuchhardt operation' The oblique sagittal osteotomy of the ramus.
Köle	1959	Graz, Austria	The first to describe bimaxillary alveolar surgery for the correction of protrusion, deep bite, or short face. The lower labial segment repositioning. New techniques for open bite and for genioplasty Contribution to the first textbook in the literature about 'Surgical Orthodontics' in 1964

Table 1.1 contd.			
Author(s)	Year	Place	Contribution to Orthognathic Surgery
Obwegeser	1955	Zurich, Switzerland	The first to describe the 'intra-oral sagittal split of the mandible' in 1955. Introduction of inverted-L osteotomy. The first to present a large series of Le Fort I osteotomies (1969) carried out in the 1960s. Description of different methods of genioplasty The first, probably, to perform total maxillary and mandibular osteotomies in 1970 (Bimaxillary surgery)
Dal-Pont	1958	Italy	Modification of the original sagittal split procedure
Hunsuck	1968	USA	Modification of Obwegeser's sagittal split procedure
Tessier	1967	France	The founder of craniofacial surgery Treated difficult cases of severe orbito-craniofacial deformities.
Sowray &Haskell	1968	London, UK	Sowray-Haskell anterior mandibuloplasty (symphysea ostectomy)
Poswillo	1968	London, UK	Improving the post-condylar cartilage grafts techniques for the correction of distocclusion in adolescence
Spiessl	1974	Switzerland	The first maxillofacial surgeon to apply the principles of rigid osteosynthesis to the fixation of a sagittal split osteotomy
McIntosh & Carlotti	1975	USA	Introduction of total subapical mandibular osteotomy
Luhr	1979	Germany	Improvements of miniplates and introduction of his first miniplate set.
Foster & Henderson	1981	London, UK	Anterior mandibuloplasty

1.1.3 Surgical interventions

Dentofacial deformities are commonly associated with marked problems, which cannot be treated ideally by tooth movements alone. Three possible treatments exist for a jaw discrepancy according to Proffit and White[(28)]: modification of growth, camouflage that produces a dental compensation for the skeletal discrepancy or surgical repositioning of the jaws and/or dentoalveolar segments to obtain proper positioning. Growth modification has proven efficacy in growing patients[(29)]. Camouflage, which is the alignment of teeth to obtain proper function without any correction of underlying jaw discrepancy, is feasible when reasonably normal dental occlusion can be achieved with acceptable facial aesthetics[(28)]. However, the more severe the condition, the more the need for surgical correction and the less likelihood that compensating tooth movements can establish proper facial balance as well as functional occlusion.

Proffit and Ackerman (1984) used the 'envelope of discrepancy', which is a schematic representation, to illustrate the limitations of movement with these three treatments[(30)].

However, this envelope is a two-dimensional representation, which does not include the third dimension, i.e. the transverse direction, of the possible movement with each type of treatment.

Surgery to the maxillofacial complex may be classified according to the number of jaws involved: one-jaw or two-jaw; type of osteotomy: total-jaw or segmental; type of approach: intra-oral, extra-oral, intra- and extra-oral; location of the surgery: midface or mandibular including ramus, body, and chin; direction of correction: vertical, anteroposterior, transverse or a combination of these(1,12,31,32).

Orthodontic treatment may not be indicated before or after surgery for several reasons, although to achieve the optimal outcome, planned orthodontics is usually incorporated.

1.1.3.1 Midface surgery

1.1.3.1.1 Total maxillary surgery

Le Fort I osteotomy is the most versatile procedure for the correction of midface deformities(17,18,33). Le Fort I 'step' osteotomy is one of its modifications to permit a horizontal maxillary movement without altering the vertical dimension(34).

Anterior Le Fort II osteotomy was proposed as a solution for nasomaxillary hypoplasia by Converse et al (1970)(35), while the pyramidal Le Fort II osteotomy was described by Henderson and Jackson (1973)(23). Quadrangular Le Fort II osteotomy was first described by Kufner (1971)(36).

The Le Fort III osteotomy is used to correct severe midfacial congenital deformities and syndromes, e.g. Apert, Crouzon and Pfieffer syndrome. Several modifications have been proposed such as the Le Fort III (malar-maxillary) advancement, Le Fort III (naso-malar) advancement and malar bone advancement. The last two operations do not contain any movement of the maxillary bone(37).

1.1.3.1.2 Segmental maxillary osteotomies:

Subapical maxillary osteotomies include: single tooth osteotomy which is limited mainly to the upper anterior teeth; corticotomy to permit surgically assisted retraction of upper anterior teeth in Class II Division 1 malocclusion(32); anterior segmental osteotomy using the Wassmund technique, the Wunderer's modification, or a more recent method to alter the premaxilla vertically and/or anteroposteriorly(37); posterior segmental osteotomy suggested by Schuchardt (1959) and modified by Kufner(36) and horseshoe ostectomy(38). These procedures can be used to correct open bite, posterior cross-bite, or to open or to close a space in the arch.

1.1.3.2 Mandibular surgery

1.1.3.2.1 Ramus procedures

Subcondylar osteotomy(10) can be done extra-orally and, more commonly, intra-orally. It is indicated, sometimes, to correct mild mandibular prognathism. Condylectomy is used mainly to treat condylar hyperplasia, mandibular asymmetry caused by hemifacial microsomia, unilateral mandibular hypertrophy or TMJ ankylosis(32).

The bilateral sagittal split osteotomy (BSSO) is the most versatile mandibular osteotomy(15,39,40). It is used mainly in mandibular setback or advancement. It could be used to correct skeletal open bite(37). Vertical subsigmoid osteotomy (VSO) is the alternative of BSSO in setback procedures and it is used, also, for correction of mandibular asymmetries. The trans-oral approach has become more popular deleting the disadvantages of having an external scar or occasional damage to the mandibular branch of the facial nerve(31). Other less common approaches are the inverted 'L' osteotomy, the 'C' osteotomy(41) and the arcing osteotomy(37). Post-condylar grafting(42,43) has also been used as an early step in the management of severe mandibular retrusion to minimize the complexity of surgical intervention later on.

1.1.3.2.2 Body procedures

Blair (1907) was the first to describe body osteotomy of the mandible(7). The main indication is the presence of deformity in the body of the mandible, and where there are missing teeth or teeth that can be sacrificed in the lower arch. Body ostectomies in the anterior part of the mandible include step osteotomy/ostectomy, midline symphyseal osteotomy/ostectomy and the Sowray-Haskell procedure[44]. Those that are carried out posterior to the mental foramen include: Thoma's Y-shaped ostectomy, rectangular ostectomy, Thomas' Trapezoid ostectomy, inverted V-shaped ostectomy[16] and L-shaped osteotomy[9]. Mandibuloplasty is a term used to describe those operations on the lower border of the mandible, such as the anterior mandibuloplasty[45].

1.1.3.2.3 Subapical osteotomies

Developed originally by Hullihen in 1849, the Köle procedure is now used to correct malposition of the lower anterior segment and to close open bite. Posterior subapical osteotomy, although a technically difficult procedure, can be employed to level super-erupted posterior mandibular teeth or to upright them[37]. The total subapical osteotomy, proposed in 1975[46], has been used mainly in Class II malocclusion with a low mandibular plane angle and a normal anterior position of Pogonion[37].

1.1.3.3 Genioplasty

Chin surgery is commonly combined with other orthognathic procedures. About 15% of all dentofacial deformities primarily involve the chin [32]. Obwegeser in 1955 first described the intra-oral approach, or labial sulcus incision, to the osteotomy of the anterior mandibular lower border[14].

Several types of genioplasty techniques exist. The functional genioplasty is used to correct abnormal mentalis muscle activity at an early age. Augmentation genioplasty, however, includes: horizontal advancement osteotomy, vertical downgraft osteotomy with interpositional graft, alloplastic onlay grafts, biological onlay grafting and lateral expansion osteotomy (midline osteotomy). Reduction genioplasty includes the following: horizontal sliding osteotomy and setback, vertical reduction osteotomy with wedge ostectomy, shave of the chin protuberance and lateral reduction. A fourth technique is the asymmetrical genioplasty with vertical or lateral shift of the genial segment[32].

1.1.3.4 Adjunctive cosmetic (aesthetic) surgery

Rhinoplasty, used to correct any nasal deformity and to improve function, is usually carried out after orthognathic surgery[32]. Where the contours of the neck are obliterated by localized accumulation of adipose tissue, suction or transoral lipectomy is indicated[32].

1.1.4 Dentofacial deformities

1.1.4.1 General Classification of dentofacial deformities

It is more appropriate to describe the skeletal relationships rather than simply the dental relationships, since orthognathic surgery is used to correct the underlying skeletal base discrepancies. The occlusion by itself may be most misleading[31].

1.1.4.1.1 Common dentofacial deformities

Table 1.2 summarizes the possible dentofacial deformities, which may exist in the maxilla or the mandible. Maxillary deformities may arise in the anteroposterior, vertical or transverse direction. Mandibular deformities include mandibular anteroposterior excess or deficiency as well as asymmetry. Chin deformities include macrogenia and microgenia which are often associated with other mandibular deformities. Combined maxillary-mandibular deformities can be seen in the short face syndrome, the long face syndrome, apertognathia and lower facial asymmetry[32].

1.1.4.1.2 Uncommon dentofacial deformities

Cleft lip and palate may be associated with Pierre Robin syndrome, Treacher-Collins syndrome or Apert's syndrome. Facial asymmetry may result from hemifacial microsomia, hemifacial atrophy, hemifacial hypertrophy or neurofibromatosis. Midface deficiencies may arise from craniosynostoses (Apert's, Crouzon's, and Pfeiffer), Binder's syndrome, achondroplasia or cleidocranial dysplasia. Mandibular deficiencies may be one of the signs of Pierre Robin syndrome, Treacher-Collins syndrome or hemifacial microsomia[32]. On the other hand, mandibular prognathism could be one of the facial characteristics of Gorlin-Goltz syndrome, osteogenesis imperfecta, Marfan syndrome or Klinefelter syndrome.

1.1.4.2 Facial characteristics of certain dentofacial deformities

1.1.4.2.1 Class I dentofacial deformity

1.1.4.2.1.1 Class I dentofacial deformity with vertical maxillary excess

In the frontal view, there is a long, tapering face with lip incompetence and excessive exposure of the upper incisor teeth when the lips are in the relaxed posture. In addition, increased lower facial third, a narrow alar base and flat paranasal areas are present(47). In the lateral view, the most common features are: relatively large nose, flat to concave paranasal areas, excessive interlabial gap, flat upper lip without a vermilion curl and usually an everted lower lip(47).

1.1.4.2.1.2 Class I dentofacial deformity with microgenia and retrogenia

In profile, microgenia is simple retrusion of the chin with a normal maxillomandibular skeletal base relationship(31). The term 'retrogenia' relates to the deficient chin in profile, while the term 'microgenia' relates to the total chin area, but clearly both may describe the same patient(31). The main features of this deformity are retrusion of the chin button, double-chin appearance, increased labiomental angle and lip incompetence.

1.1.4.2.2 Class II dentofacial deformity

1.1.4.2.2.1 Mandibular deficiency in patients with short or normal face height

There is a well-developed chin button, with an appearance of deficiency at the lower lip. Lower face height tends to be short, and the shorter it is, the greater the tendency for a lower lip curl which accentuates the labiomental fold. The upper face and midface appear normal and well balanced. The elevator muscles of the mandible appear well developed. Skeletally, the mandibular plane angle tends to be flat and the gonial angle relatively squared(31,48).

1.1.4.2.2.2 Mandibular deficiency in patients with open bite

The main features are increased lower third face height, excessive interlabial distance, everted lower lip, recessive chin and usually decreased exposure of the upper anterior teeth(47).

1.1.4.2.3 Long-face syndrome

The primary distinguishing characteristic is the large total face height especially in the lower third. This is usually accompanied with anteroposterior jaw malrelationships. One sign of excessive face height is lip incompetence, with separation of the lips at rest, which exceeds 4 mm[49]. On smiling, there is excessive upper incisor display[31]. Narrow cheeks, narrow and pinched nostrils, pointed chin, separated lips, exaggerated shadows beneath the eyes, and increased nasolabial angulation in profile are characteristic[31,49].

1.1.4.2.4 Short-face syndrome

The so-called 'short-face syndrome' is characterized by: a broad and square face, reduced anterior facial height, broad nose, increased alar flare, decreased nasolabial angle, wide oral commissure, reduced upper anterior tooth display and a profile which looks more normal with the mandible in the rest position[31,50,51].

1.1.4.2.5 Class III dentofacial deformity

The Class III deformity is multifactorial in its developmental process. A large mandible, small maxilla or both, and possibly open bite may be components. On frontal facial examination, those with a significant component of mandibular prognathism usually show a flat appearance in the lower face with little or no projection of the chin button and a reduced labiomental fold. The tight soft tissue seems to be related to soft-tissue stretch as throat length increases[52].

From the profile view, a well-defined inferior mandibular border is noticed in true prognathism, whereas in relative prognathism, where the maxilla is at fault, the neck-chin angle often is poorly defined and the submental area may show some layers of excess connective and adipose tissue[52]. A skeletal Class III patient with midface deficiency often displays a flat appearance of the upper lip along with a thin vermilion border and reduced maxillary incisor display at rest[52]. Upper lip height is often reduced below its Caucasian normal values of 20 – 24 mm. Frequently there is an acute nasolabial angle with the columella of the nose oriented more horizontally than in normal due to reduced nasal growth[52]. One of the important features of midface deficiency is the narrowed alar base and deficient malar, paranasal and infraorbital areas, the latter usually resulting in increased scleral show[31,52].

1.1.4.2.6 True midface dentofacial deformities

According to Epker et al[47], three basic variations of the true midface dentofacial deformity can be observed: maxillary-malar deficiency / retrusion, maxillary-nasal deficiency / retrusion and maxillary-malar-nasal deficiency / retrusion. One of the common findings in the three types is the paranasal hollowness, while the retrusion of the malar eminence is absent in maxillary-nasal deficiency. Infraorbital rim retrusion is present in the three types but nasal dorsum retrusion does not characterize the maxillary-malar deficiency[47].

Midface deficiencies may also be classified according to Henderson and Jackson (1973) as follows: supra-apical maxillary hypoplasia, nasomaxillary hypoplasia and total midfacial hypoplasia. Nasomaxillary hypoplasia is divided into four subgroups: involvement of the dentoalveolar segment, Binder's syndrome, cleft palate syndrome and panfacial problems[23].

1.1.4.2.7 Facial features with other deformities

1.1.4.2.7.1 Transverse maxillomandibular discrepancy

A transverse maxillomandibular discrepancy exists if the teeth exhibit a disparity in arch width when the dental models are held in centric occlusion or centric relation. The transverse discrepancy may exist as the primary problem or it may appear associated with maxillary, mandibular or maxillomandibular dentofacial deformities[47].

With isolated cases, in which the transverse discrepancy is the only problem, the facial features are not affected significantly unless there is a large discrepancy. The smile could be one of the facial expressions that is related to some degree to the relative transverse dimension of the maxilla to the mandible. The enlargement of the rami of the mandible transversely is called 'bilateral massetric hypertrophy', which is secondary to an enlarged masseter muscle and characterized by overdevelopment of the angles of the mandible[31].

1.1.4.2.7.2 Bimaxillary protrusion

Bimaxillary protrusion is a musculo-skeletal dentofacial deformity characterized by protrusion of the alveolar bone and teeth in both the upper and lower jaws with variable anteroposterior skeletal relationships- Class I, Class II or Class III [53]. The facial features in the full-face view, regardless of the severity of the condition, include upper and lower lip protrusion, very marked labiomental fold and eversion of the lips. Laterally, the common features are upper and lower lip protrusion, acute nasolabial angle, low lip line and in many cases mild chin retrusion [31,54,55].

1.1.4.2.7.3 Dentofacial asymmetry

Mild degrees of left-right asymmetry, in apparently symmetric faces, are of little concern. More severe asymmetries of the face and jaws, large enough to be easily detected on clinical examination, are found frequently in those with dentofacial deformity[56]. Deviation of the chin to one side is one of the most common features frontally. Hemifacial microsomia causes asymmetry, but has a lot of variations in its clinical features[31]. Congenital or syndromic unilateral dentofacial deformities (e.g. cleft lip and palate) are outside the focus of this literature review and will not be discussed here.

1.2 Methods of facial morphometric assessment

1.2.1 Anthropometry

Morphometry derives from the Greek: 'morph' meaning 'shape' and 'metron' meaning 'measurement'. Anthropometry is a specialised area of morphometry relating to the human form. Facial anthropometry is, therefore, the measurement of the shape of the human face[57]. It has been widely accepted that facial anthropometry is a useful clinical means of quantitative assessment of facial surface anantomy[58]. The technique relies on the identifaction of soft-tissue landmarks and the direct measurement of distances, arcs and angles between these points. In the last three decades, the face has been assessed comprehensively using the standardised methodology developed by Farkas in order to provide a normative database[59-61]. However, direct anthropometry has several limitations as a method of facial assessment and documentation. Great skill is required to apply callipers to the face to avoid surface depression, thereby, introducing error in the assessment. It is a time- and labour-consuming procedure, which limits the number of measurements that can be performed directly on the patient's face. Lack of a unified methodology between different research centres has resulted in confusion in the application of techniques and in the interpretation of findings[58]. In addition, the conventional morphometric methods applied in facial anthropometry (i.e. linear, archial and angular measurements) do not provide any information about the geomotric properties and relationships between the different facial features under assessment[57].

1.2.2 Conventional two-dimensional methods

1.2.2.1 Cephalometry

In 1931, the methodology of cephalometric radiography came to full fruition when Broadbent in the USA and Hofrath in Germany simultaneously published methods to obtain standardized head radiographs[62,63]. The principle of standardized head radiography involves a constant focal-spot-to-object distance and preferably a constant object-to-film distance[64]. Broadbent's cephalometer was designed to enable the operator to obtain a lateral cephalogram as well as a frontal one[62]. After the invention of cephalometric radiography, Lucien de Coster from Belgium was the first to publish an analysis based on proportional relationships in the face conforming to principles used in antiquity[65].

Various methods in ancient civilizations have applied mathematical measurements to the human face and form[64]. The search to relate the ideality of proportions to the physical reality flourished through the contributions of Leonardo da Vanci in the fifteenth century and the *Books of Proportions* by Dûrer in the beginning of the seventeenth century[64]. Camper in the eighteenth century adopted the idea that a change in the angulation of the vertical to the horizontal axes of a coordinate system could produce differences in facial profile. His line, which extended from 'porus acusticus' to a point below the nose, became the reference line for the angular measurements used in studies of facial morphology and aging[66]. The terms 'prognathic' and 'orthognathic', introduced by Retsius, are tied to Camper's illustrations of facial form in man and primates[64].

The first cephalometric analysis in the USA by Downs was designed to illustrate the spread of all measurements of an individual by plotting these values on a chart at ± 1 and ±2 standard deviations around a vertical representing the midpoint of the distribution of each variable[67,68]. Downs' polygon was an effective method of quantitatively and qualitatively illustrating a static cephalometric analysis[69]. Downs' analysis included three important measurements: the facial angle, angle AB to the facial plane and the angle of convexity. The facial angle is the angle of the facial plane (N-Pog) to the Frankfort plane; it indicated whether the lower face was protrusive, retrusive or upright. The angle AB to the facial plane described clearly the relationship between the facial profile and the skeletal bases of the upper and lower teeth. The angle of convexity (N-A to A-Pog) was used to evaluate the relationship between the maxillary dental base and the mandible as seen in profile, thus giving an indication of the contour of the face[67,68]. However, this analysis just dealt with the skeletal and dental components of the face without any direct measurement from the soft tissues.

Steiner in 1953 proposed the appraisal of various parts of the skull separately, namely the skeletal, dental and soft tissues[70]. The soft tissue analysis provides a means of assessing the balance and harmony of the lower facial profile. Steiner elected to use the anterior cranial base (Sella to Nasion) as the line of reference to which the jaws would be related[70], instead of the Frankfort Horizontal line used by Downs. The lips, in well-balanced faces, should touch a line extending from the soft tissue contour of the chin to the middle of an S formed by the lower border of the nose. This line is referred to as the S-line[71]. Steiner's S-line is still used in orthodontics and orthognathic research in addition to Steiner's skeletal and dental parameters[72-75].

Burstone was the first to define landmarks on the soft-tissue profile on the lateral cephalogram[76]. He defined six key landmarks, which were used in a system of angular measurements to evaluate contours and inclinations of segments of the facial profile. Nasolabial angle and facial contour angle are two of many soft-tissue measurements that he proposed for use.

Sassouni's analysis was the first cephalometric analysis to emphasize vertical as well as horizontal relationships and the interaction between vertical and horizontal proportions[77]. Sassouni coined the terms 'skeletal open bite' and 'skeletal deep bite' depending upon the divergence or convergence of the four horizontal anatomic planes used in his analysis. This archial analysis was used later in a photo-cephalometric analysis in treatment planning for surgical correction of dentofacial disharmonies[78], but it did not gain popularity.

Ricketts' analysis was another good tool to assess the facial form from cephalograms. Evaluation of the facial width, facial height and facial contour depended upon the use of the facial angle, the XY axis and the facial plane. Facial contour was measured as the angle between the facial plane (N-Pog) and A-Pog[79]. The aesthetic line (E-line) of Ricketts is one of the common lines to assess the balance of the facial profile, which has been used in many orthognathic and orthodontic analyses[73,75,80,81]. E-line extends from soft-tissue pogonion to pronasale (tip of the nose). Ricketts analysis contains eleven measurements, which were categorized into four subgroups: the chin in space, skeletal convexity, teeth and profile[82,83].

In an effort to create a clinically useful analysis, McNamara divided the craniofacial skeletal complex into five major sections: maxilla to cranial base, maxilla to mandible, mandible to cranial base, dentition and airway[84]. McNamara stated that the maxilla in the skull should be assessed clinically by observing the soft-tissue profile, and then evaluated by comparing the various lateral cephalometric measurements to normative standards[73,84]. Soft-tissue evaluation consists of the nasolabial angle and the cant of the upper lip. The average nasolabial angle in adult males and females with well-balanced jaws was indicated to be 102°. It was clear that McNamara's analysis could not be utilised for comprehensive analysis of soft-tissue changes following orthognathic surgery.

Several tools and analyses have been proposed to help in the assessment of orthognathic patients, pre- and post-operatively, such as the 'dentofacial deformities evaluation'[85], Burstone's method[86], Di Paolo's quadrilateral analysis[87,88], the lateral photometric analysis described by Butow [89] and Bergman's analysis[90].

There are, currently, many measurements to assess soft-tissue facial changes but the most common ones include: vertical facial proportions, facial asymmetry measurements, anterior upper teeth exposure at rest, dental exposure on smiling, middle to lower facial third ratio, upper lip to lower lip height ratio, nose width and length, nasolabial angle, upper lip prominence, lower lip prominence, interlabial gap, labiomental fold, zero-meridian, chin prominence, chin-neck angle, soft-tissue angle of facial convexity, E-line of Ricketts, S-line of Steiner, Z angle of Merrifield, and Holdaway's soft-tissue measurements(70,73,76,80,82,86,90-93,93-96).

A cephalometric evaluation of the craniofacial complex requires a plane of reference from which to assess the location of various anatomic structures. Traditionally, two planes have been used, namely the Sella-Nasion plane (SN) and the Frankfort horizontal (FH). The 'SN' plane may provide erroneous information if the inclination of this plane is either too high or too low. The 'FH' plane has been advocated to represent more accurately the clinical impression of jaw position(97,98). As an alternative, the use of a constructed horizontal drawn through nasion at an angle of 7 degrees to the SN line has been suggested by Legan and Burstone(86). Another approach involves obtaining the cephalogram with the head in the natural head position(99). 'True Horizontal' is then drawn perpendicular to a plumb line on the radiograph. The Delaire's cranial base line(100) and the Bishara's constructed 'NO' line(101,102) have not been been used commonly as reference frames in the orthognathic literature.

A posteroanterior cephalometric film is used usually in the assessment of facial asymmetry. Therefore, the analysis of the film is oriented primarily toward quantifying and locating any asymmetry that may be present(103). Another indication for its use is the atypical vertical maxillary excess deformity when 5 mm or more of maxillary superior repositioning is contemplated(47). Frontal radiographs, however, have not been used widely in cephalometric research over the last four decades and their main use has been restricted to asymmetry and some three-dimensional studies (104,105).

Each cephalometric study examines several different measurements to arrive at the diagnosis and treatment plan. When different cephalometric analyses were used to examine the same orthognathic patients, different diagnoses, treatment plans and treatment outcomes were generated(106). Wylie et al concluded, "cephalometrics could not be considered as the primary diagnostic tool in the correction of dentofacial deformities."

1.2.2.2 Photography and photogrammetry

Although diagnostic judgments may be made from the clinical examination of the orthognathic patient, extraoral and intraoral photographs are an essential part of diagnostic records. The most common extraoral photographs for the assessment of the face are full-face with lips relaxed, full-face smile, 45-degree oblique and profile(103).

Jacobson and Vlachos considered the human face as a "complex mosaic of lines, angles, shapes, textures and colours" and "the interplay of these elements produces an infinite variety of facial forms from near perfect symmetry to extreme disproportions"(95). An aesthetically pleasing face is regarded as one in which the various facial features are well proportioned and balanced and relate well to the other facial features, whether viewed from the front or the side(95).

Photogrammetry is defined as "the science or art of obtaining reliable measurements by means of photographs"(107). The major role of photographs in assessing facial traits, before and after treatment, followed the work of Sheldon on 'photogrammetry' in 1940(107). Neger(108) used different reference lines and angles to make his method of analysis sensitive enough to detect differences between the various malocclusion types. Extraoral photographs cannot detect asymmetries in dynamic lip functions, the relationship of dental to skeletal midlines or the 3D nature of the clinical appearance of asymmetry(103). Furthermore, many researchers believe that photogrammetry depends on a single view of the face, so it can only provide 60 percent of the measurements provided by anthropometry(109).

1.2.3 Three-dimensional (3D) imaging techniques

Many three-dimensional techniques have been used in attempts to capture facial topography and to meet the shortcomings of conventional two-dimensional (photograph or radiograph) methods(110). These techniques have included: morphanalysis(111), laser scanning(112,113), 3D computerized tomography scanning(114), Stereolithography(115), 3D ultrasonography(116), 3D facial morphometry(117,118), digigraph imaging(119), Moiré topography(120) and contour photography(121).

1.2.3.1 3D cephalometry

3D cephalometry is based on manual techniques for abstracting 3D coordinate data from two biorthogonal head films, i.e. lateral and posteroanterior radiographs[122-124]. The main drawbacks of this technique are patient exposure to radiation, difficulties in locating accurately the same landmarks in two biorthogonal radiographs, lack of soft-tissue contour assessment and the time-consuming nature of the procedure.

1.2.3.2 Morphanalysis

Morphanalysis is a method of obtaining 3D records using photographs, radiographs and study models of a patient[111,125]. Rabey[126] claimed that the principal benefits of morphanalysis in orthognathic surgery were analytic validity, statistical validity, accuracy and superior communications. The equipment, however, is elaborate and expensive. The technique is time consuming and is not very practical for every day use. A similar system was proposed by Fanibunda[127] to provide the orthodontist with a true life-size illustration of hard and soft tissues of the face in their correct relationship to each other. The shortcomings of this system are similar to those of the original morphanalysis system.

1.2.3.3 CT-assisted 3D imaging

In the mid-1980's CT-assisted 3D imaging and modelling of the skull structures were introduced for use in maxillofacial surgery[114]. The main disadvantages of this technique are: patient exposure to a high radiation dose and as a result it is not suitable for long-term assessment following orthognathic surgery; limited resolution of facial soft-tissues due to slice spacing, which can be 5mm or more; and metal objects such as dental restorations and fixed orthodontic appliances create artefacts, because of the reduced penetrability to CT.

Recently, Xia et al[128]developed a system for reconstructing 3D soft- and hard-tissues from sequential CT slices using a surface rendering technique followed by extraction of facial features from 3D soft-tissues. A conformed facial mesh was constructed from a generic mesh. Three digitised colour portraits were texture-mapped onto the 3D head mesh. Although this technique was interesting in showing the importance of having the full colour details of patients' faces in the final output, the validity of the construction process was not evaluated. The three 2D colour portraits were taken on a different occasion from the CT scans, with potential for change of facial expression. The accuracy of the reconstructed 3D soft-tissue model is affected by the long capture time (about 2 seconds), which would not be suitable for children. In addition, landmark-identification reproducibility tests were not performed to assess the accuracy of facial texture mapping.

1.2.3.4 Stereolithography

Stereolithography is a method of organ-model-production based on computed tomography scans which enables the representation of complex 3D anatomical structures[115]. The obvious shortcomings of this technique are: the need for experienced and skilled operators to obtain accurate 3D modelling; expense of the method; patient exposure to radiation for CT scans; and no production of soft-tissue in machine-readable form[110].

1.2.3.5 3D Laser Scanning

The development of laser scanning techniques provides a less invasive method for capturing the maxillofacial region in three dimensions. It has been used in clinical auditing of surgical outcome and measuring surgical relapse[112,113]. The data are stored in computer memory and approximately 20,000 coordinates on the facial surface are derived. The shortcomings of this technique are: the slow imaging method, taking 8 - 10 seconds to scan the face, so any change in the patient's head or facial expression during scanning or any alteration in facial configurations will distort the scanned image; the patient's eyes should be closed during scanning for protection; soft-tissue surface texture is not captured, which results in difficulties in identification of some landmarks which are dependent on surface colour. While white-light laser approaches are now capable of imaging surface texture colour, the shortcomings listed above persist.

1.2.3.6 Moiré topography and contour photography

Both techniques use grid projections during exposure resulting in standardised contour lines on the face[120,121]. Moiré topography delivers 3D information based on the contour fringes and fringes intervals. Difficulties are encountered if a surface has sharp features, so these two methods are simple to use on smoothly contoured faces.

In addition, great care is needed in positioning the head as a small change in head position produces a large change in fringe pattern. A 3D measuring system was proposed by Motoyoshi et al[18] but this system does not capture the normal facial texture and, subsequently, landmark identification would be difficult. The authors did not propose any objective method for studying facial changes following surgery.

1.2.3.7 Three-dimensional Facial Morphometry (3DFM)

This system comprises two charge-coupled-device (CCD) cameras that capture the subject, real-time hardware for the recognition of markers placed on patients' faces and software for the 3D reconstruction of landmarks' x, y, z, coordinates relative to a reference system[(117,118,129)].

This system was used to assess soft-tissue differences between children with Class I and Class II occlusions[(117)], sexual dimorphism in normal children[(118)], facial asymmetry[(130,131)], differences in facial morphology in female adults[(132)], the relationship between 3D facial morphometry and the perception of attractiveness in young children[(133)]. In addition, head flexion and extension in young subjects[(134)], growth and development of the nose[(135)], facial volume changes during normal human growth and development[(136)], craniofacial growth from 6 years to adulthood[(137)] and facial changes following orthognathic surgery[(129)] have been evaluated.

The process of placing landmarks on the face is time- and labour-consuming and cannot be performed consistently between consecutive sessions due to movement of facial features. Although the system has been used extensively to investigate facial changes, no life-like models have been produced to show the natural soft-tissue appearance of the face. This system could not be used as a 3D treatment-planning tool or as a communication medium with orthognathic surgery patients.

1.2.3.8 3D Ultrasonography

Ultrasonography was also proposed to capture 3D data. This technique delivers a reflection picture, which is transformed into digital information[(116)]. Ultrasonography waves do not visualize bone or pass through air, which acts as an absolute barrier both during emission and reflection. Therefore, a specific contact probe is required to generate a 3D database. This system would give the 3D coordinates of the landmarks chosen but it will not produce a 3D image. The procedure is time consuming and necessitates a cooperative patient as well as a skilful operator. Motion of the head during data acquisition introduces errors, while touching facial soft-tissues may cause distortions of their spatial positions.

1.2.3.9 3D electromagnetic contact-based digitisers

In the past few years, Ferrario and his co-workers(138,139) started to obtain the three-dimensional coordinates of landmarks using an electromagnetic three-dimensional digitiser. Their preliminary report showed that this digitiser could assess the coordinates of facial landmarks precisely and reliably. Analysis of the lips was done quantitatively by collecting the three-dimensional coordinates of soft tissue landmarks on the lips and nose in 180 healthy young adults(139).

1.2.3.10 Stereophotogrammetry

1.2.3.10.1 Preliminary stereophotogrammetry

Stereophotogrammetry refers to the special case where two cameras, configured as a stereo-pair, are used to recover the 3D distance to features on the surface of the face by means of triangulation. This technique has evolved to provide a more accurate evaluation of the face and may adopt one or more stereo-pair views to increase the number of 3D measurements that can be obtained to compute a 3D facial surface model. To reduce inaccuracy due to movement, photographs from each side of the face are taken simultaneously and the duration of exposure has been reduced with improvement in technology.

Clinical use of stereophotogrammetry was first reported by Thalmann-Degan in 1944 according to Burke and Beard(140). Several stereophotogrammetric techniques have been proposed in the literature before the onset of contemporary digital stereophotogrammetry(140-144).

Burke and Beard applied stereophotogrammetry clinically by using a portable stereometric camera that is simpler, less expensive, and is optically linked with a simple plotting instrument(141). The clinician could record directly x, y and z coordinates of facial landmarks identified on the face with a white brush, immediately before taking the photograph. The linear measurements could be produced in minutes [145]. The stereophotogrammetric method was also employed by MacGregor et al[142] with a stereoplotter and electronic coordinate recorder. They immobilised the patient's head with individually prepared acrylic earpieces and a nosepiece to investigate facial changes following the loss of teeth[142]. A similar method was used by Bjorn et al[143] to assess facial swelling.

Berkowitz and Cuzzi[144] used three stereometric cameras to assess facial changes produced by reconstructive surgery for five patients with craniofacial deformities. Each stereometric camera consisted of a specially designed pair of individual metric cameras and a surface contrast optical projector unit. To compress the hair uniformly, a thin elastic cap was used, but measurements related to the cranium were not reliable. A minicomputer was programmed to scale each view from model scale to object scale, to perform coordinate axis transformations, to place all coordinates in the same orthogonal system and to store data in the form of optical and graphic three-dimensional analogs (contour maps, cross sections) for future review.

1.2.3.10.2 Contemporary digital stereophotogrammetry

The incorporation of recent technology has given the ability to process complex algorithms in order to convert simple photographs to 3D measurements of facial changes.

Kobayashi et al[146] used reference points marked on the face, a metal reference frame, a pair of cameras and a computer to produce 3D wire-frame models which could be seen from any point of view. The soft-tissue analysis consisted of calculating 3D values of reference points on the face by perspective transformation of their values into two pairs of photographs. Ras et al[147] demonstrated a stereophotogrammetric system that gives the 3D coordinates of any chosen facial landmarks. However, the configuration of their system was not enough to cover the whole face and the final output lacked the colour information needed for accurate landmark identification.

Techalertpaisarn and Kuroda[148] used two LCD projectors, charge-coupled device (CCD) cameras and a computer to produce a 3D image of the face that can be edited, shifted or rotated in any direction. This system needed at least 2 seconds to capture an image through projecting eight alternating patterns of black and white stripes (structured light) onto the patient's face, which is too long to be reliable in avoiding head movements especially in children. No life-like soft-tissue models were produced by this method.

Recently, Nguyen et al[149] described a 3D imaging system that required structured light also to capture the patient's face. With this system, however, there is a high possibility of having jagged areas on the reconstructed image because of head movements between multiple captures. A complete facial model necessitated the rotation of the head around a vertical axis, which was difficult and impractical. Consequently, the clinical applicability of their system was not proven and the project was concluded without any further developments[150].

1.2.3.10.3 A 3D non-contact vision-based imaging system: C3D®

C3D® was based on the Active Stereo Probe[151,152], funded by the UK Department of Trade and Industry, that employed a new image-matching algorithm[153]. The C3D system has been developed for clinical applications[154] in a collaboration between the University of Glasgow Dental School and the Turing Institute of the Department of Computing Science at Glasgow University. Currently, C3D range imaging is based on the use of stereo-pairs of digital cameras and special textured illumination[155], which provides quick capture times (50 milliseconds) and makes the system appropriate for imaging children and infants in addition to adults.

The longer the exposure (or data capture time), the more unreliable or blurred the imaged data becomes and this has important implications if measurement of the face to sub-millimetre accuracy is required. A third digital camera (full colour) has been appended to each stereo-pair to enable C3D to capture the natural surface appearance of the patient's skin and then "drape" this skin texture over the constructed 3D model of the face. Accordingly, C3D provides the clinician with a life-like 3D model of the patient's head that may be used for diagnosis, treatment planning and surgical outcome analysis[155].

The system is described in more detail in Section 3.1.1. The accuracy of the system for paediatric imaging was evaluated[156], by comparing x-, y-, z-coordinates of specific landmarks digitised from on-screen 3D models for twenty one plaster-casts of cleft models with the x-, y-, z-coordinates derived directly from these models using a previously validated 3D contact ultrasonic measuring system. The overall error between both measurements was below 0.89 mm[156]. However, the accuracy and reproducibility of the C3D system configured for capturing adult patients has not been evaluated yet.

Table 1.2 summarises the main properties of several 3D imaging systems employed in the orthodontic and the orthognathic literature. System accuracy and reproducibility have been assessed in different ways[141,157,158] and, generally, differences below 0.5 mm from the gold-standard measurements were considered acceptable and the 3D system was deemed suitable for use.

Different types of landmarks have been employed[112,133,159,160], and many of the soft-tissue landmarks were defined according to Farkas[61] who conducted extensive research work on facial anthropometry. The reproducibility of locating these landmarks has been evaluated in several studies. The least reproducibility was reported by Ferrario et al[133] who found an overall inconsistency of about 2 mm. This was clearly beyond the acceptable limits for the assessment of change in facial morphology due to surgical or orthodontic intervention. Mathematically constructed landmarks have been used in some studies based on the location of anatomical landmarks[148,161]. Manual landmark identification has been performed in the majority of these studies but a recent study by Yamada et al[162] introduced the concept of automated facial landmark extraction based on geometric distances from specific planes, maximum 3D curvatures in specific areas and the discriminant analysis of RGB data. Their proposed method reduced the amount of manual intervention in locating facial landmarks and improved reproducibility.

Table 1.2 Some of the properties of the employed 3D imaging systems in the orthodontic and orthognathic literature

Author(s)	Year	3D system (Important components)	System accuracy	System reproducibility	Use of landmarks	Employed Landmark identification method*	Reproducibility of landmark identification	Speed	3D model visual output
Burke and Beard[141]	1967	Manual Stereophotogrammetry	Differences in distances were below 1 mm	Unspecified	Not used	N/A	N/A	Unspecified	NO Contour maps only
Robertson & Volp[157]	1981	Telecentric photogrammetry (3 cameras + two contour-lines projection flashes)	RMS error= 0.33 mm	RMS error= 0.30 mm	8 Anthro.	Direct	Unspecified	Unspecified	NO
Trocme et al[163]	1990	Biplanar cephalometric stereoradiography	Range of error: -0.36 mm to +0.46 mm	SD ranged from 0.06 to 0.18 mm	N/A Metal markers were used	N/A	0.36 mm for linear measurements	Unspecified	NO
Bookstein et al[159]	1991	3D cephalometry	RMS error= 0.377 mm	RMS error= 0.204 mm	6 Anatom.	Direct using 10 dry skulls	Not applicable	Unspecified	NO
McCance et al[112]	1992	3D laser scanning	0.5 mm	Unspecified	10: 5 Anthro. 5 Const.	Indirect	Mean error: 0.2 – 0.82 mm (x-axis); 0.05-0.32 mm (y-axis); 0.01-0.59 mm (z-axis).	10 seconds to scan the face	YES (Shaded models)
Motoyoshi et al[158]	1992	Moiré topography (3 cameras + projector)	X-axis: 0.04 mm; Y-axis: -0.03 mm; Z-axis: 0.08 mm	Unspecified	N/A	N/A	N/A	Unspecified	YES (Wire frame or shaded models)
McCance et al [114]	1992	3D CT scanning	Unspecified	Unspecified	5 Anthro.	Indirect	Mean error in x-axis: 0.03 – 0.11 mm; in y-axis: 0.02 – 0.08 mm; in z-axis: 0.01 – 0.13 mm	Unspecified	YES (Shaded models)

Table 1.2 Contd.

Author(s)	Year	3D system (Components)	System accuracy	System reproducibility	Use of landmarks	Landmark identification method*	Reproducibility of landmark identification	Speed	3D model visual output
McCance et al (164)	1993	3D CT scanning	Unspecified	Unspecified	5 Antrho.	Indirect	Mean error: X axis 0.03 – 0.11 mm Y axis 0.02 – 0.08 mm Z axis 0.01 – 0.13 mm	Unspecified	YES (Shaded)
Moss et al (113)	1994	3D laser scanning	0.5 mm	Unspecified	10 5 Anthro. 5 Const.	Indirect	Mean error: 0.2 – 0.82 mm (x-axis); 0.05-0.32 mm (y-axis); 0.01-0.59 mm (z-axis).	10 seconds to scan the face	YES (Shaded)
Ras et al(147)	1996	Stereophotogrammetry (One stereopair + one texture projection flash)	Unspecified	Unspecified	3 Anthro.	Indirect	The greatest error 1 mm for linear 1.1° of angular measurements	Unspecified	YES + Facial texture (mono-chrome)
Ferrario et al(133)	1997	3D facial morphometry (stereopair of infrared-sensitive CCD cameras).	Unspecified	0.1 mm	22 Antrho.	Direct	2 mm	0.1 sec for each of the two acquisition sessions.	NO
Coward et al (165)	1997	3D laser scanning	0.5 mm	Unspecified	21 Anthro.	Indirect	Most of the absolute differences ranged from 1- 2 mm.	9 – 10 seconds per scan	YES (Shaded)
Techalert-paisarn and Kuroda (148)	1998	Structured light technique (2 LCD projectors and 2 CCD cameras)	Unspecified	Unspecified	75 Const.	Indirect	Measurements errors in central areas of face: 0.1 – 0.3 mm; whereas in the peripheral areas: 0.3 – 0.5 mm.	2 seconds	YES (vertices, wireframe, or shaded)

Table 1.2 Contd.

Author(s)	Year	3D system (Components)	System accuracy	System reproducibility	Use of landmarks	Landmark identification method*	Reproducibility of landmark identification	Speed	3D model visual output
Yamada et al[166]	1999	Liquid crystal range finder (LCRF) – a stereophotogrammetric method	0.5 mm	Unspecified	18 Anthro.	3 indirect 15 automatic	Median SD of manual extraction: 0.55 mm; median SD of automatic extraction: 0.40 mm	1 sec for each stereopair	YES + Facial texture (coloured)
O'Grady & Antonyshyn [167]	1999	3D laser scanning (revolving scanning head + one camera + one colour camera)	Unspecified	Unspecified	16 Anthro.	Indirect	Intraclass correlation coefficients between repeated identifications were very high (>0.979).	17 seconds for 360° scanning	YES + Facial texture (coloured)
Ferrario et al[168]	2000	Electromagnetic soft-tissue contact-based digitiser	0.25 mm	Unspecified	10 Anthro.	Direct	DEM: Angular meas.: 0.53° - 1.12° Linear meas.: 0.41 – 1.22 mm	60 seconds for digitisation	NO
Nute et al[161]	2000	3D Laser scanning	0.5 mm	Unspecified	15: 10 Antrho. 5 Const.	Indirect	Overall error of data acquisition and landmarking did not exceed 1 mm	10 seconds	YES (Shaded)
Kusnoto & Evans[160]	2002	3D laser scanning	Facial tests: mean error 1.9 mm	No significant differences between repeated scans	12 Anthro.	Direct	N/A	0.6 second	YES + Facial texture (coloured)

Abbreviations used: Anthro= anthropometric landmarks, anatom= anatomical landmarks, const= constructed landmark; N/A= not applicable

(*) Direct identification requires marking up or attaching markers on the subject's face, whereas indirect identification occurs on-screen after building the 3D model

1.2.4 Shape analyses in 2D and 3D

1.2.4.1 Mesh diagram analysis

Proportional analysis of the human face in a mesh coordinate system dates back to ancient China, Egypt and India[64]. Thompson[64] compared growth and form of primate skulls to those of a human skull by means of Cartesian coordinate system transformations. A transformation of a mesh coordinate system was advocated by Lusien de Coster[65] and has been used consistently since 1948 to convey graphically the essential aspects of facial development for orthodontic diagnosis. The mesh diagram is constructed by first drawing a core rectangle, oriented on the extracranial vertical and scaled on upper face height and face depth. Then by drawing additional horizontal and vertical grid lines, the mesh is completed. Thus, the mesh diagram analysis is concerned only with the proportional location of landmarks within their small rectangles[169]. The use of a computerized mesh diagram is another step to make this analysis less time-consuming and more flexible in assessing facial disfigurement and in manipulating the grid to reach the best treatment alternatives. The analysis can be applied on frontal cephalograms as well[169].

This analysis has been used to study facial morphology of young adults[170], to establish craniofacial norms[171-174] and to assess facial growth[175]. Subsequently, this analysis has evolved into a three-dimensional computerized mesh diagram analysis and was applied in the assessment of soft-tissue changes due to growth and development[176].

1.2.4.2 Proportionate template analysis

The proportionate template was designed for use on adults in treatment planning associated with orthognathic surgery. It is a more practical and convenient method of identifying dental and skeletal disharmonies by direct visual comparison[177,178]. To compare lateral head film tracings of persons with craniofacial skeletal dysplasia, a template with average skeletal proportions was developed from the data of Broadbent and his co-workers[179].

1.2.4.3 Tensor analysis

Tensor analysis, which permits the computation of differences in form (size and shape), has been employed to describe facial changes in lateral cephalograms[180]. The technique is dependent on connecting three landmarks on a lateral skull radiograph to form a triangle; a circle is drawn within this triangle such that it contacts all three sides. If the same three landmarks are located and connected in a subsequent radiograph, the circle would be transformed into an ellipse. The amount and direction of these distortions may be calculated and the lengths of the axes measured. Change in shape is defined as the larger axis divided by the smaller and change in size is the product of the two axis measurements.

This method, which was first introduced by Bookstein in 1982, has been used to assess growth-related skeletal changes in general[181], orthodontically-induced skeletal changes[182-184] and craniofacial characteristics in cleft lip and/or palate patients[185,186]. In all of these studies, the researchers depended upon two-dimensional data extracted from lateral cephalograms. This analysis has not been applied yet on three-dimensional data or in the field of orthognathic facial changes.

1.2.4.4 Finite Element Scaling Analysis (FESA)

This method, based on engineering principles, was first introduced for the study of biologic form by Lewis et al[187]. A biological object is divided into smaller geometric forms called finite elements. The location of each vertex is defined by the coordinate of a biologically meaningful landmark that can be located reliably on each of the forms considered in the comparison. FESA compares forms in order to determine the amount of change required to produce a target (older) morphology from an original (younger) morphology. The difference between forms is estimated from information on the location of landmarks at the vertices of the elements and the actual connectivity of these landmarks in the construction of the elements[188]. Elements should be designed to encompass biologically homogenous areas and the potential dangers of improper element design in the application of FESA have been raised[189,190].

Finite element analysis has been used to analyse two-dimensional facial growth on cephalograms for a normal population[191] and those with craniofacial abnormalities[190]. In orthognathic surgery, this method has been applied to assess skeletal changes[192] and soft-tissue changes [158,193].

Finite element analysis has been used to analyse three-dimensional cranial base growth in some craniofacial abnormalities[188] and facial growth on laser scans of dried skulls[194]. There appears to be no reference in the dental literature to the application of 3D FESA in assessing the outcome of orthognathic surgery.

1.2.4.5 Thin Plate Spline Analysis (TPS analysis)

Bookstein developed this technique as a morphometric approach to the comparison of configurations of landmarks in two or more specimens[195]. Thin-plate spline (TPS) transformations produces a rigorous quantitative analysis of the spatial organization of shape change that can be decomposed into a series of components ranging in scale from features that span the entire form ("principal warps") to features that are highly localised ("partial warps"). In TPS analysis, the differences in two configurations of landmarks are expressed as a continuous deformation using regression functions in which homologous points are matched between forms to minimize the *bending energy*[195].

Bending energy can be defined as the energy that would be required to bend an infinitely-thin metal plate over one set of landmarks so that the height over each landmark is equal to the coordinates of the homologous point in the other form[195]. TPS analysis facilitates the construction and display of transformation grids that capture the shape change between forms as an evolution of the method originally proposed by D'Arcy Thompson[195].

TPS analysis has been applied to compare cranial base configuration between Class III and Class I subjects[196], to evaluate the shape characteristics of the face and tongue in obstructive sleep apnoea patients[197] and to assess soft-tissue deformations in subjects with untreated Class III malocclusions[198]. Baccetti and Franchi[199]applied this analysis to evaluate the treatment effects of rapid maxillary expansion and face mask therapy in early Class III malocclusions. It appears that this morphometric method has not been used to assess skeletal shape changes after orthognathic surgery.

1.2.4.6 Fourier Analysis

Fourier analysis is another mathematical method that analyses the characteristics of an object independently from its size. Fourier series are mathematical functions that describe the objects outline. Complex forms are decomposed into series of cosine and sine functions of increasing frequency. The sine and cosine coefficients can be used to compare different objects, independently from their size, spatial orientation or relation to reference planes.

Kapur et al(200) demonstrated the feasibility and utility of fitting Fourier functions to accurately characterize changes in shape associated with facial aging, orthodontic and orthognathic surgery. Fourier functions have been used to study growth and development of soft-tissue facial shape(201), ethnic difference in facial profile(202), skeletal changes following Function Regulator therapy(203), growth-related shape-changes in the mandible(204) and the relationship between mandibular form and facial morphology(205).

Facial changes with orthognathic surgery have not been studied using this methodology but a longitudinal study about the shape changes in the cleft palate maxilla has been conducted(206).

1.2.4.7 Euclidean Distance Matrix analysis

Euclidean-distance matrix analysis (EDMA) using 2D or 3D coordinates of soft tissue landmarks provides an objective measurement of form differences. It compares the form of two objects individualised by a group of homologous landmarks. EDMA first calculates all the possible Euclidean distances between selected landmarks on a single object, then compares the two objects by calculating a matrix of ratios of corresponding linear distances measured on each object. It separates the contributions of size and shape as well as localising the sites of major variations by suggesting which landmarks are more involved in the form difference(207)

EDMA has been applied in two-dimensional studies as well as in three-dimensional ones. Two-dimensionally, it has been used in the analysis of craniofacial congenital diseases(190,208), dental arch shape and asymmetry(209) and sexual dimorphism in the human face[118]. Furthermore, Class III malocclusions were evaluated by this method[210]. EDMA has also been applied in the assessment of shape changes after different orthognathic interventions[207,211].

Three-dimensionally, it has been used to assess the cranial base growth in craniosynostosis[188]. Three-dimensional landmark coordinate data were taken from the preoperative and postoperative CT scans, then two shape analyses were applied (FESA and EDMA) and comparisons were made.

1.2.4.8 Procrustes Analysis

The Procrustes algorithm[212] provides a mechanism for optimal superimposition of two sets of homologous landmarks on their shared centroid. The remaining mismatch between the two sets of landmarks provides size, orientation and positional information. The advantages of this method over traditional cephalometric superimposition techniques according to Palomo et al[104] are: size is treated as a separate variable and does not over-determine the result; no landmark is seen as primary or stationary during the superimposition and the result is presented in diagrammatic form resembling the original data rather than a column of numbers (angles and distances).

When comparing two objects with homologous landmarks, the Procrustes superimposition involves three basic steps: translation, rotation and scaling. First, the geometric centres of the two objects are found. The objects then are translated so that they are superimposed on their geometric centre. Rotation follows the translation, moving one object about its geometric centre until the best fit is found between all homologous landmarks. The object then is scaled, if required, so that the homologous landmarks are as close as possible without altering the original shape of either object[212].

Procrustes analysis has been recognized recently in clinical craniofacial and orthodontic research studies[190,213]. Procrustes-bases analysis of 3D landmark configurations was used in the assessment of skeletal growth from 3D cephalometric records[104,214], 3D facial expressions in repaired cleft lip and palate patients[215], reproducibility of facial expressions in normal subjects[216] and facial features of cleft and non-cleft three-year-old children[57]. Cakirer et al[217] demonstrated the use of Procrustes superimposition in two skeletal Class III orthognathic patients treated by maxillary advancement alone. Shape change was evaluated one year after surgery using 3D skeleto-dental data as well as 3D soft-tissue data. Shape change, however, was dependent on the landmark configuration used, which was not the same in the two cases presented. This might bring into question the applicability of the proposed method.

1.2.4.9 Other shape analysis methods

Coombes et al[218] described a mathematical method of comparing 3D changes in facial surface. A laser scan of the face is decomposed into fundamental shape patches (peaks, ridges, valleys, saddles) by computer, producing a quantitative and qualitative description of the face. This surface shape analysis has been employed recently in a study about the effect on the face of extraction and non-extraction orthodontic treatment in skeletal Class I patients[219]. It has not been yet used to evaluate soft-tissue morphology following orthognathic surgery.

1.3 3D soft-tissue changes following orthognathic surgery

Ten published studies evaluated the three-dimensional morphometric changes in soft tissues following orthognathic surgery (Table 1.3).

1.3.1 Linear and angular measurements

Berkowitz and Cuzzi[144] were the first to use linear and angular measurements in the assessment of 3D facial soft-tissue changes following corrective surgery of different craniofacial deformities. The heterogeneity of the surgical interventions and the small sample size did not help in deriving any conclusions from their study. The vertical axis in the established coordinate system was created depending on soft-tissue Nasion and Subnasale despite the expected change in the relative position of Subnasale following surgery. Ferrario et al[129] applied their 3DFM system on 5 orthognathic patients treated by bimaxillary surgery and illustrated the possible diagnostic tools that could be employed in the analysis of surgical outcomes. Again, their study sample was too small to arrive at any valid conclusions.

1.3.2 Displacements of landmarks

Displacements of soft tissues in the midsagittal plane after Class III surgical correction were studied by Techalertpaisarn and Kuroda[148] with the aid of 75 constructed points. They found that the largest movements were located between Labrale inferius and Pogonion and that the amount of displacements decreased gradually in the lateral direction. Although no maxillary procedure was performed, the upper labial landmarks showed slightly backward movements. This study explored one dimension of change and the complete picture of soft-tissue behaviour would not be totally understood unless the other two dimensions are explored. Moss et al[113] evaluated facial soft-tissue morphology on 15 Class II orthognathic patients with the aid of radial measurements calculated from a central axis of the skull. Colour millimetric maps were used to show changes over the whole face. They found general advancement of the facial complex with maximal changes occurring in the chin region. Little or no relapse was documented in their study between 3 and 12 months postoperatively.

1.3.3 Volumetric assessment

The first study to assess volumetric changes in orthognathic patients was conducted by Kobayashi et al (1990)[146] on 28 skeletal Class III patients, in which the lower part of the 3D facial model was divided into 8 different sites using six intersecting planes. Although these mathematically constructed volumes did not have any clinical meaning per se, the differences calculated between pre- and post-operative values revealed some useful information. The accuracy of their stereophotogrammetric technique and the reproducibility of facial landmark identification were not evaluated. Patients' facial deformities do not have the same vertical, transverse and anteroposterior dimensions. Therefore, the position of the parasagittal and frontal planes should have been related to anatomical landmarks rather than fixed distances from stable landmarks.

Motegi et al[220] addressed the morphologic changes in the perioral soft-tissues after surgical correction of mandibular hyperplasia in another way. 3D facial models were built following the use of laser scanning. 3D models were superimposed on stable structures. Curved lines were created between perioral landmarks and two areas of interest were established: subnasale-upper lip area and lower lip-menton area. The enclosed volumes between corresponding areas after the alignment of pre- and post-operative models were calculated. The validity of the procedure was not investigated fully. The long acquisition time (10 seconds) could have affected the accuracy of the built models due to possible head movements, changes in facial expression or breathing cycles. Errors in landmark identification were not explored and the accuracy of the algorithm in measuring changes was not evaluated.

Table 1.3	Overview of 3D imaging systems that assessed facial changes following orthognathic surgery				
Author(s)	**Year**	**3D system used**	**Number of patients**	**Type of surgery**	**Type of evaluations**
Berkowitz and Cuzzi[144]	1977	Stereophotogrammetry (3 stereo-cameras + stereo-plotting instrument)	5 Cranio-facial deformities	Reconstructive surgery	Linear and angular measurements regarding the following facial features: eyes, nose, mouth, and chin.
Kobayashi et al[146]	1990	Two pairs of photographs were taken simultaneously at an angle of 25° with the head in a reference metal frame on which the standard points of known 3D values were set.	28 Class III	One-jaw surgery Mandibular setback (BSSO or BBO)	• Volumes of soft tissues at eight sites divided by six planes. • Directional index of asymmetry of the facial soft tissue. • From the 3D cephalometric data: postoperative 3D changes and the directional index of mandibular asymmetry.
McCance et al[112]	1992	Laser scanning	16 Class III 60 control	Bimaxillary surgery Maxillary Le Fort I osteotomies Mandibular setback (BSSO or VSSO)	• Using colour millimetric scale, comparisons were made between male and female facial features in the control group. • Changes in the skeletal Class III group postoperatively in males and females • Comparisons between the patients group and the control group.
McCance et al[114]	1992	Three-dimensional CT scanning	16 patients Class III	Bimaxillary surgery Maxillary advancement (13: Le Fort I procedure, 3: Kufner procedure) Mandibular setback (BSSO or VSSO)	Using a colour mm scale, skeletal changes were assessed postoperatively. Radial measurements were obtained for skin surfaces and for bone surfaces, then soft-tissue to hard-tissue movement ratios were calculated.
McCance et al[164]	1993	Three-dimensional CT scanning	17 patients Class II	Bimaxillary surgery Maxillary Le Fort I procedure Mandibular advancement (BSSO mainly)	• Using a colour mm scale, skeletal changes were assessed postoperatively. • Radial measurements were obtained for skin surfaces and for bone surfaces, then soft-tissue to hard-tissue movement ratios were calculated

Table 1.3 Contd.

Author(s)	Year	3D system used	Number of patients	Type of surgery	Type of evaluations
Moss et al[113]	1994	Laser scanning	15 patients Class II 30 control	Bimaxillary surgery Maxillary Le Fort I procedure Mandibular advancement (BSSO mainly)	• Using colour mm scale, difference between patients' group and control group were obtained preoperatively and postoperatively • Comparisons were also made within the patients' group before and after surgery
Techalertpaisarn and Kuroda [148]	1998	Cephalostat (chair and headrest), measuring units (2 LCD projectors and 2 CCD cameras) and a main controller. The face is illuminated with eight alternating patterns of black and white stripes from the LCD projectors in 2 sec.	40 Class III	One-jaw surgery Mandibular setback (BSSO)	Changes in facial soft-tissue were illustrated using tomographic cross sections at one-cm intervals. Sagittal soft-tissue dislocations of 75 facial measurement points were also calculated; correlation between soft-tissue movements and hard –tissue movements assessed by lateral cephalograms.
Motegi et al[220]	1999	Laser scanning	12 Class III	One-jaw surgery Mandibular setback 10: BSSO; 2: VSSO	Volumetric assessment of facial changes in two areas: Subnasale-upper lip area and lower lip-Menton area
Ferrario et al[129]	1999	3D Facial Morphometric system using infrared photogrammetry	5 Class III	Bimaxillary surgery Le Fort I Advancement Mandibular setback (BSSO)	Different methods were demonstrated • Linear and angular measurements • Volumetric assessment • Global and localised facial asymmetry indices
Cakirer et al[217]	2002	Structured light technique for soft-tissue reconstruction and 3D cephalometry for hard-tissue reconstruction	2 Class III	One-jaw surgery Maxillary advancement	• The only article to demonstrate the possibility of evaluating shape change one year following surgery employing full ordinary Procrustes alignment of landmark coordinates. • In addition, comparison was made between the preoperative and the 'normative' 3D craniodental data.

Abbreviations used: BSSO= bilateral sagittal split osteotomy, VSSO= vertical subsigmoid osteotomy; BBO= bilateral body ostectomy

1.4 Cephalometric changes following orthognathic surgery

1.4.1 Hard-tissue changes and skeletal stability

Stability after surgical repositioning of the jaws varies depending on the direction of movement, the type of fixation used and the surgical technique employed, largely in that order of importance(221). The various jaw movements possible at surgery were ranked in order of stability(222). Superior repositioning of the maxilla was the most stable orthognathic procedure, closely followed by mandibular advancement in patients whom anterior facial height is maintained or increased(222). Stability of mandibular advancement was influenced by the pattern of rotation of the mandible as it was advanced. The combination of moving the maxilla upward and the mandible forward was significantly more stable when rigid internal fixation is used in the mandible. Surgical widening of the maxilla was the least stable of the orthognathic procedures(222).

Three principles that influence post-surgical stability have been proposed as follows: stability is greatest when soft tissues are relaxed during surgery and least when they are stretched; neuromuscular adaptation is an essential requirement for stability and, fortunately, most orthognathic procedures lead to good neuromuscular adaptation(223); and neuromuscular adaptation affects muscular length, not muscular orientation. This concept is best illustrated by the effect of changing the line inclination of the mandibular ramus when the mandible is setback or advanced(221).

1.4.1.1 One-jaw surgery

1.4.1.1.1 Maxillary superior, anterior, or inferior repositioning

1.4.1.1.1.1 Maxillary Impaction

In general, excellent stability was reported by many studies(102,224-226). Bell and McBride (1977) examined 41 patients with vertical maxillary who underwent maxillary superior repositioning with Le Fort I osteotomy. Their results indicated clinical stability with minimal relapse(226). Bishara et al (1992) described the postsurgical skeletal stability after the Le Fort I maxillary impaction. They found that after the initial surgical superior repositioning, the maxilla continued to move superiorly, and most of the upward movement occurred during fixation(102). Table 1.4

summarizes eight studies, which assessed skeletal stability following maxillary impaction.

1.4.1.1.1.2 Maxillary advancement

Seventeen studies that assessed stability of maxillary advancement with Le Fort I osteotomy are summarised in Table 1.5. Araujo et al[(227)] found up to 68% relapse of the advancement if pterygomaxillary bone grafts were not used and advocated overadvancement of the maxilla in these cases. Teuscher and Sailer, on the other hand, reported stable results five years after maxillary advancement[(228)].

In a study to compare skeletal stability between maxillary impaction and advancement, Bishara and Chu found significant differences in the vertical maxillary postsurgical changes between the two groups[(102)]. For patients requiring a maxillary advancement and who express minimal exposure of the maxillary incisors before surgery, they recommended that 'burying the incisors beneath the lip' should be avoided since the maxilla moves superiorly an additional 2.0 mm during fixation.

1.4.1.1.1.3 Maxillary inferior repositioning

Downward movement of the maxilla has been regarded as one of the more unstable surgical movements, second only to transverse widening of the maxilla[(222)]. This is supported by several studies from those summarised in Table 1.6. Costa et al[(229)], on the other hand, concluded that maxillary inferior repositioning stabilized with rigid fixation and bone grafting seemed to be a predictable procedure with minimal relapse.

Several factors have been proposed to explain the instability of this procedure[(230,231,231-233)].The forces exerted by the elevator muscles before their adaptation to the new position have been mentioned[(230,231)] together with their possible increased contractile strength[(231)]. The relapse is documented to occur within the first few months following surgery[(232,233)].

Table 1.4	Studies on the stability of maxillary impaction procedures							
Author(s)	Year	N	Type	Impaction*		Relapse*		Follow up
				A	P	A	P	
Willmar[224]	1974	3	OJS	+7.70	+3.67	+0.66	-0.017	1 year
Schendel et al[225]	1976	18	OJS (14) DJS (4)	Unspec.	Unspec.	-0.27	+0.27	13.8 months
Bays[234]	1986	11	OJS (3) DJS (8)	+4.64	+4.00	-0.27	+0.18	16 months min.
Bishara et al[101]	1988	31	OJS	+3.00	+3.50	+0.99	+0.43	4 months
Skoczylas et al[235]	1988	30	IMF (15) RIF (15)	+2.86 +2.34	+4.14 +3.84	+0.62 +0.13	+1.00 +0.24	IMF: 8 weeks RIF: 4 weeks
Carpenter et al[236]	1989	16	OJS	+5.75	Unspec	+0.46	-0.36	6 months
Emshoff et al[237]	2003	26	DJS	+ 3.0	Unspec.	-0.1	Unspec.	1 year
Mihalik et al[238]†	2003	49	OJS	Unspec.	Unspec.	-0.73	-0.60	6.8 years
		34	DJS	Unspec.	Unspec.	-0.74	-0.39	6.5 years

(*) Mean values are stated here (in millimetres) with positive values indicating superior movements and negative values indicating inferior movements. (†) Long-term relapse was measured between 1-year postsurgery to the long-term recall.

Abbreviations used

A=anteriorly; P= posteriorly, N= number of patients, OJS= one-jaw surgery, DJS= double jaw surgery, IMF= intermaxillary fixation, RIF= rigid internal fixation, Unspec= unspecified.

Table 1.5	Studies on the stability of maxillary advancement procedures					
Authors	**Year**	**N**	**P**	**Advance***	**Relapse***	**Follow-up**
Araujo et al[227]	1978	21: G1: 10 +BG G2: 11 -BG	A	Unspec	G1: -1.9 G2: -2.3	G1: 30 mons G2: 26 mons
Teuscher and Sailer[228]	1982	16	A	+7.1	ST: -0.38 LT: -0.08	Five years
Luyk and Ward-booth[239]	1985	11 RIF	Pr	+3.7	-0.3 (8.1%)	10 mons
Harsha and Terry[240]	1986	7 RIF	A	+5.5	-0.2 (3.63%)	1 year
Bays[234]	1986	7 RIF	A	+3.0	-0.14 (4.67%)	16 mons min.
Carlotti and Schendel[100]	1987	30: RIF (8) and WF (22)	A	+7.4	-0.5 (6.75%)	15.4 mons
Rondahl et al [241]	1988	24: G1: 10 IWF G2: 14 EWF	A	G1: + 5.6 G2: + 5.9	G1: -1.00 G2: -0.60	1 year
Carpenter et al [236]	1989	19 RIF	M	+3.5	-0.4 (11.4%)	6 mos
Larsen et al [242]	1989	30: G1: 13 RIF G2: 17 WF	A	Unspec.	G1: -2.00 G2: - 1.24	1 year
Law et al [243]	1989	6 RIF	A	+3.6	-0.4 (11.1%)	9 mons
Proffit et al [244]	1991	49: G1: 18 RIF G2: 31 WF	A	G1: + 4.8 G2: +3.9	G1: -0.9 G2: -0.9	1 year
Louis et al[245]	1993	20 RIF +BG	UIE	+8.95	0.95 (10.6%)	18.5 mons
Hoffman et al [246]	1994	15 RIF	ANS	5.84	-0.59 (10.1%)	1 year
Egbert et al[247]	1995	25: G1: 13 RIF G2: 12 WF	ANS	G1: +6.9 G2: +8.7	G1: -0.4 (5.8 %) G2: -1.2 (13.8%)	1 year
Hoffman and Moloney[248]	1996	15 RIF	UIA	+8.79	-0.61 (6.96%)	1 year
Waite et al[249]	1996	22: G1: 11 RIF-BG G2: 11 RIF+BG	UIE	G1: +10.0 G2: +9.70	-1.8 (18%) -0.7 (7%)	10.5 mons
Kwon et al[250]†	2000	25	UIE	+ 3.69	+ 0.01	6 mons

(*) Mean values stated here in millimetres, with positive values indicating forward movement and negative values indicating backward movement. (†) Results obtained from 3D cephalometric data.

Abbreviations used:

N= Number of patients, G1: Group 1, G2: Group 2, +BG: with bone grafting, -BG: without bone grafting, OJS= one-jaw surgery, DJS= double jaw surgery, Unspec= unspecified, mos: months, M= maxillary landmark suggested by the authors, UIA= upper incisor apex landmark, UIE= upper incisor edge, min= minimum, IWF= intra-osseous wire fixation, EWF= extra-osseous wire fixation.

Table 1.6	Stability of maxillary inferior repositioning following Le Fort I osteotomy							
Authors	Year	N	Stab. Type	Inf. Rep.*		Relapse*		Follow-up
				A	P	A	P	
Hedemark and Freihofer[251]	1978	12	WF +BG	-3.16	N/A	+2.2	N/A	Min. of 6 mos
Bell and Scheideman[252]	1981	11	WF +BG	-6.8	N/A	+1.9	N/A	1 year
Bays[234]	1986	12	RIF +BG	-4.72	-2.15	+0.41	+0.46	Min. of 16 mos
Persson et al, [232]	1986	16	RIF -BG	-7.1	-0.6	+1.5	0.0	6 mos
Quejada et al[233]	1987	10	WF BG	-8.9	N/A	+2.1	N/A	1 year
Wardrop and Wolford[253]	1989	11	WF + Alloplasts	-5.4	-3.8	+0.5	+0.4	≈ 2 years
Rosen[254]	1990	9	WF + Alloplasts	-6.2	N/A	+0.5	N/A	1 year
Proffit et al[244]	1991	10	G1: WF +BG	-0.8	-1.7	+0.2	+0.7	1 year
		6	G2: RIF +BG	-7.4	-0.6	+3.6	+1.0	
Major et al[255]	1996	11	G1: WF +BG	-4.5	-2.8	+2.4	+0.5	G1: 20 mos
		9	G2: RIF +BG	-7	-3.1	+0.4	+0.8	G2: 16 mos
De Mol van Otterloo et al[256]	1996	6	G1: WF +BG	-4.2	+1.2	+0.96	N/A	1 year
		5	G2: RIF+BG	-3.6	+1.8	+0.5	N/A	
Perez et al[257]	1997		RIF +BG	-4.6	-1.8	+1.28	+1.23	16 mos
Gurstein et al[258]	1998	15	RIF +BG	-4.9	-0.7	+0.02	+0.13	30 mos
Wagner and Reyneke[259]	2000	13	RIF (10) WF (3)	-3.0	+0.3	+0.8	- 0.1	≈ 14 mos
Junger et al[260]	2003	15	RIF	- 5.1	N/A	+ 0.4	N/A	≈14 mos

(*) Mean values are stated here in millimetres, with positive values indicating upward movement and negative values indicating downward movement.

Abbreviations used:

N= Number of patients, Stab type= Stabilisation type, Inf. Rep.= Inferior repositioning, G1: Group 1, G2: Group 2, WF= Wire fixation, RIF= Rigid internal fixation, +BG: with bone grafting, -BG: without bone grafting, SJS= single-jaw surgery, DJS= double jaw surgery, mos: months, A= anterior maxilla, P=posterior maxilla, N/A= not available.

1.4.1.1.2 Mandibular setback

The bilateral sagittal split osteotomy (BSSO) provides a broad bony contact, which allows rapid osseous healing[261]. Its compatibility with rigid fixation techniques is also considered to be an average over the intraoral vertical ramus osteotomy[262]. While some have considered it a stable procedure[263-265], other studies have reported relapse rates as high as 44%[266], 55%[267] and 91%[268] of the surgical correction, even with the use of rigid fixation. A 2-mm postoperative change has been considered of clinical significance(268).

Fifteen studies, which assessed stability of mandibular setback by BSSO, are given in Table 1.7. Several factors have been cited as responsible for relapse following mandibular setback surgery, including altered activity and failure of masticatory muscles to adapt to the repositioned segments, altered condylar position secondary to rotation or distraction of the proximal segment during fixation, positional change of the tongue with reduced space after setback, and continued condylar growth(261). Several studies have drawn particular attention to the alterations occurring at the proximal segment, which has two aspects: change in the condyle/fossa relationship(269) and rotation of the segment as a whole(267,270). Mobarak et al showed that most of the relapse took place during the first 6 months after surgery; however, they concluded that BSSO with rigid fixation for mandibular setback appeared to be a fairly stable clinical procedure(261).

With VSO, intermaxillary fixation (IMF) is usually used to secure the occlusion and allow healing of the osteotomy sites(269). Nineteen studies, which assessed stability of mandibular setback by VSO or its variants, are given in Table 1.8.

During the period of the IMF, clockwise rotation of the distal segment with an increase in anterior facial height, shortening of the rami, and dental compensations were common findings(271-273). Follow-up cephalograms frequently showed that there was a chance for further backward movement of the mandible postsurgically. Paulus and Steinhauser were among the first to use rigid fixation with vertical ramus osteotomies(274). They compared a group of patients with wire osteosynthesis to another group receiving two screws on each side and reported only small differences in stability.

1.4.1.1.3 Mandibular advancement

Retrospective studies that have examined the stability of mandibular advancement reported varying relapse from 1% to 100%(275-279). Inconsistent conclusions regarding the frequency and the pattern of these changes have also been reported. McNeill et al indicated that relapse occurred mainly during the first few weeks postoperatively and is accompanied by repositioning of maxillary and mandibular dental and skeletal structures(275). Schendel and Epker found continuous relapse up to one year after the procedure (278). Bhatia et al(280) also found a significant amount of horizontal and vertical relapse up to 9 months after surgery. Phillips et al(281) showed that in 94% of their patients who were treated successfully, 10% relapse was seen at B point one year after surgery. Table 1.9 summarises twenty-one studies that assessed skeletal stability following mandibular advancement.

1.4.1.1.4 Chin surgery

1.4.1.1.4.1 Advancement genioplasty

Most studies have shown that there is good stability of the bony segment following genioplasty. Polido and Bell reviewed ten patients who had undergone large advancement genioplasty by the pedicled method(282). The genial segment was surgically advanced a mean of 11.7 mm. They found that 83 per cent of the surgical advancement was maintained when reviewed at a mean of 26.8 months after surgery.

Ayoub et al(192) emphasised the need to use skeletal landmarks other than Pogonion. Measurements based on this point may be less accurate. Gnathion, Genion and the centre of the symphysis (Steiner's point 'D'(70)) have been suggested. No bony remodelling of Gnathion or Menton was observed. Bone resorption was seen at the osteotomy sites (the anterosuperior and posteroinferior aspects of the advanced genial segment)(14,283-286). Bony apposition has occurred at B point and the inferior border of the osteotomy(286).

1.4.1.1.4.2 Setback genioplasty

Few studies have evaluated the stability of setback genioplasty. Hohl and Epker(287) were among the first to study the treatment results following the surgical correction of macrogenia. They concluded that the long-term stability of the procedure was excellent. Several procedures have been employed in the correction of a horizontally excessive chin(288-290) and further research work is required to draw valid conclusions about the stability of each.

Table 1.7	Studies on the stability of mandibular setback by BSSO						
Author(s)	Year	No	Fixation	Point	Setback*	Relapse*	Follow-up period
Pepersack and Chausse[291]	1978	43	WF	Pog	-9.0	+1.3 (14.4%)	5 years
MacIntosh[292]	1981	Unspec	WF	B	Unspec	31.9% Occlusal relapse	6 mos at least
Paulus and Steinhauser[274]	1982	G1: 40 G2: 43	G1: WF G2: RIF	N/A	Unspec	G1: 17.5% G2: 7% with Edge-to-edge/Xbite	≈2 years
Phillips et al[262]	1986	19	WF	Pog	-4.9	+2.2 (45%)	1 year
Kobayashi et al[263]	1986	44	WF	Pog	-8.4	+0.2 (2.4%)	1 year
Komori et al[270]	1987	17: G1: 10 G2: 7	G1: SSW G2: MMF	Pog	G1: -6.3 G2: -8.4	G1: -1.0 (15.9%) G2: -3.0 (35.7%)	4 to 5 weeks
Franco et al[266]	1989	14	RIF	Pog	-4.3	+1.8	6 months to 3 years
Sorokolit and Nanda[264]	1990	25	RIF.	B	-5.1	+0.5 (10%)	15.3 mos
Proffit et al[268]	1991	40: G1: 29 G2: 11	G1: WF G2: RIF	B	G1: -5.5 G2: -5.8	G1: +2.6 G2: +3.2	1 year
Schatz and Tsimas[267]	1995	13	RIF	Pog	-6.4	+3.5 (55%)	1 year
Ingervall et al[265]	1995	29	RIF	Pog	-6.0	+1.3 (20%)	14 months
Mobarak et al[261]	2000	80	RIF	Pog	-6.3	+1.6 (26%)	3 years
Kobayashi et al[293]	2000	145: G1: 40 G2: 105	G1: WF G2: RIF	Pog	WF: -8.5 RIF: -6.7	G1: +0.5 G2: +0.4	1 year min
Ayoub et al[269]	2000	15	RIF	Gen	-5.71	+2.5	1 year
Kwon et al[250]†	2000	25	RIF	II	-5.70	+1.09	6 months

*** Mean values are stated here (in millimetres) with positive values indicating forward movements and negative values indicating backward movement; † results obtained from 3D cephalometric data.**

Abbreviations used:

VSCO = vertical subcondylar osteotomy; OSO = oblique sliding osteotomy; VRO = vertical ramus osteotomy; BSSO= bilateral sagittal split osteotomy; OVO= oblique vertical osteotomy; OSCO= oblique subcondylar osteotomy; VSO= vertical subsigmoid osteotomy; EO= extraoral; IO= intraoral; WF= wire fixation; NW= non-wiring group; MMF= maxillomandibular fixation; RIF= rigid internal fixation; SSF= skeletal suspension fixation; N/A= not applicable; Unspec= unspecified; E-To-E= Edge to edge relationship; Xbite= crossbite.

Table 1.8	Studies on skeletal stability following mandibular setback with vertical subsigmoid osteotomy or its variants						
Authors	**Year**	**N**	**Osteotomy (Approach)**	**Point**	**Amount of setback**	**Horizontal relapse**	**Follow-up period**
Ware and Taylor[294]	1968	12	VSCO (EO)	Pog	-12.2	+2.0	I year
Åstrand and Ridell[295]	1973	55	OSO (EO)	Gn	-12.0	+2.6	30 months for 20 patients
Morrill et al[296]	1974	22	VRO (EO)	Pog	-11.2	+1.5	1year
Isaacson et al[297]	1978	18	VSCO (16) BSSO (2) (EO)	Go	-10.3	+1.4	Unspec.
Johanson et al[298]	1979	112	OSO (EO)	Gn	-10.6	+3.0	5 years
Wisth[299]	1981	44	OVO (EO)	SNB angle	- 7°	+1.6°†	10 years
Egyedi et al[300]	1981	81	OSCO + WF (EO)	Pog	-10.2	+3.2	1 year min.
Paulus and Steinhauser [274]	1982	G1: 13 G2: 25	VRO: G1: WF G2: RIF (IO)	NA	Unspec	G1: 15% G2: 16% E-To-E Or Xbite	≈2 years
Greebe and Tuinzing[301]	1982	35	VRO (IO)	Pog	-7.5	-1.2 mm	1 year
Åstrand et al[302]	1983	WF: 14 NW: 15	OSO: G1: WF G2: NW (EO)	Gn	G1: 10.4 G2: 12.1	G1: +1.2 G2: +2.0	18 months
Jonsson et al[303]	1985	82	OSO (EO)	Gn	-12.2	+2.7	5 years
Rosenquist et al[304,305]	1985 and 1986	14	OSO, 2D and 3D analysis (EO)	IS	-5.4	+0.4	2 years
Phillips et al[262]	1986	20	VRO (IO)	Pog	-5.2	-0.5	1.6 year
Tornes and Wisth[306]	1988	G1: 48 G2: 32	VSCO: G1: IMF G2: IMF + SSF (IO: 40, EO: 40)	SNB angle	G1: -5.3° G2: -5.1°	G1: + 0.3° G2: +0.4° †	6 months
Ahlen and Rosenquist [307]	1990	IO: 15 EO: 6	OSO (IO or EO)	Gn	-9.1	+0.9	18 months
Proffit et al[268]	1991	19	VRO (IO)	B	-6.6	-0.3	1 year
Athanasiou et al[273]	1992	G1: 26 G2: 26	VRO + IMF: G1: WF G2: NW (EO)	B	-5.8	G1: -0.74 G2: -0.86	1 year

Table 1.8 Contd.							
Authors	**Year**	**N**	**Osteotomy (Approach)**	**Point**	**Amount of setback**	**Horizontal relapse**	**Follow-up period**
Mobarak et al[308]	2000	44: G1: 22 G2: 22	G1: VRO + RIF G2: VRO + IMF + SSF (EO)	Pog	G1: -5.5 G2: -7.1	G1: +0.6 G2: -1.8	1 year
Ayoub et al[269]	2000	16	VSO + IMF (IO)	Ge	-5.9	-0.5	1 year

(*) Mean values are stated here in millimetres with positive values indicating forward movements and negative values indicating backward movements

(†) Post-fixation changes; ‡surgical and fixation changes

Abbreviations used:

VSCO = vertical subcondylar osteotomy; OSO = oblique sliding osteotomy; VRO = vertical ramus osteotomy; BSSO= bilateral sagittal split osteotomy; OVO= oblique vertical osteotomy; OSCO= oblique subcondylar osteotomy; VSO= vertical subsigmoid osteotomy; EO= extraorally; IO= intraorally; WF= wire fixation; NW= non-wiring group; IMF= intermaxillary fixation; RIF= rigid internal fixation; SSF= skeletal suspension fixation; E-To-E= edge to edge relationship; Xbite= crossbite; NA= not applicable; Unspec= unspecified.

Table 1.9	Studies on skeletal stability following mandibular advancement with BSSO or other procedures						
Author(s)	**Year**	**N**	**Surgery**	**Point**	**Advance***	**Relapse**	**Follow-up period**
Thomas et al[309]	1986	14	BSSO	B	+ 5.3	+ 0.5	6 wks
Kirkpatrick et al[310]	1987	20	BSSO + genio	B	+ 5.7	8% (-)	6 months at least
Van Sickels et al [311]	1988	51	BSSO + genio	Pog	+ 4.6	+ 0.45	6 months to 3 years
Rubens et al [312]	1988	20	BSSO + IMF	Pog	+ 5.4	18.7% (-)	6–14 months
Caskey et al[313]	1989	20	BSSO + midline split	Pog	+ 4.8	9.6%(+)	10-27 months
Watzke et al[314]	1990	35	BSSO + 9 genio	Pog	+ 6.9	-0.14	1 year
Gassmann et al[315]	1990	25 G1: 13 G2: 12	G1: Relapse G2: Stable	Pog	G1: + 7.9 G2: +5.2	G1: > 25% (-)	6 months at least
Kierl et al [316]	1990	19	BSSO	B	+ 6.7	- 1.3	3 years
Moenning et al[317]	1990	14	BSSO IMF	Pog	+ 4.4	3.2 % (-)	6 months at least
Mommaerts[318]	1991	13	BSSO	Pog	+ 6.1	11% (-)	1 year
Douma et al[319]	1991	16	BSSO	Pog	+5.6	31.4% (-)	11.2 months
Watzke et al[320]	1991	G1: 30 G2: 26	BSSO G1: PS G2: LS	B	G1: +5.4 G2: + 5.3	G1: - 0.6 G2: - 0.3	1 year at least
Van Sickels[321]	1991	G1:11 G2:15	BSSO G1: RIF G2: RIF + SW	Pog	G1: + 10.9 G2: + 12.2	G1: 34% G2: 4 %	6 months at least
Abeloos et al[322]	1993	20	BSSO	Pog	+ 5.0	(+) With no values	6 months at least
Scheerlinck et al[323]	1994	103	BSSO	Pog	+ 5.9	8.9% (-)	Two years at least
Blomqvist and Isaksson[324]	1994	G1: 16 G2: 22	BSSO G1: screws G2: plates	Pog	G1: + 8.0 G2: + 7.8	G1: 15% (-) G2: 21.8%	6 months
Thuer et al[325]	1994	30	BSSO	Pog	+ 4.6	37% (-)	13 months
Blomqvist et al[326]	1997	G1: 30 G2: 30	BSSO G1: screws G2: plates	Pog	4.9 – 6.1 mm	10.1-18.4%	6 months
Kallela et al[327]	1998	25	BSSO biodeg	Pog	+ 3.9	15% (-)	1 year
Mobarak et al[328]	2001	61	BSSO	Pog	+ 5.9	33% (-)	3 years
Emshoff et al[237]	2003	26	BSSO RIF	B	+ 5.6	+ 0.3	1 year

(*) Values are stated in millimetres (or percentages when the '%' symbol is used). Positive values indicate forward movements negative values indicate backward movements.

Abbreviations used

N= number of patients; G1: group 1; G2= group 2; BSSO= bilateral sagittal split osteotomy, PS= position screws; LS= lag screws; RIF= rigid internal fixation; SW= skeletal wiring.

1.4.2 Soft-tissue changes after orthognathic surgery

1.4.2.1 General considerations

Many studies have been performed to evaluate soft-tissue changes associated with orthognathic surgery. No standardized quantitative or qualitative criteria were used in these studies, which resulted in some difficulties in drawing a clear picture of the anticipated soft-tissue changes for each surgical intervention. In an attempt to make some objective comparisons between methodologically different studies, a set of characteristics for the theoretically ideal study of the soft-tissue changes has been proposed by Betts and Fonseca[(329)]. These are summarised in Table 1.10.

In most studies, the relationship between soft tissue and hard tissue changes has been presented in 'ratios', which described the two-dimensional (x and y) relationship of two specific points. There are many concerns about the accuracy of soft-tissue predictions when they are made using simple soft- to hard-tissue correlations [(330)]. The complex behaviour of the facial soft-tissue drape is best described by the interaction of several factors. This may explain some of the wide variability that many investigators have faced[(331-335)]. Therefore, ratios may provide a general appreciation of the expected outcome[(335)]. If important variables have been included such as the method of soft-tissue closure, type of osseous contouring, age, sex and race, in addition to the presence of sufficient numbers of subjects with uniform specific vectors of osseous movements, improved predictions would have been achieved[(333-336)]. Recent investigations have demonstrated better predictive calculations when patients were categorised by vector-specific movements of the osseous segments[(336,337)].

Table 1.10	Ideal characteristics of a study to investigate the soft-tissue changes associated with orthognathic surgery (summarised after Betts & Fonseca[329])
Design Prospective - adequate sample size - randomised treatments if they differ within the sample **Inclusion criteria** Nongrowing patients – one ethnic group – one vector of surgical movement – one surgical procedure with soft-tissue incision and wound closure – bony segments stabilised with RIF (one technique) - constant presence or absence of orthodontic appliances. **Exclusion Criteria** Any patient with a history of facial trauma - craniofacial syndromes (e.g. cleft patients) - concomitant or prior soft-tissue surgery - concomitant osseous surgery on the facial skeleton - segmental surgical procedures - hard-tissue contouring (e.g. recontouring of the anterior nasal spine) **Data collection protocol** One cephalostat with identical source-subject and subject-film distances - soft tissues in repose for all cephalograms - superimposition on the nearest osseous structure not affected by surgery (for cephalograms) or on a stable reference line - evaluation of both profile and full facial soft tissue changes, or performing a 3D analysis - uniform follow-up intervals - follow-up time at least 6 months (1 year is preferable) - Error analysis of measurement and landmark identification	

1.4.2.2 Soft-tissue considerations

The changes in soft-tissue morphology after combined orthodontic and surgical therapy are dependent on several factors: the surgical procedure[333,335,338-341], the method of wound closure[333,335,338,340,341], the new spatial arrangement of the skeletal and dental element[340]; the adaptive qualities of the soft tissues[340,342]; growth[339,343]; orthodontic vectors of tooth movement[339,340]; lip thickness[331,333,339,344,345]; lip tonus[335,342]; lip area; lip contact (competence); lip strength; interlabial gap; amount of overjet; amount of fatty tissue and musculature and postoperative oedema[339].

Because of swelling, tissue redistribution and functional adaptation, long-term follow up is required to assess soft tissue changes following surgical procedures. Most reports suggest that the soft tissues stabilize after a six-month period[331,339,340,344,346]. Others suggest that at least 3 months are required[337,347].

Horizontal incision in the upper labial vestibule, commonly used to gain access to the maxilla for the Le Fort I osteotomy, causes shortening of the lip with loss of vermilion and a decrease in lip thickness[335,341,348]. However, the use of vertical incisions with a tunnelling approach for the same surgical procedure shows minimal postoperative lip changes[340]. In a study investigating the soft-tissue response to maxillary surgery, it appeared that soft-tissue changes were consistent and may be more affected by the type and position of the soft-tissue incision and methods used in closure than by the surgically induced hard-tissue change[336].

Thin lips move more predictably than thick lips[331,333,339,344,345,349]. The actual bulk of a thick lip may have a tendency to absorb a large amount of bony advancement without a perceptible change in soft-tissue contour. 'Dead space' under the lip may absorb the first portion of a bony advancement before the soft tissue is affected[331,333,339,342,344,345,349]. As the soft-tissue of the face is relatively incompressible, the morphologic changes seen in the face as a result of surgery may be attributed to soft-tissue redistribution[335,350]. Minimal postsurgical change has been observed in the area of the upper lip, lower lip, and chin, with return to preoperative values[335,350,351].

The general trend noted in the literature is that the horizontal changes in the soft tissues are often predictable, whereas the vertical changes are less predictable. This may be due to smaller movements in the vertical plane and the use of soft- and hard-tissue landmarks better suited for horizontal assessment[330]. Also, hard tissue change is less predictable and less stable in the vertical dimension.

1.4.2.3 Soft-tissue changes following orthodontic incisor movement

Early studies in the orthodontic literature stressed that the soft-tissue profile was closely related to the skeletal and dental structures[352]. In a subsequent report, Subtelny[343] mentioned that the soft-tissue drape did not follow directly the underlying bony movements. Burstone agreed and suggested that a direct relationship between hard- and soft-tissue changes may not always exist because of variation in the thickness of the soft tissues covering the face [353]. The effects of growth and development, large ANB differences, positional relationship of the upper incisor on the lower lip (overbite and overjet), type of malocclusion and adipose tissue are other factors that confuse the issue and may contribute to the wide variability observed[342,354,355].

The changes in the soft tissues associated with orthodontic movement of the incisors are displayed in Table 1.11. With incisor retraction, the upper lip rotates posteriorly around the Subnasale point, with an associated reduction in the prominence of the lips relative to their adjacent sulci [(332)]. Also, upper lip thickness increases with maxillary incisor retraction: 1 mm with 3 mm of incisor retraction[(113)]; 1 mm with 1.5 mm of incisor retraction[(356)]. Correlation analysis indicates that upper lip response is not only related to the upper incisor retraction, but also to lower incisor movement, mandibular rotation and the position of the lower lip[(332)].

The lower lip moves less predictably with retraction of the incisors than does the upper lip[(332)]. Several theories have been advanced to explain this phenomenon. Hershey has theorized that this is because the lower lip is much more self-supporting and not as dependent on underlying incisor support. Other investigators[(357)] believe that both the upper and lower incisors have effects on the lower lip positioning. They feel that the upper teeth, not the lower, establish the curve of the lower lip. Therefore, if the upper incisor is retracted more than the lower incisor, the lower lip may displace more posteriorly than the lower incisor [- 1.56:1[(357)]; - 1.22:1[(332)]; -1.29:1[(358)]].

In a relatively recent study by Phonpraserth et al[(342)], orthognathic patients were divided into three groups depending on their original deformity and the effect of presurgical orthodontic decompensation on soft tissues was evaluated. Ratios of soft-tissue to dental landmark displacements varied markedly between the three groups. These with Class II division 2 patients showed the least soft-tissue changes following decompensation. Class III malocclusion had the highest ratios of maxillary soft to hard tissue changes, whereas Class II division 1 malocclusion had the greatest mandibular soft to hard tissue changes.

Table 1.11	Soft-tissue changes associated with orthodontic tooth movement			
Author(s)	**Year**	**Soft-tissue/hard-tissue Landmarks**	**Direction**	**Ratio**
Bloom*[354]	1961	sls: IS ls: IS ils: II li: II li: IS	H Retr. H Retr. H Retr. H Retr. H Retr.	0.89:1 0.87:1 0.87:1 0.93:1 0.82:1
Rudee*[357]	1964	ls:IS li: II li: IS	H Retr. H Retr. H Retr.	0.34:1 1.56:1 1:1
Robinson et al*[359]	1972	Incisor protrusion or retraction to upper and lower lip	Retr. Prot.	0.75-0.9:1
Hershey[332]	1972	ls: IS li: II	H Retr. H Retr.	0.5:1 1.22:1
Attarzadeh et al[355]	1990	ls: IS	H Retr.	0.63:1
Kasai[358]	1998	ls: IS li: II	H Retr. H Retr.	0.44:1 1.2:1
Phonpraserth et al[342]	1999	Class II div 1 ls: IS li:II Class II div 2 ls: IS li:II Class III ls: IS li:II	H Prot. Prot. H Prot. Prot. H Retr. Prot.	 0.4:1 1.4:1 0.01:1 0.1:1 1.7:1 0.9:1

(*) The sample included growing patients.

Abbreviations used

H = horizontal ratio; Retr: retraction of the incisors; Prot= protrusion of the incisors ls = labrale superius; li = labrale inferius; IS= incision superius; II= incision inferius; sls= superior labial sulcus; ils= inferior labial sulcus.

Many factors contribute to the final position of the lower lip. Mandibular rotation has a greater influence on lower lip response than incisor movement and there is a complex interaction between dental movement, mandibular rotation, and the perioral soft tissues, as well as a complex relationship within the soft tissues themselves[330].

1.4.2.4 Maxillary surgery

1.4.2.4.1 Generally affected tissues by Le Fort I osteotomy

The majority of the soft-tissue change after Le Fort I surgery is manifested in the nasal and labial structures[360-362]. Different movements of the maxilla have distinct effects on the nasal and labial morphology (Table 1.12).

Table 1.12	Nasal effects of maxillary surgery Summarised after O'Ryan and Schendel[360]				
Direction	**Alar bases**	**Nasal tip**	**Supratip Depression**	**Hump**	**Nasolabial Angle**
Superior	Increase	Increase	Increase	Decrease	Decrease
Anterior	Increase	Increase	Increase	Decrease	Decrease
Inferior	Increase	Decrease	Decrease	Increase	Increase

Movement of the maxilla affects the lower aspect of the nasal dorsum[287,331,333,360,361]. The general trend is a widening of the alar base regardless of the vector of maxillary movement. An associated shortening of the columella height, alar height and nasal tip projection has been observed and the nasolabial angle decreases or remains constant in most cases[336].

Superior repositioning of the maxilla causes elevation of the nasal tip, widening of the alar bases and a decrease in the nasolabial angle[363]. Inferior repositioning produces loss of nasal tip support, downward movement of the columella and alar bases, thinning of the lip, and an increase in the nasolabial angle. Anterior repositioning of the maxilla has a profound effect on the nose and upper lip, resulting in advancement of the upper lip, Subnasale, and Pronasale; thinning of the lip[338]; widening of the alar bases; and an increase in the supratip break if the anterior nasal spine is left intact[334,360,361]. The nasal tip advances approximately one half the distance of the subnasale[287]. The explanation for this may be widening at the alar base which reduces nasal tip protrusion[336]. A narrow nose has been observed to widen more at the alar base than a broad nose[336,364].

The following labial changes have been described. The upper lip widens and lengthens at the philtral columns after maxillary surgery[336]. Shortening of the upper lip and loss of exposed vermilion can occur if a V-Y closure technique is not used at the time of surgery[338].

1.4.2.4.2 Maxillary advancement

This movement is accompanied by an advancement of the upper lip, subnasale, and nose[333,360-362], slight shortening of the upper lip; thinning of the lip (≈ 2 mm)[349,360-362,365] widening of the alar bases[360-362], and a deepening of the supratip depression if the anterior nasal spine is left intact.[287,345,360-362,366]. A progressive increase in the horizontal soft-tissue displacement is seen from the tip of the nose to the free end of the upper lip(361). A concomitant decrease in nasolabial angle is observed with only slight changes in the lower lip(331). Leaving the anterior nasal spine intact has a favourable effect on the forward displacement of the upper lip and especially on the base of the nose(344). The ratios derived from thirteen previous investigations are given in Table 1.13.

A significant difference is noted between the ratio of the horizontal change of the upper incisor to the vermilion border of the upper lip in previous studies (0.6:1) (287,333,344) compared with the ratio reported by Carlotti et al(366) which was 0.9:1. The difference was attributed to the use of the alar cinch suture and V-Y closure during the surgical procedure. The ratio reduces with larger advancements because of soft-tissue stretching. If the anterior nasal spine is left intact, the nasolabial angle may remain relatively unchanged. As the nasal tip rises slightly, the subnasale migrates forward along with the upper lip(341).

Table 1.13	Horizontal soft-tissue changes following maxillary advancement		
Author(s)	Year	Landmark	Ratio
Lines and Steinhauser(367)	1974	ls: IS * ls: ANS	0.67:1
Dann & Fonseca(331)	1976	ls: IS ls: IS NLA: IS prn: IS	0.5:1 0.3:1 -1.2°:1 0.28:1
Freihofer(344)	1976	sn: A ls: IS **	0.57:1 0.56:1
Freihofer(346)	1977	sn: A prn: A **	0.57:1 0.28:1
Radney and Jacobs(334)	1981	prn: IS ls: IS	0.17:1 0.5:1
Mansour et al(333)	1983	prn: IS sn: IS sls: IS ls: IS	0.17: 1 0.24:1 0.52:1 0.62:1
Bundgaard et al(347)	1986	stms: A stms: A	0.5:1 -0.3:1
Carlotti et al(366)	1986	sls: A ls: IS	0.8:1 0.9:1
Rosen(345)	1988	sn: A ls: IS stms: IS	0.51:1 0.82: 1 -0.31:1
Stella et al(349)	1989	sn: A sn: A	0.3:1 with thick lips 0.46:1 with thin lips
Ewing and Ross(368)	1992	prn: IS sn: A** ls: IS	0.36:1 0.63:1 0.66:1
Hack et al(369)	1993	sn: ANS sls: A point ls: IS	0.60:1 0.38: 1 0.91:1
Clemente-Panichella et al(370)	2000	sn:IS sls: IS ls: IS stms: IA	1:1 0.63:1 0.67:1 0.67:1

(*) Cleft patients removed, (**) clefts patients, V = Vertical; H = Horizontal

<u>Abbreviations used</u>

prn= Pronasale; sn= Subnasale; sls= superior labial sulcus; ls= Labrale superius; stms= Stomion superius; li= Labrale inferius; IS= incision superius; ANS= anterior nasal spine.

1.4.2.4.3 Maxillary impaction

Superior repositioning of the maxilla results in elevation of the nasal tip(287,360-362), widening of the alar bases (2 – 4 mm)(345,348,360-362), and a decrease in the nasolabial angle(360-362). Soft-tissue to hard-tissue displacement ratios following maxillary impaction are given in Table 1.14. The upper lip follows closely the displacement of the maxillary incisor in the horizontal plane. The lip follows superiorly by approximately 40 % of the vertical maxillary change. This lip shortening is accentuated with combined anterior and superior maxillary movements[345]. The amount of vertical soft-tissue change increases progressively form the nasal tip to Stomion superius with the loss of vermilion if a V-Y closure is not used[333,334]. However, Phillips et al[348] found that the vermilion border of the upper and lower lips decreased slightly in the lateral portion of the lip, even with a V-Y closure. Interestingly, when superimposition is done on maxillary landmarks, the soft tissues of the upper lip migrate downward in relation to the maxilla. This may be due to the connection of the upper lip of the nose[333,349].

Table 1.14	**Soft-tissue changes associated with maxillary impaction**			
Author(s)	**Year**	**Soft- to hard-tissue landmark**	**Direction**	**Ratio**
Schendel et al[225]	**1976**	**ls: IS**	**V**	**0.38:1**
Radney and Jacobs[334]	**1981**	**prn: IS**	**V**	**0.16:1**
		sn: IS	**V**	**0.20:1**
		sls: IS	**V**	**0.25:1**
		ls: IS	**V**	**0.30:1**
		stms: IS	**V**	**0.40:1**
Mansour et al (333)	**1983**	**prn: Pr**	**V**	**0.15:1**
		sn: Pr	**V**	**0.28:1**
		sls: Ia	**H**	**0.76:1**
		ls: Pr	**V**	**0.31:1**
		sls: IS	**V**	**0.42:1**
		ls: Ia	**H**	**0.89:1**
Sakima and Sachdeva (335)	**1987**	**sls: ANS**	**V**	**0.12:1**
		ls: ANS	**V**	**0.06:1**
		stms: ANS	**V**	**0.41:1**
Lee et al[371]	**1996**	**pn: ANS**	**V**	**0.19:1**
		ls: ANS	**V**	**0.22:1**
Hack et al[369]	**1993**	**sn: ANS**	**V**	**0.29:1**
		sls: A	**V**	**0.54:1**
		sls: IS	**V**	**0.72:1**

Abbreviations used

prn= Pronasale; sn= Subnasale; sls= superior labial sulcus; ls= Labrale superius; stms= Stomion superius; IS= incision superius; II= incision inferius; ANS= anterior nasal spine; Pr= Prosthion.

1.4.2.4.4 Inferior repositioning of the maxilla

Maxillary inferior repositioning produces loss of nasal tip support, downward repositioning of the columella and alar bases, thinning of the lip and an increase in the nasolabial angle[360-362]. Lengthening and thinning of the upper lip are also observed.

1.4.2.4.5 Posterior repositioning of the maxilla

Maxillary setback procedures result in loss of nasal tip support because of posterior movement of the anterior nasal spine and the bony support area around the piriform aperture[361]. The lip rotates posteriorly and superiorly about subnasale increasing the nasolabial angle[225,334] and the lip thickens slightly[225].

Most maxillary movements are multidirectional (e.g. anterior and superior, anterior and inferior, posterior and superior, or posterior and inferior). The expected soft-tissue changes are a combination of the expected changes from the pure vectors of movement[330].

1.4.2.5 Mandibular surgery

Generally the soft tissues of the mandible follow the hard tissues closely. The exception is the lower lip. Because of its contact with the upper incisor and upper lip, its movement is often variable and unpredictable.

1.4.2.5.1 Posterior repositioning of the anterior segment of the mandible

The lower lip follows the lower incisors posteriorly, which causes a flattening of the labiomental fold. There is less posterior displacement of the soft tissues as the chin is approached[367].

1.4.2.5.2 Mandibular advancement

The soft-tissue changes associated with mandibular advancement surgery are given in Table 1.15. There is little change in the upper lip[325,367,372] and none above the subnasale[351]. The lower lip advancement is variable and the lip often lengthens[351]. The lower labial sulcus and chin adhere to the bony structure of the mandible. Consequently, they follow the underlying osseous tissues closely, advancing more than the lower lip. This leads to an opening of the labiomental fold. As with maxillary and genial surgeries, the vertical changes are variable. As Menton moves posteriorly, the labiomental angle opens and the labiomental depth decreases[372].

The position of the lower lip is affected by the upper incisor as well as the lower incisor. The anteroposterior position of the upper half of the lower lip touches the upper incisor in Angle Class II (non-open bite cases) and is usually folded forward. As the mandible is advanced, the chin and lower labial sulcus come forward, but the superior portion of the lower lip does not, because it was already folded forward by its contact with the upper incisor. This causes an opening of the labiomental fold and may explain why the ratio of advancement at the Labrale Inferius to the Incisor Inferius is reduced[351,367].

Table 1.15	**Horizontal soft-tissue changes associated with mandibular advancement**		
Authors	**Year**	**Soft- to hard-tissue landmarks**	**Ratio**
Lines and Steinhauser[367]	**1974**	**li: II** **pog: Gn**	**0.62:1** **1:1**
Quast et al[337]	**1983**	**li: II** **ils: B** **pog: Pog** **gn: Gn** **men: Men**	**0.38:1** **0.97:1** **0.97:1** **0.97:1** **0.87:1**
Mommaerts & Marxer[372]	**1987**	**li: Ii** **ils: B** **pog: Pog** **men: Men**	**0.56:1** **1.06:1** **1.03:1** **0.93:1**
Dermaut & De Smit[351]	**1989**	**li: II** **ils: B** **pog: Pog**	**0.26:1** **1.19:1** **1.1:1**
Thuer et al[325]	**1994**	**li: II**	**0.66:1**
Keeling et al[373]	**1996**	**ils: B** **pog: Pog**	**0.88:1** **1:1**

Abbreviations used

li= Labrale inferius; ils= inferior labial sulcus; pog= soft-tissue Pogonion; gn= soft-tissue Gnathion; men= soft-tissue Mention; ANS= anterior nasal spine; Pr= Prosthion; IS= incision superius; II= incision inferius; Pog= hard-tissue Pogonion; Gn= hard-tissue Gnathion; Men= hard-tissue Menton.

1.4.2.5.3 Mandibular setback

Studies which assessed soft-tissue changes associated with mandibular setback are given in Table 1.16. A slight posterior displacement of the upper lip, with lengthening[350,374], and a slight increase in the nasolabial angle were observed[375]. The soft tissues follow the mandible posteriorly, with the chin following most closely, followed by the inferior labial sulcus and the lower lip. The lower lip shortens and becomes more protrusive by curling out, and the labiomental fold deepens and becomes more acute[350,374-376].

During superior mandibular repositioning, the lower lip becomes shorter, protrusive and smaller in area. On the other hand, inferior mandibular repositioning, lengthens and broadens the lower lip[350]. The correlation between soft- and hard-tissue movements was found to be poor vertically[359].

Table 1.16	Horizontal soft-tissue changes associated with mandibular setback		
Author(s)	**Year**	**Soft- to hard-tissue landmark**	**Ratio**
Aaronson[375]	**1967**	**li: Pog** **ils: Pog**	**0.69:1** **0.93:1**
Robinson et al[359]	**1972**	**ils: B** **pog: Pog**	**≈1:1** **≈1:1**
Lines and Steinhauser[367]	**1974**	**ls: II** **li: II** **pog: Gn**	**0.2:1** **0.75:1** **1:1**
Hershey and Smith[376]	**1974**	**ls: Pog** **li: Pog** **pog: Pog**	**0.2:1** **0.6:1** **0.9:1**
Gaggl et al[377]	**1999**	**ls: Pog** **li: Pog** **men: Pog**	**0.32:1** **0.79:1** **0.90:1**
Chunmaneechote and Friede[378]	**1999**	**ls: Pog** **li: B** **ils: B** **pog: Pog**	**0.15:1** **0.81:1** **0.97:1** **0.96:1**

Abbreviations used

ls= Labrale superius; li= Labrale inferius; ils= inferior labial sulcus; pog= soft-tissue Pogonion; II= incision inferius; Pog= hard-tissue Pogonion; Gn= hard-tissue Gnathion.

1.4.2.5.4 Soft-tissue changes with autorotation

Soft tissues tend to follow the bony landmarks on an approximately one-to-one ratio[333,334], except for the lower lip, which falls slightly lingual to the arc of rotation[333,334,341](Table 1.17). A slight increase in the labiomental angle can also be seen [333], as well as a small amount of thickening of the lips due to the reduction of the vertical facial height[367].

Table 1.17	**Soft-tissue changes associated mandibular autorotation**		
Authors	**Year**	**Soft- to hard-tissue landmark**	**Ratio**
Lines and Steinhauser[367]	**1974**	**pog: Gn**	**0.8:1(V)** **1:1(H)**
Radney & Jacobs[334]	**1981**	**ils: B** **pog: Pog**	**1:1(H)** **1:1(H)**
Mansour et al[333]	**1983**	**li: II** **ils: B** **pog: Pog** **stmi: IS** **men: Men**	**0.75:1(H)** **0.9:1(H)** **0.86:1(H)** **0.93:1(V)** **1.2:1(V)**
Sakima and Sachdeva[335]	**1987**	**ils: Men** **pog: Men** **stmi: Men** **li: Men** **ils: Men** **pog: Men**	**0.61:1(H)** **0.79:1(H)** **1.03:1(V)** **1.48:1(V)** **1.05:1(V)** **0.98:1(V)**

Abbreviations used

V= vertical ratio; H= horizontal ratio; stmi= Stomion inferius; li= Labrale inferius; ils= inferior labial sulcus; pog= soft-tissue Pogonion; men= soft-tissue Menton; II= incision inferius; Pog= hard-tissue Pogonion; Gn= hard-tissue Gnathion.

1.4.2.5.5 Genioplasty

The major change can be detected in the soft tissue of the chin, while the lower labial sulcus and the lower lip react to a lesser extent[287,364,379,380].

1.4.2.5.5.1 Advancement genioplasty

The soft-tissue changes following horizontal advancement genioplasty depend on the magnitude and direction of the positional change of the genial segment, the design of the mucosal and osseous incision, the amount of soft-tissue stripping and other concomitant jaw movements[14,283,284,286,381]. Twelve studies which assessed soft-tissue behaviour following advancement genioplasty are given in Table 1.18.

Several investigators demonstrated that minimal soft tissue stripping gave a more predictable hard- and soft-tissue response because of less bone resorption of the advanced segment[284,285,364,381-383]. When the technique of minimal soft-tissue stripping was used, soft tissues followed hard tissues closely without chin droop[284,364,381,382,384]. There was also an increased submental length, an improved lower-lip-to-tooth relationship[284], less soft-tissue thinning[384] and an improved neck-chin angle[330].

Those patients who had both vertical reduction and advancement genioplasty showed slightly larger soft-tissue advancement than those who had advancement genioplasty only (0.93:1 vs. 0.81:1). When the soft tissues are bunched (vertical reduction more than advancement), the soft tissues advance more than when the soft tissues are stretched (advancement only)[284].

Table 1.18	Horizontal soft-tissue changes associated with advancement genioplasty			
Author(s)	**Year**	**Landmark**	**Ratio**	**Comments**
Bell and Dann[283]	1973	pog: Pog	0.57:1	Anterior sliding
McDonnel et al[286]	1977	pog: Pog	0.75:1	Horizontal sliding (some: multistep)
Bell[381]	1981	Unspec.	≈1:1	Horizontal with broad soft-tissue pedicle and VSSO setback
Busquets and Sassouni[379]	1981	li: Pog pog: Pog	0.44:1 0.83:1	Horizontal movement Some cases with ostectomy
Scheideman et al[384]	1981	pog: Pog	0.97:1	Horizontal with broad pedicle and VSSO setback
Bell and Gallagher[382]	1983	Unspec.	0.85:1	Horizontal with broad pedicle
Gallagher et al[284]	1984	pog: Pog	0.81:1	Advancement only: horizontal sliding with broad pedicle.
		pog: Pog	0.93:1	Advancement + vertical reduction. Horizontal sliding with broad pedicle.
Tulasne[385]	1987	pog: Pog	0.73:1	Overlapping bone flap
Park and Ellis[364]	1989	pog: Pog	0.97:1	Horizontal sliding with broad pedicle
Krekmanov and Kahnberg[285]	1992	pog: Pog	1:1	
Ewing and Ross[368]	1992	pog: Pog	1.1:1	
Polido and Bell[282]	1993	pog: Pog	0.83:1	Horizontal sliding with broad pedicle (large advancements)

Abbreviations used

VSSO = vertical subsigmoid osteotomy; li= Labrale inferius; pog= soft-tissue Pogonion; Pog= hard-tissue Pogonion; Unspec= unspecified.

1.4.2.5.5.2 Setback genioplasty

Early attempts at reduction of horizontal excess of the genial segment of the mandible by bony recontouring caused little improvement of the soft tissue profile[287]. As a result, this technique has been abandoned. The soft-tissue changes associated with setback genioplasty are not as well correlated to the hard-tissue movements during advancement genioplasty. The documented soft- to hard-tissue displacement ratios at the Pogonion level ranged from 0.33:1 to 0.75:1[285,287,288,386].

1.4.2.5.5.3 Vertical repositioning of the chin

A one-to-one soft- to hard-tissue displacement ratio was demonstrated by Wessberg et al[386] in vertical augmentation genioplasty. On the other hand, the ratio of soft-tissue to hard-tissue change in vertical reduction genioplasty was less and ranged from 0.25:1 to 0.40:1[285,287,364,368].

1.5 Psychosocial characteristics of orthognathic patients

1.5.1 Psychological and social implications of dentofacial deformities

The relationship between facial appearance and social acceptance is well documented[387-389]. The face produces the greatest concern regarding physical attractiveness; it is the source of vocal and emotional communications with others[390]. Facial disfigurement is defined as 'a physiognomic form that is sufficiently negatively marked so as to set the individual apart form the general population'[391]. The public reaction to facial disfigurement is a function of many factors, including the nature of the disfigurement, the type of interaction, and the anticipated duration of the interaction[2]. Research into the behaviour of the general public toward facially disfigured individuals and non-disfigured individuals suggests that the difference lies in non-verbal communication, e.g. averting the gaze or ignoring someone's presence[2]. A study by Bull[392] showed that less money was collected by researchers with a 'port-wine birthmark' than those without this defect when the former appeared at houses to collect for charity.

In a survey of over 1000 adults, Berscheid et al[393] found that those who were satisfied with their facial features expressed greater self-confidence. The face and its individual features also symbolise significant aspects of the self[394]. Attractive adults and children are evaluated as more successful, more intelligent and more socially skilled than unattractive persons[395,396]. Evidence is growing that social responses may influence an individual's self concept, not only in terms of perceived attractiveness but also in defining oneself as confident and socially skilled[390].

Shaw[397] proposed that a dentofacial anomaly might have an adverse effect on an individual's self-esteem and self-confidence as well as evoke an undesirable social response, e.g. teasing and ridicule. Cunningham et al[2] described teasing as 'one of the most destructive instruments humans can use to cause anger and distress'. Shaw et al[397] found that dental anomalies are the cause of considerable teasing and that children who are teased about their teeth are particularly upset by it. They are also twice as likely to suffer 'general playground harassment' than are other children who are not teased about their teeth. Unfavourable self-perceptions of facial appearance have been expressed more often by young adults with extreme overjet, deep bite and crowding[398]. Concerns with overall body image have been expressed more often by women (42%) than by men (27%) and were much more frequent among respondents with a malocclusion.

Individuals with dentofacial and craniofacial deformities frequently complain that they are rejected by others and that people behave in a negative manner in social interactions[399]. This might be influenced to some extent by facially disfigured individuals frequently exhibiting shyness, apprehension and even defensiveness. Jones[391] compared the self-concept of children with cleft lip and palate to children without this anomaly and found a significantly lower self-concept in the former group. Both boys and girls from 8 to 18 years of age with cleft lip and palate expressed poorer self-concept than did non-cleft children but this was an especially serious problem for young girls[400]. Children with craniofacial anomalies (e.g. craniofacial dysostosis and hemifacial microsomia) were found to be more introverted and neurotic and to express poorer self-concept than do normal children[387]. Tobiasen et al[401] mentioned that behavioural problems were cited more often by parents of children aged 2 to 12 years with cleft lip and palate and were exacerbated in children with associated congenital malformations such as Pierre Robin syndrome and neuromotor dysfunction. Early intervention can prevent social rejection by family members and peers and promote development of higher self-esteem[390]. Strauss et al[402], using photographs, obtained ratings from 227 adolescents comparing the attractiveness, intelligence and social acceptance of children with Down syndrome before undergoing surgery to children who had no abnormalities. The children with Down syndrome were rated less intelligent, less attractive and less socially acceptable. Postoperative ratings of these children were significantly more positive in all three domains and improvement in facial appearance was correlated with the intelligence rating[402].

Hutton[403], in a survey of 32 patients who had undergone surgery for mandibular prognathism, found that almost unanimous agreement emerged on improved appearance (90%), and 50% reported improvement in their personality. However, the author did not measure specific personality traits in this study. Orthognathic surgery differs from surgery for congenital anomalies in that the changes in appearance may be less dramatic and improvements in occlusion, mastication, speech and TM joint function are likely to be other major motives for treatment. However, patients undergoing this type of surgery want and expect aesthetic changes. The global effect of orthognathic surgery on the health-related quality of life (HRQL) has not been studied yet using condition-specific instruments[404]. Cunningham et al[404] highlighted the importance of using outcome measures that are of importance to the patients as well as the clinician. They developed a condition-specific health-related quality of life measure, Orthognathic Quality of Life Questionnaire (OQLO), targeting the orthognathic population. Questionnaire reliability[405], validity and responsiveness[404] have been assessed in their previous investigations and these suggested that this instrument might prove useful in future clinical trials as well as in quality assurance.

The following sections will review the literature with regard to patients' motivation to undergo orthognathic surgery, patients' perception of their facial appearance pre- and postoperatively, personality characteristics and postsurgical satisfaction.

1.5.2 Motivation for treatment

The motivational patterns of patients seeking surgical treatment have been varied [406-414]. Motives include improvement in aesthetics or function, prevention of periodontal disease and tooth loss, alleviation of temporomandibular joint problems as well as increasing work or social performance. Patients seek orthognathic surgery for other external reasons, e.g. family pressure, an orthodontist's recommendation or to please others[406,408].

To date, fifteen studies have assessed motivation to undergo orthognathic surgery (Table 1.19). Edgerton and Knorr[406] described two types of motivation, external and internal. External motivation includes patient's desire to please others, patient's 'paranoid' ideas that surgery will make the external environment easier or patient's belief that his/her career is being hindered by his/her physical appearance. Internal motivation is usually a more valid form of motivation and it often involves patients with long-standing inner feelings about the deficiencies in their appearance. These patients are usually good surgical candidates and they are better candidates than those with short-term distresses related to transient periods of unhappiness in their private lives[406].

Table 1.19 Patients' motives to undergo orthognathic surgery

Author(s)	N	Deformity Type	Method of data collection	Motives	Gender differences
Laufer et al[407]	25 21 F 4 M	Mand prog.	Retrospective Questionnaire	56% aesthetics 32% chewing difficulty 8% family pressure 8% speech difficulty	Not available
Ouellette et al*[415]	66 51 F 15 M	Mixed	Retrospective Questionnaire	45% appearance 36% advice from doctor 13% urging of parents/friends 6% other (e.g. function)	Not available
Kiyak et al[408]	73 45 F 28 M	Mixed	Prospective Questionnaires	Professional advice from an orthodontist: 83% for M and 76% for F Trouble with mastication: 41% for M and 29% for F Aesthetic appearance: 41% for M and 54% for F:	More women reported aesthetic appearance and pressure from family and friends to be major reason for seeking surgery, whereas more men described mastication and speech difficulties as their primary motives. However, these differences were not statistically significant.
Jacobson[409]	50 34 F 16 M	Mixed	Retrospective Questionnaires	76% facial appearance 70% improve jaw function 58% urged by doctor 22% urged by family and/or friends. Single most important reason Facial appearance 46% Heath of gums& teeth 26% Chewing ability 20%	Not available
Auerbach et al[416]	30 24 F 6 M	Mixed	Prospective Questionnaires	Functional goals: 77% improving chewing 27% preventing loss of teeth 27% reduction of jaw pain Aesthetic goals: 60 % improved profile Psychosocial goals: 27% improved confidence and self-esteem	Not available

Table 1.19 Contd.

Author(s)	N	Deformity Type	Method of data collection	Motives	Gender differences
Athanasiou et al[417]	152 93 F 59 M	Mixed	Retrospective Questionnaires	77.6% improving appearance was 'very important' 32.9% improving function of teeth was 'very important'	Female patients desired improvement of appearance more often.
Ostler and Kiyak[418]	27 20: F 7: M	Mixed	Prospective Questionnaires	90.0% occlusion 81.5% appearance of teeth 74.0% chewing 70.0% facial profile 66.6% tooth loss	Men and women gave similar responses with regard to motives
Frost and Peterson[419]	57 F	Mixed + TMJ cases	Retrospective Questionnaires	33% headaches 21% jaw discomfort 16% bruxism 12% overbite/underbite 4% facial aesthetics	Not applicable
Garvill et al[412]	27 17 F 10 M	Mixed	Prospective Interviews	85% functional problems 74% facial appearance 59% craniomandibular symptoms (i.e. TMJ problems) 27% phonetic problems 27% gastro-intestinal problems. Single most important 44% functional problems 33% facial appearance 22% craniomandibular symptoms	Craniomandibular symptoms were more frequent among female patients than among the males (71% vs. 40%).
Finlay et al[413]	61 37 F 24 M	Mixed	Prospective Questionnaires	52% facial appearance 31% functional reasons 10% self-confidence increase 7% advice from a dentist, orthodontist or doctor	Not available

Table 1.19 Contd.

Author(s)	N	Deformity Type	Data collection method	Motives	Gender differences
Phillips et al[420]	135 78 F 57 M	Mixed	Prospective Questionnaires	Age ≤ 25 / >25 Self-image 61% 57% Oral function 42% 62% TMJ 28% 49% Future health 28% 48% Social well-being 13% 6% Nasal function 8% 13%	Males, on average, have stronger social well-being motivation than did females, while females had stronger TMJ concerns.
Forssell et al[421]	100 71 F 29 M	84% mand. prog.	Prospective Questionnaires	92% occlusion 70% TMJ problems 68% chewing 67% appearance of teeth 39% facial appearance	Not available
Nurminen et al[422]	28: 19 F 9 M	Mand Retro Mand Prog Mand Asym Max. Retro, Apertognathia	Retrospective Questionnaires	68% problems in biting and chewing. 36% dissatisfaction with facial appearance 32% TMJ problems 32% symptoms from head only 36% other reasons	42% of women were dissatisfied with facial appearance compared with 22% for men. Nearly every man had difficulty in eating, while women experienced this less frequently.
Hoppenreijs et al[423]	282 F & M	Anterior Open Bite Deformity	Retrospective Questionnaires	61% biting and chewing problems 47% facial appearance 36% TMJ dysfunction	Not available
Zhou et al[424]	94 54 F 40 M	Class III deformity	Retrospective Questionnaires	94% improvement in occlusion 93% improvement in facial appearance 85% improvement in dental appearance 73% improvement in chewing	Not available

*** This sample consisted of 30% orthognathic surgery only, 15% orthodontic treatment only, 55% combination of the two.**

Abbreviations used

N= number of patients; F= females, M= males, Mand= mandibular, Max= maxillary, Retro= retrognathism, Prog= prognathism, Asym= asymmetry,

Some studies have highlighted the importance of improving the facial appearance as it was the primary motive for orthognathic surgery[407,409,413,417,420], while others emphasized the importance of improving or correcting oral functional problems; i.e. mastication, chewing, occlusion, TMJ and speech[408,416,418,419,421-423]. Psychological motives as well as social concerns were mentioned to a much lesser degree[413,416,420]. Functional reasons are thought to be mentioned because of the perception that these are more acceptable reasons for referral than solely cosmetic reasons[390,409].

It is difficult to draw valid conclusions from direct comparisons between the different studies summarised in Table 1.21. They have been conducted on different sample sizes, racial groups, dentofacial deformities and types of surgical interventions. Different times of observations, research methodologies and designs of questionnaires were also noticed among these studies. The facial aesthetic need as a motivation for surgery varies between 4%[419] to 93%[424]. This large variation can be attributed to the previously mentioned factors as well as socio-cultural differences and types of information given by professionals[421]. No demarcation of psychosocial profile has been drawn between different subgroups in investigations that contained different dentofacial deformities. Few studies focused on one specific deformity and all of them were retrospective in their nature[407,423,424].

Men and women today pay similar attention to physical attractiveness and there has been an increase in the number of males seeking cosmetic-type surgery[390]. Sex differences in motives of orthognathic patients have not been studied elaborately in the literature. Kiyak et al[408] showed that more women reported aesthetic appearance and pressure from family and friends to be major reason for seeking surgery, whereas more men described mastication and speech difficulties as their primary motives. However, these differences were not statistically significant. Flanary et al confirmed the importance of appearance as a rationale for surgery for both men and women but, in contrast to the finding by Kiyak et al, they reported that significantly more females stated appearance as a motivation factor[411]. The original 13-item questionnaire of 'Motives for Treatment' developed by Kiyak et al (1981) was further developed and modified to contain 24 items by Phillips et al[420]. They studied gender differences and found that the distribution of scores of social well-being and TMJ dimensions were significantly different for males and females. Males, on average, have stronger social well-being motivation than did females, while females had stronger TMJ concerns. Nurminen et al[422] could not detect any significant difference between males and females with regard to their motivational patterns and this could be attributed to their small sample size.

1.5.3 Personality characteristics before and after surgery

Tables 1.20 and 1.21 summarise studies that have dealt with personality characteristics of patients undergoing orthognathic surgery. Each variable will be reviewed separately in the following sections.

Although many researchers have claimed that orthognathic patients are essentially normal and do not exhibit the psychological disturbances attributed to patients who seek plastic surgery[408,416,425], psychiatric disturbances have been assigned to 92% of orthognathic subjects in the study of Wictorin et al[426] and to 32% in the study of Flanary et al[427].

1.5.3.1 Self-concept and self-esteem

There is considerable evidence that one's self-concept changes as a result of significant personal experience[428] and orthognathic surgery is evidently such an experience. Self-esteem can be defined as the individual's assessment of his or her own self-worth[390]. Different types of standardised questionnaires have been used to assess self-esteem, i.e. Rosenberg Index of Self Esteem (RSE)[429], Tennessee Self-Concept Scale (TSCS)[408,416,427,430,431] and Secord and Jourard's Self Cathexis Scale[413]. A common finding was that all orthognathic patients had presurgical self-esteem scores within the normal range, apart from one study which found them slightly below normative data[413].

The general trend for self-esteem is to improve in the post-surgical period, either in the short-term[416,432] or the long-term[413,427]. Cunningham et al[429], however, could not detect any significant difference between pre- and post-surgical scores of self-esteem. Kiyak et al[430,431]showed a significant drop in this variable nine months after surgery and attributed it to the continuing orthodontic treatment but self-esteem returned roughly to its presurgical values two years postoperatively[431].

1.5.3.2 Neuroticism

Eysenck Personality Inventory (EPI)[433] has been used to assess neuroticism of orthognathic patients in the presurgical phase[408,413,427], although Finlay et al[413] assessed neuroticism pre- and post-operatively. According to Eysenck, a person who scores high on the neuroticism scale tends to be emotionally labile and overresponsive to environmental cues. Although some studies showed normal values of neuroticism at the first assessment[408,434], other studies showed slightly higher scores[413] or lower scores[427]. Females were more neurotic than males in Kiyak's investigation[408], a difference which was statistically significant in Flanary's study[427].

1.5.3.3 Extroversion/Introversion

Extroversion/introversion have been analysed using EPI[433,435] by different researchers[413,430]. Eysenck has defined an extrovert as one who is sociable, craves excitement and is generally impulsive. In contrast, an introvert prefers solitary activities and privacy. Although Kiyak et al[430] found a significant increase in extroversion 9 months after surgery, Finlay et al[413] could not detect any significant difference regarding extroversion/introversion scores in their longitudinal study. Lovius et al[436] employed Social Avoidance and Distress (SAD) and Fear of Negative Evaluation (FNE) scales to assess social anxiety of orthognathic patients. The SAD scale contains items concerned with subjective distress, feeling ill at ease socially and the tendency to avoid social situations. The FNE assesses apprehension about others' evaluations and distress caused by their negative evaluations. They found improvements on both measures postoperatively, with a statistically significant difference on the SAD scale[436].

1.5.3.4 Locus of control

Locus of control has been defined as one's perceived source of control over one's life. People with external control believe that their fate is controlled by others; those with internal control perceive themselves as determining their own fate[437]. This variable was measured before surgery and was tested as a potential predictor of postsurgical satisfaction by Kiyak et al[438] and Flanary et al[411]. Orthognathic patients scored in the external range of Rotter's Internality-Externality Scale, which was administrated to them preoperatively[438].

1.5.3.5 Body image

Body image (BI) is defined as the individual's self-concept of his or her physical being[430]. Body image is considered as a complex psychological concept related to the mental representation of self and it has been assumed that a change in body image may occur due to surgical intervention[439]. Self-perception of facial deformity is an important factor in the decision to undergo orthognathic surgery[410]. These perceptions have also been found to predict satisfaction with surgical outcomes. Patients who perceive a significant improvement in their appearance tend to report greater postoperative satisfaction than do people who see minimal or no change in body image[432].

Different methods have been used to assess facial body image and patients' perception of their facial appearance (Table 1.21). These can be divided into three categories: validated and standardised questionnaires, visually oriented measures designed by the authors and questionnaires specially designed by the authors.

Validated questionnaires included Secord and Jourard's Body Cathexis Scale (SJBCS) [413] or a modified version of it [408,431,432,438-442]. 'Body Cathexis' refers to the feeling of satisfaction or dissatisfaction with the various parts and processes of the body. Kiyak et al [408] added more body parts to the scale, especially those related to facial features and created a subset of items called 'facial body image'. Arndt et al[428] used Hay's Rating Scale (HRS) to study a group of children with different craniofacial deformities pre- and post-operatively. Lovius et al[436] utilised Body Satisfaction Scale (BSS), which included 16 body parts ranging from head to feet.

Visually oriented measures included self-rating of facial profiles developed by Bell et al[410] and used afterwards by other researchers[440,441]. Self-perception of facial profile, without the aid of photographs, was assessed using four rating scales of profile drawings. Each nine-point scale represented a different dimension of skeletal or dental disharmony: vertical deficiency – vertical excess; maxillary prognathism – retrognathism; mandibular retrognathism – prognathism and dentoalveolar protrusion – retrusion. The other visual method used to assess patients' perception of facial appearance was devised by Kiyak and Zeitler[440], who asked their patient to sketch their profile, indicating how it differed from a previously shown ideal profile at any point from the forehead to the neck. A millimetre grid was later applied to the lower half of the face to measure deviations from ideal in the maxilla, the mandible and the vertical dimension.

Some authors preferred to design their own questionnaires with some questions about patient's perception of facial appearance using dichotomous answers[(403,443)], 5-point Likert rating scales[(412,423)] or Visual Analogue Scales (VAS)[(439)].

With regard to the presurgical analysis of facial appearance, van Steenbergen et al[(442)] were able to prove that self-concept was the most important predictor of patient presurgical satisfaction with facial appearance assessed by SJBCS, regardless of the severity of the facial disharmony. Cunningham et al[(439)] observed significant changes associated with the presurgical orthodontic phase for the body image index, but this was largely amongst those respondents whose perceived severity was mild or moderate. The facial body image index was 'saturated' before presurgical orthodontics, which prevented further increase in score at the immediate presurgical assessment.

With regard to the impact of orthognathic surgery on self-perception of facial appearance, some studies revealed a high percentage (>80%) of patients satisfied with their postsurgical appearance reporting positive changes[(403,412,443)]. Kiyak et al[(431)] showed a drop in body image at 9 months postoperatively, but it returned gradually to the presurgical values exceeding them to a statistically significant level. Significant changes of facial body image were detected in the work of Arndt et al[(428)] and Lovius et al[(436)] using HRS (Hay's Rating Scale) and BSS (Body Satisfaction Scale), respectively.

Visually oriented analyses revealed the following facts: patients who rejected orthognathic surgery perceived their profiles as being more within the normal range[(410)]; patients tended to select profiles in the abnormal range in several ratings scales (or dimensions), even when the diagnosis of dentofacial deformity was limited to a single dimension[(440)]. At the long-term follow up assessment, patients tended to choose profiles and produce drawings in the normal range[(440)]. Body image (BI) assessed by SJBCS is not a useful measure to differentiate among patients with different dentofacial deformities[440] and body image (BI) questionnaires are not always consistent with patients' visual description of their facial features[441].

Table 1.20	Personality characteristics of patients undergoing orthognathic surgery					
Author(s)	**N**	**Dento-facial deformity**	**Method**	**Self-concept (including self-esteem)***	**Extroversion/introversion and neuroticism**	**Anxiety, depression, self-confidence and other variables**
Hutton[403]	32: 21F 11M	Mand Prog.	Retro. Ques.	Not available	Not available	50% gained self-confidence and became more sociable
Crowell et al[443]	33	Mand Prog.	Retro. Ques.	Not available	Not available	More than 50% commented on their increased self-confidence and overcoming shyness.
Laufer et al[407]	25 21 F 4 M	Mand Prog	Retro. Ques.	Not available	Not available	68% noted beneficial change in personality
Ouellette et al[415]	66 51F 15M	Mixed	Retro. Ques.	Not available	Not available	75% mentioned that facial change gave self-confidence
Kiyak et al[408]	73 45F 29M	Mixed	Pros. Ques.	Preop, self-esteem was in the high normal range for both sexes.	Neuroticism was in the normal range. Women had higher scores.	Locus of control was marginally in the external range of the related scale before surgery
Kiyak et al[430,431]	55† 46	Mixed	Pros. Ques.	Significant drop of overall self-esteem at 9-month interval postoperatively From 9 mos. to 24 mos. postoperatively, overall self-esteem returned roughly to its presurgical values.	Significant increase in extroversion 9 months after surgery among most patients.	Depression was noticed among many patients through the 9-month observation period
Auerbach et al[416]	30 24 F 16 M	Mixed	Pros. Ques.	Preoperatively, within the normal range. Positive changes after surgery during the following 4 months	Preoperatively, neuroticism within the normal range.	Preoperatively, self-confidence within the normal range. All subscales of SCL-90 within the normal range. After surgery, decline in phobic anxiety and anxiety subscales.
Kiyak et al[444]	156‡	Mixed	Pros. Ques.	The higher the person's self-esteem scores, the fewer reports of negative emotions at the later stages of treatment.	Neuroticism was significantly correlated with all emotional dimensions up to six months after surgery	The overall mood states were lowest immediately after surgery and improved during the fixation period, to six months after surgery.

Table 1.20 Contd.

Author(s)	N	Dento-facial deformity	Method	Self-concept (including self-esteem)*	Extroversion/introversion and Neuroticism	Anxiety, depression, self-confidence and other variables
Kiyak et al[432]	156‡	Mixed	Pros. Ques.	Overall self-esteem improved from before surgery to fixation removal but declined to a level slightly lower than before surgery.	Values not mentioned.	Not available
Stewart & Sexton[445]	6: 5F &1M	Mixed	Retro. Interv.	Not available	Not available	5 out of 6 patients showed postsurgical depressive symptoms.
Flanary et al[427]	61: 38 F 23 M	Mixed	Pros. Ques.	Presurgery: TSCS scores showed normal self-esteem. At 24 months postsurgery, significant improvement of all TSCS subscales of self-concept.	Presurgery: Neuroticism was slightly below the normal range using EPI. Women were significantly more neurotic than men. EPI showed values of extroversion slightly below the normal range in the presurgical assessment.	MBHI showed normal scores with 'confident' as one of the prevalent coping styles. Using TSCS, 36% had individual scores outside the normal range in one of the sub-scales that pointed to personality disturbances. However, abnormal personality dimensions improved significantly by the 24-month interval.
Lovius et al[436]	41§ 35 F 6 M	Mixed	Pros. Ques.	Not available	Using SAD and FNE questionnaires, there was a significant improvement and less social anxiety postoperatively.	No conclusions could be derived from the results of GHQ, which analysed the following subscales: 'somatic symptoms', 'anxiety/insomnia', 'social dysfunction' and 'severe depression'.
Frost and Peterson[419]	65 57 F 8 M	Mixed	Retro. Ques.	Not available	Not available	70% reported a short period of depression in different times following surgery. Factors beyond depression could be attributed to medication, house confinement, need for second surgery, or inability to eat.
Garvill et al, [412]	27 17 F 10 M	Mixed	Pros. Interv.	Not available	Not available	40% mentioned that they experienced depression during the 2-month period after surgery.

Table 1.20 Contd.

Author(s)	N	Dento-facial deformity	Method	Self-concept (including self-esteem)*	Extroversion/introversion and Neuroticism	Anxiety, depression, self-confidence and other variables
Finlay et al[413]	61 37 F 24 M	Mixed	Pros. Ques.	Mean personal self-esteem was slightly lower than normative data, and increased insignificantly between before and one-year after surgery.	Higher neuroticism scores than normative data. No significant changes were seen regarding neuroticism and extroversion scores throughout the treatment.	No specific conclusions derived from GHQ scores (the results were not clearly shown).
Cunningham et al[429]	148¶	Mixed	CrSec. Ques.	There was no statistically significant change of self-esteem between before and after surgery using RSE.	Not available	No significant difference was found between the two groups for anxiety or depression using HADS. Generally, depression was low in both groups although 80% of respondents reported feeling of depression at some time in the immediate postoperative period.
Hoppenreijs et al[423]	282	AOB	Retro. Interv.	Not available	Not available	38% mentioned improvement in their self-confidence one year after surgery and 3% mentioned worsening.
Bertolini et al[446]	13 8 F 5 M	Mixed	Pros. Ques.	54% said that they had better self-esteem.	Not available	Anxiety was higher than the presurgical level significantly using STAI questionnaire, but the results were not shown clearly in relation to other personality and mood scales.
Scott et al[434]	117 86 F 31 M	Mixed	Pros. Ques.	Not available	EPI neuroticism scores were within normal limits.	Scores of the Global Severity Index (a subscale of the SCL-90-Revised) and other subscales showed normal scores with no presurgical psychopathology.

(*) Body Image is reviewed in detail in Table 1.22. (†) Another two publications of the same sample collected initially by Kiyak et al (1981) but with 55 subjects in 1982's article and 46 subjects in 1984's article. (‡) This study consisted of 90 orthognathic cases, 33 who refused surgery but underwent orthodontics only and 33 who did not undergo any treatment. (§) This study contained two groups: one prospective group of 41 patients, and another cross-sectional sample of two independent subgroups pre- and postoperatively. The results presented are related to the first group. (¶) Cross-sectional study consisting of 67 patients in the presurgical group and 81 patients in the postsurgical group.

Abbreviations used: N= number of patients; F= Females; M= Males; Pros= Prospective; Retro= Retrospective; CrSec= cross-sectional study; Ques= Questionnaires; Interv= Interviews; Diff= Different; AOB= Anterior Open Bite; SCL-90= Symptom Check List – 90; POMS= Profile of Mood States; TSCS= Tennessee Self-Concept Scale; EPI= Eysenck Personality Inventory; MBHI= Millon Behavioural Health Inventory; SAD= Social Avoidance and Distress; FNE= Fear of Negative Evaluations; GHQ= General Health Questionnaire; RSE= Rosenberg Self-Esteem; HADS= Hospital Anxiety and Depression Scale.

Table 1.21	Body Image (BI) of patients undergoing orthognathic surgery		
Author(s)	**Year**	**Pre- and Post-operative results**	**Other conclusions**
Hutton[403]	1967	91% reported that they have noticed a major change in their facial appearance.	
Crowell et al[443]	1970	88% reported that they have noticed major facial changes.	
Kiyak et al[408]*	1981	The overall BI was within the normal limits pre- and post-operatively	Males were significantly more positive than females when evaluating their facial profiles*.
Kiyak et al[430]*	1982	Facial BI dropped significantly 9 months after surgery, while the chin image improved significantly at the final follow-up.	The overall body-image did not show significant changes longitudinally
Kiyak et al[431]*	1984	BI was significantly higher at 24 months postoperatively than the baseline mean scores Facial BI dropped at 9 months and rose again at 24 months.	Profile BI improved gradually and insignificantly until 24 months postsurgery, where the overall change was significant
Bell et al[410]	1985	Patients who had decided to have surgery perceived themselves as having profiles that deviated from the ideal range, while those who decided against surgery perceived their own profiles as being more within the normal range.	One's self-perception of profile may be the most important factor in the decision to elect surgical correction.
Arndt et al[428]†	1986	There was a high significant difference between pre- and post-surgical ratings for th[e] group of children who were severely and mildly affected (heterogeneous sample).	
Kiyak et al[432]*	1986	The least positive level of body image was seen at the initial assessment. There was a dramatic improvement in all body image measures at the immediate postsurgical stage and continued to improve up to six months after surgery.	Females' scores changed in a sporadic pattern over the observation period, while males' scores changed in a linear pattern.
Kiyak and Zeitler[440]‡§	1988	Patients tended to select profiles in the abnormal range in several or all four rating[s] scales, even when the diagnosis of dentofacial deformity was limited to a singl[e] dimension. The self-drawing of facial profiles showed findings similar to profil[e] ratings. At 2-year postoperatively, patients tended to choose profiles and produc[e] drawings in the normal range.	Patients can characterise mandibular and vertical deformities best and tend to characterise maxillary deformities as a mandibular deformity in the opposite direction. BI assessed by SJBCS is not a useful measure to differentiate among patients with different dentofacial deformities.
Lovius et al[436]¶	1990	Significant change was seen in the direction of greater satisfaction following surgery on the three out of the four indices, i.e. 'general', 'head' parts and 'teeth and jaws' measures of the BSS.	There was no significant change on the 'body parts' measure, suggesting that the improvement was a specific rather that a general one.
Maxwell and Kiyak[441]*‡§	1991	Patients could draw their mandibular and vertical defects more readily than they coul[d] their maxillary appearance, whereas they could accurately match existing drawings t[o] their own images on the maxillary and mandibular dimensions. The self-rating metho[d] seemed to be valid for assessing mandibular, maxillary, and dentoalveolar defects whereas the self-drawing method was useful to describe mandibular defects.	Subjective values by patients regarding their facial attractiveness (assess by BI questionnaires) are not always consistent with their visual description of their facial features.

Table 1.21 Contd.

Authors	Year	Pre- and Post-operative results	Other conclusions
Garvill et al[412]	1992	81% thought that their facial appearance had changed moderately or greatly on a 5-point rating scale.	
Finlay et al[413]	1995	No significant differences could be detected for the physical and personal self-esteem using the original format of SJBCS in the comparisons between preoperative values and postoperative values at different intervals	
Cunningham et al[414]	1996	Very highly significant differences were detected regarding patients' perception o improvement of facial appearance and dental appearance.	
van Steenbergen et al[442]	1996	Using a modified version of SJBCS to a group of patients before surgery revealed that self-concept was the most important predictor of patient satisfaction with facial appearance, regardless of the severity of the facial disharmony	The high correlation between the patients' psychological distress and satisfaction with facial appearance and self-concept indicated the importance of distress in orthognathic surgery patients.
Hoppenreijs el[423]	1999	Patients' self-judgement of facial appearance was slightly, but significantly, lower thai the score given by friends and relatives on a 5-point scale ranging from 1 (much mon ugly) to 5 (much more beautiful)	Overall, 85% were satisfied with facial appearance, but 6% were not. 69% felt that treatment was worth the change of facial appearance.
Cunningham et al[439]	2001	Significant changes associated with presurgical orthodontic phase were observed for the body image index, but this was largely amongst those respondents whose perceived severity was mild or moderate.	The facial body image index was 'saturated' before presurgical orthodontics, which prevented further increase in score at the immediate presurgical assessment.

(*) Using a modified version of Secord and Jourard's Body Cathexis Scale, in which more body parts especially those related to facial features were included in the scale. (†) Using Hay's Rating Scale, which ranges from 1 (perfect feature) to 9 (marked imperfection). (‡) Using the same profile sketches proposed by Bell and Kiyak[410] with four facial profile dimensions. (§) Using 'self-drawing of facial profile' method. (¶) Using Body Satisfaction Scale, which includes 16 body parts, and ranges from head to feet.

Abbreviations used: SJBCS= Secord and Jourard's Body Cathexis Scale; BSS= Body Satisfaction Scale.

1.5.3.6 Anxiety

Auerbach et al[416] showed that their sample scored within the normal range regarding all the subscales of Symptom Checklist-90 (SCL-90). SCL-90 is a 90-item self-report clinical rating scale that asks patients to rate how much given problems currently bother them. It measures the following symptoms: somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation and psychoticism. When they compared the postoperative values with those measured preoperatively, one significant difference was detected in relation to phobic anxiety subscale, which declined after surgery. They noticed a tendency for scores on the anxiety subscale to decrease. However, their results reflected the short-term effect of orthognathic surgery with a postsurgical observation period of 4 months. Flanary et al[427] used the 16-Personality-Factor questionnaire (16PF), which is a 187-item inventory to assess 16 primary personality traits (e.g., practical versus imaginative, or tense versus relaxed) on orthognathic patients with different types of surgical interventions. The investigation revealed that their patients were relatively healthy and well adjusted in all of the psychological parameters tested. As mentioned earlier, Lovius et al[436] found a significant improvement and less social anxiety with their sample when they applied the SAD (Social Avoidance and Distress) scale.

The General Health Questionnaires were applied in two studies[413,436], but no significant difference could be detected with regard to anxiety/insomnia subscale in the longitudinal comparison. Cunningham et al[429] employed the Hospital Anxiety and Depression scale to assess the impact of orthognathic surgery on these two parameters and found no significant difference in anxiety between the pre- and post-operative groups. Recently, Bertolini et al[446] applied State-Trait Anxiety Inventory and Zung anxiety test on a group of patients pre- and postoperatively. State anxiety levels (or current anxiety) were found to be intermediate to high preoperatively, and a significant increase occurred postoperatively. The presurgical anxiety could be attributed to the fear of the surgical operation and/or the fear of the postsurgical change in body image with its social and psychological ramifications[446]. Although it might have been expected that the anxiety should have resolved after surgery, the high levels noticed were attributed to possible patients' expectations of a new body image, greater self-esteem and changed social relationships. On the other hand, anticipatory anxiety, as assessed by the EPI and SCL-90-Revised, was not evident within the study conducted by Scott et al[434].

1.5.3.7 Depression

The open-ended comments at the end of the questionnaires used by Kiyak et al[430] to assess patients experiences, immediately and 9 months following surgery, drew the attention to symptoms of depression. One of the comments was: 'Worst part of surgery is how you look after surgery and the depression that follows during the time of fixation'. Peterson and Topazian[425] warned that 'the surgeon must explicitly inform all patient that they will be depressed for a few days during the immediate postoperative course'. In a later study by Kiyak et al[444], low overall mood scores were found postsurgery, but a small number of patients experienced depression. Depression scores increased immediately after surgery, but improved progressively from fixation removal to 6 months postoperatively.

Stewart and Sexton[445] examined 6 orthognathic patients postoperatively in semi-structured interviews. Five out of 6 patients had met or exceeded the criteria for a major depressive episode defined as 'dysphoric mode or loss of interest or pleasure in all or almost all usual activities and pastimes, with symptoms such as being depressed, sad, blue, hopeless, low, down in the dumps and irritable'. Some symptoms appeared on a daily basis for at least two weeks indicating depression, such as poor appetite or significant weight loss; insomnia or hypersomnia; psychomotor agitation or retardation[445]. These symptoms appeared either in the first three weeks immediately after surgery or in the following three weeks before fixation removal. The General Health Questionnaire used by other researchers did not reveal any specific conclusions in this field[413,436]. However, open-ended questionnaires revealed different proportions of patients reporting a depression period postoperatively, varying from 40%[412] to 80%[429]. Frost and Peterson[419] tried to attribute postsurgical depression to medication, house confinement, need for second surgery or inability to eat. Many researchers believe that the use of rigid internal fixation may reduce the tendency to depression[2,427,444,445]. In addition, if patients are forewarned of a possible transient depression, the impact of this response both on the patient and their families may be reduced[2].

1.5.4 Satisfaction with surgery

Patient's satisfaction following orthognathic surgery is one of the indicators of a successful outcome. Focus has been oriented in many studies to evaluate the postsurgical levels of satisfaction among orthognathic patients and this has been performed either prospectively (418,447)or retrospectively(403,443,448). Seventeen studies have assessed satisfaction following surgery and these are summarised in Table 1.22.

Assessment of satisfaction has been accomplished using questionnaires with dichotomous answers(403,407,443), ordered categorical response scales(422,446), Likert ordinal scales (418) and visual analogue scales (VAS)(448). Furthermore, satisfaction was assessed through structured interviews(447). The validity of questions about the immediate levels of satisfaction following orthognathic surgery, in retrospective studies conducted several months postoperatively, is questionable(415). Accuracy is increased when such an assessment is performed using standardised tools at predetermined times in a longitudinal prospective studies.

Satisfaction has been found to vary between 71% to 100%(403,407,413,414,427,430,446,447). The proportion of patients expressing satisfaction is also dependent on the type of question being posed. If satisfaction is defined as 'patient's willingness to undergo surgery if he/she had to make the decision again', the proportion ranged from 76%(407) to more than 95%(291). If recommendation of orthognathic surgery to others can be considered as an indicator of satisfaction, the proportion of respondents making that recommendation was 75% among patients in Cunningham's study(414) compared with 89% in Finlay's study(413). Satisfaction with healing postoperatively has also been high(418). Cheng et al (448) differentiated between satisfaction with function, satisfaction with aesthetics and the overall satisfaction. They found that the satisfaction percentages were 92%, 97% and 99% respectively.

Postsurgical dissatisfaction is generally attributed to an unfavourable interpersonal relationship between patient and surgeon and rarely related to the technical skills of the surgeon(2). Macgregor(394) mentioned three factors for dissatisfaction following an apparently successful operation: patient factors (e.g. psychological problems, unrealistic expectations or undergoing surgery to please others); surgeon factors (e.g.

improper evaluation of the patient, incomplete presurgical preparation) and surgeon-patient-interaction factors (e.g. poor communication).

Lewis et al[449] created a checklist to avoid treating 'dissatisfied' patients and this list consisted of medical, physiological, interpersonal and psychological considerations. Four psychological characteristics required assessment before considering a patient suitable for orthognathic surgery: self-assessment of attractiveness, anxiety, fear and expectations[449]. The less anxious the patient is, the greater the chances for postsurgical success. Patients with compulsive traits and many fears about the operation are unlikely to show good satisfaction following surgery. Patients with realistic expectations are the best candidates for this type of treatment. It is worth mentioning that surgery free of complications also increases the levels of satisfaction following surgery[438].

Several researchers have emphasised that the assessment of satisfaction following surgery cannot be evaluated thoroughly without taking into account other important psychosocial factors such as patients' perception of their facial appearance as well as their personality characteristics[390]. Personality type (such as neuroticism) has emerged as a predictor of several short-term outcomes, but has not affected satisfaction in the long term[431]. One study[431] showed that self-esteem and perception of facial image fell nine months postsurgery but increased at 2 years postsurgery. An accompanying decline in the overall satisfaction score was also observed at the nine-month assessment time followed by an increase at two years.

Cunningham et al[2] concluded that postsurgical dissatisfaction can be best avoided by giving enough importance to patient selection and by providing detailed explanations of the problems to be anticipated.

Table 1.22 Studies which assessed patients' satisfaction following orthognathic surgery

Author(s)	Year	N	Type of assessment	Satisfaction following orthognathic surgery	Time of assessment
Hutton[403]	1967	32	Retro.	93.75% of patients would undergo the surgery if they had to make the decisioı again 96.88% would recommend this surgery to others	Patients were seen 6 months to 16 years postoperatively
Crowell et al[443]	1970	33	Retro.	96.96% would undergo the surgery again 96.96% would recommend this surgery to others	Time interval since surgery ranged from 3 mos to 3 ½ years
Laufer[407]	1976	25	Retro.	76% would go through the operation if they had to make the decision again.	Patient were seen following surgery but the time was unspecified
Pepersack and Chausse[291]	1978	67	Retro.	95.5% were satisfied with the overall result More than 95% would undergo the operation again	Patients were at a minimum of a 5-year follow-up
Ouellette[415]	1978	66	Retro.	More than 50% were happy with the results immediately after the end o treatment The overall end satisfaction was reported by 93% of patients	14 months following surgery
Olson & Laskin[447]	1980	52	Pros.	100% were satisfied with the functional change 92% were satisfied with the aesthetic change Generally, patients who were pleased with the aesthetic results did not think major changes had occurred.	T1: preop T2: 6 months postop
Rittersma et al[450]	1980	100	Retro.	71.4 % were satisfied or very satisfied with the end result, whereas 25.5 % werε moderately satisfied and about 3.1 % were dissatisfied. 87% of the patients would recommend surgery to others. 3% regretted undergoing surgery	Questionnaires were sent to patients who had had surgery at least one year before
Flanary and Alexander[451]	1983	90	Retro.	10% showed a moderate to strong disagreement to re-elect surgery again.	Patients had had orthognathic surgery from 2 months to 14 years before the assessment.
Frost et al[419]	1991	65	Retro.	89% would recommend this surgery to others	Patients were seen from 3 months to five years following surgery
Ostler and Kiyak[418]	1991	27	Pros.	High satisfaction among patients. The highest scores were in the areas of healing and general satisfaction with the results	T1: 2.9 months preop. T2: 18.3 months postop.
Barbosa et al[452]	1993	41	Pros.	92.68% considered the treatment satisfactory	T1: one week before surgery T2: 30-40 days after T3: at fixation release T4: 8months to 5 years postop

Table 1.22 Contd.

Authors	Year	N	Type of assessment	Satisfaction following orthognathic surgery	Time of assessment
Finlay et al[413]	1995	61	Pros.	87% were satisfied. 84% had no regrets about their surgery. 77% would be happy to undergo the surgery again. 89% happy to recommend the procedure to others.	T1: one month before T2: three months after T3: six months after T4: one year after
Cunningham et al[414]	1996	49	CrSec.	90% were satisfied (treatment outcome) 86% felt that undergoing this surgery was worthful 71% would re-elect to have surgery if they had to make the decision again.	Patients were at a minimum of a 5-year follow-up
Cunningham et al[429]	1996	81	CrSec.	95% were satisfied with the results. 76.5% said that they would make the same decision again (to underg(surgery). About 75% would recommend orthognathic surgery to others.	Patients in the postsurgical group were seen at least 9 months postoperatively
Cheng et al[448]	1998	139	Retro.	92% satisfied with function 97% satisfied with appearance 99% satisfied generally	Patients were seen one year at least postop.
Nurminen et al[422]	1999	28	Retro.	96.4% were moderately to highly satisfied.	Patients were seen 6 to 2 years postoperatively
Bertolini et al[446]	2000	20	Pros.	92.3% were satisfied or very satisfied with the surgical outcome.	T1: within 1 week preop. T2: 2 - 8 months postop.

(*) Developed by the authors

Abbreviations used: N= number of patients; Preop= preoperatively; postop= postoperatively; pros= prospective study; retros= retrospective study; CrSec= cross-sectional study.

Chapter Two

Aims & Null Hypotheses

2 Aims and Null Hypotheses

2.1 Aims

First Aim: To test the reliability of the stereophotogrammetry-based 3D imaging system (C3D) and the applicability of landmark-based morphometric analyses in studying facial soft-tissue morphology and the change in morphology following orthognathic surgery.

Second Aim: To determine the effect of orthognathic surgery on the 3D soft-tissue morphology and to test the stability of the 3D soft-tissue morphology at three months and six months following surgery

Third Aim: To assess skeletal changes following orthognathic surgery and the possible relapse up to six months postsurgery

Fourth Aim: To evaluate soft-tissue to hard-tissue displacement ratios in the overall assessment (between the first and the last assessment times)

Fifth Aim: To ascertain the impact of orthognathic surgery on patients' perception of their facial appearance and their psychosocial characteristics, and to evaluate any possible postsurgical changes in these variables

Sixth Aim: To explore the effect of dentofacial deformity, sex and age on the psychosocial characteristics

Seventh Aim: To evaluate the compatibility between the cephalometric and the three-dimensional measurements

Eighth Aim: To determine if the magnitude anteroposterior of facial soft-tissue changes affects the perception of facial changes at different facial regions assessed by the perception questionnaires at six months following surgery.

2.2 Null Hypotheses

Null Hypotheses related to the first Aim (1-3):

- The C3D system is not reliable in capturing and producing 3D facial models.
- Landmark identification on 3D facial models is not reproducible.
- The assessment of volumetric changes of facial regions on C3D-produced 3D models is inaccurate.

Null Hypotheses related to the second Aim (4-5):

- There are no statistically significant differences in soft-tissue morphology following orthognathic surgery.
- There are no statistically significant differences in soft-tissue morphology in the postsurgical period.

Null Hypotheses related to the third Aim (6-7):

- There are no statistically significant differences in maxillary and mandibular positions following surgery.
- There is no statistically significant relapse in the maxillary and mandibular positions in the postsurgical period.

Null Hypothesis related to the fourth Aim (8):

- There are no statistically significant displacement ratios between facial soft tissues and the underlying hard tissues.

Null Hypotheses related to the fifth Aim (9-10):

- There is no impact of orthognathic surgery on patients' perception of their facial appearance.
- There are no statistically significant changes in the psychosocial measures in the postsurgical observation period.

Null Hypothesis related to the sixth Aim (11):

- Three are no statistically significant differences between Class II and Class III patients, females and males, older and younger patients in their psychosocial profiles pre- and post-operatively.

Null Hypothesis related to the seventh Aim (12):

- There are no statistically significant differences between measurement obtained two-dimensionally and three-dimensionally.

Null Hypothesis related to the eighth aim (13):

- For each facial region, patients who perceived a maximum change did not have a statistically significant different z-displacement of landmarks compared with patients who perceived little or no change at six months following surgery.

Chapter Three

Materials and Methods

3 Materials and Methods

3.1 3D Imaging

The stereophotogrammetric imaging system (C3D®) has been developed in collaboration between Glasgow Dental Hospital and School, Turing Institute and the Faraday Partnership (Department of Computing Science, Glasgow University[110,154]). Further developments to the system and its related software have been undertaken by the 3DMATIC Research Laboratory[155].

3.1.1 3D imaging equipment

The technique is based on the use to two 'stereopairs' of digital cameras connected to a personal computer (Figure 3.1). The camera system consists of two pods, and each pod consists of the following items:

- One high-resolution colour digital camera (1000x800 pixels resolution) to capture the natural appearance of the face
- Two high-resolution monochrome digital cameras (1000x800 pixels resolution) serving as a 'stereopair' for building the model.
- One white light flash synchronised to operate with the colour camera
- One speckle texture projection synchronised to operate with the monochrome cameras (Figure 3.2).

The distance between the two pods is 1.6 metres and the distance between the stereopair and the target is 1.2 metres (Figure 3.3). The camera system was connected to a 'Dell Dimension XPS T500' personal computer (Dell, United Kingdom), which had the following specifications:

- 500 MHz Pentium III processor
- 512 Mb of RAM capacity
- 20 Gb hard disk C capacity
- 40 Gb hard disk D capacity
- 32 Mb accelerated video graphics card

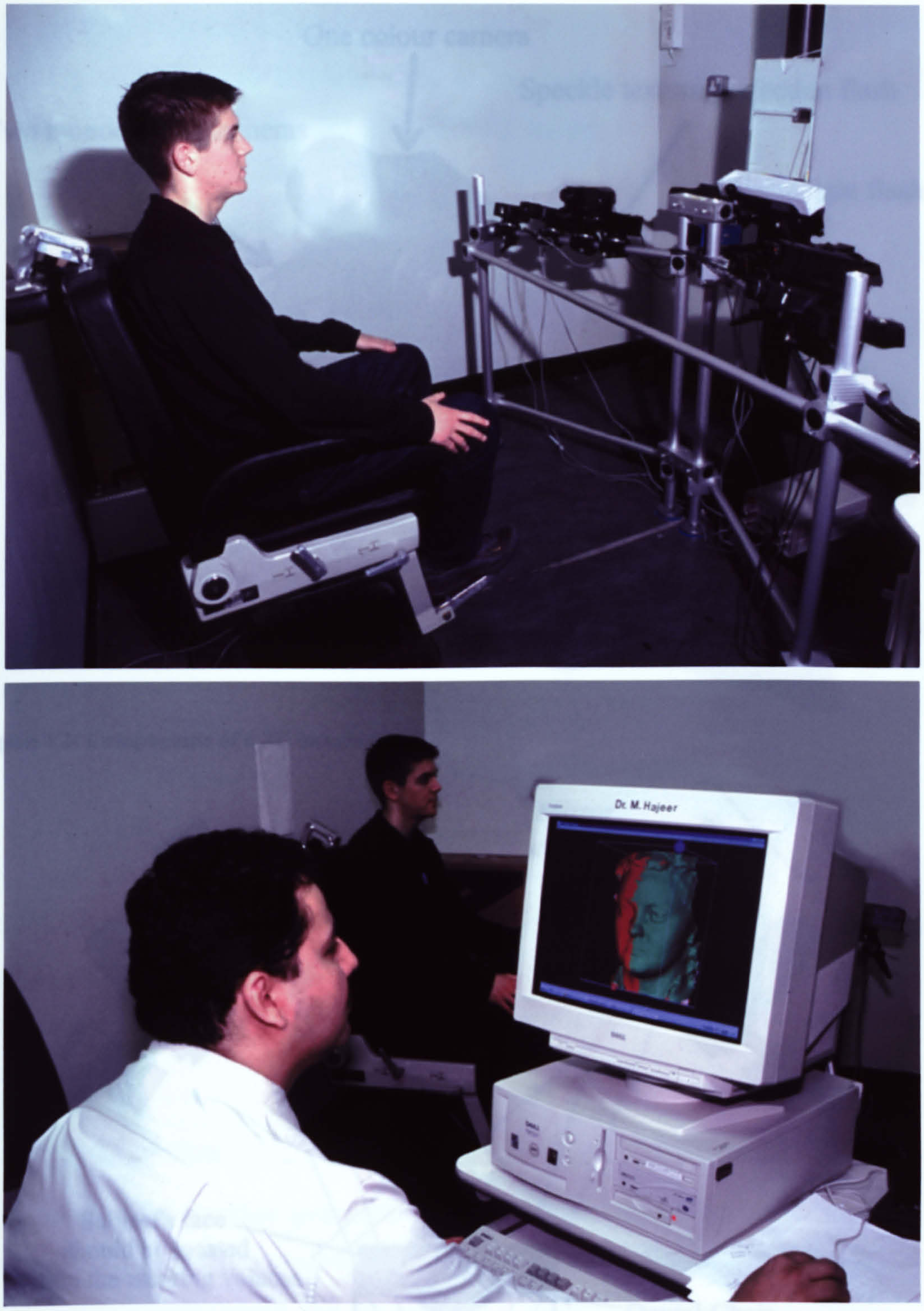


Figure 3.1: C3D® system is a non-contact vision-based imaging system. To begin the process, the patient sits on a chair in front of the system. Six images are captured within 50 milliseconds and the images are transferred to a PC where the operator can check their quality before building 3D models.

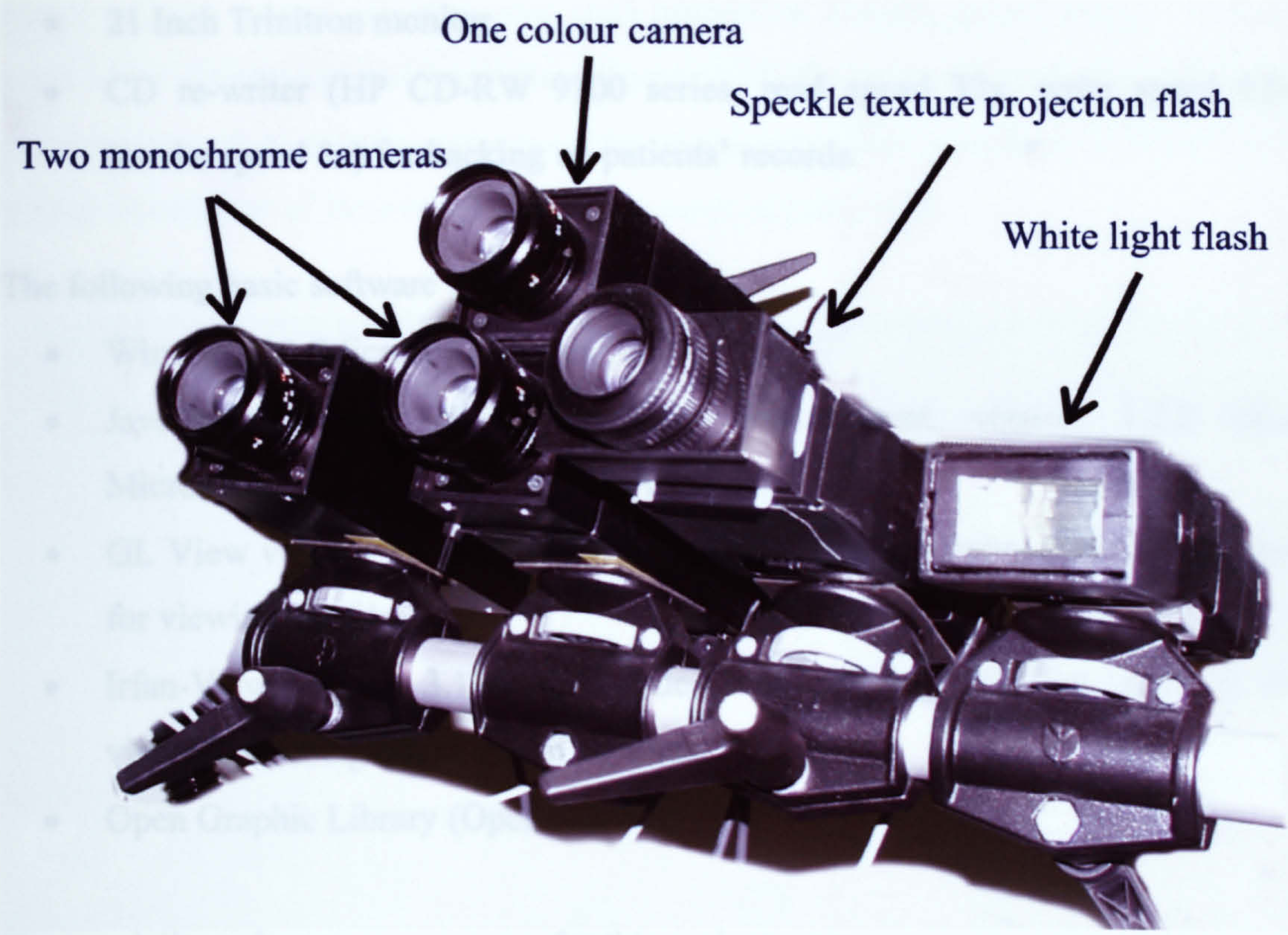


Figure 3.2: Components of a 3D imaging pod

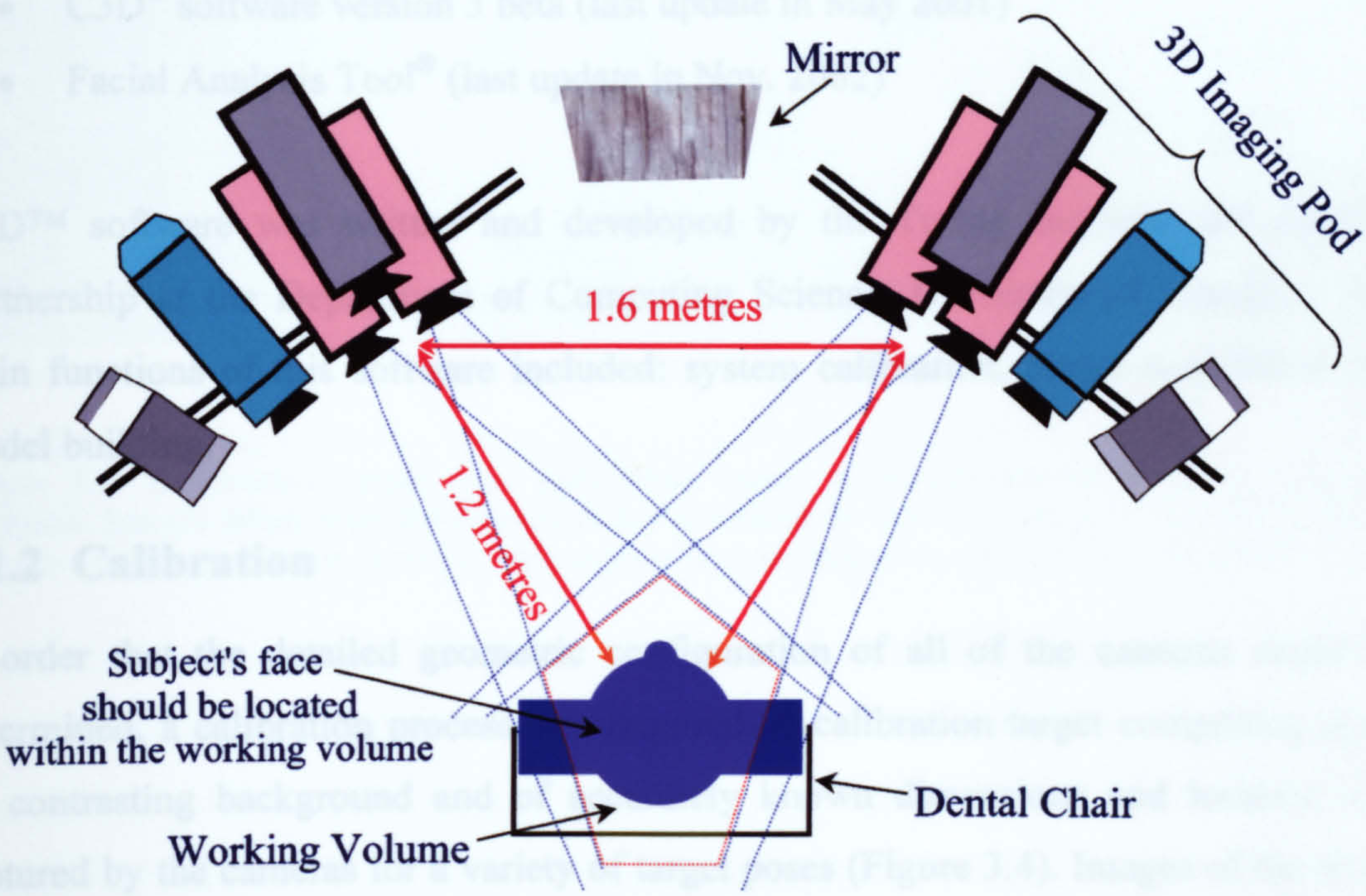


Figure 3.3: Diagram representing the configuration of the 3D imaging system. The distance between the monochrome cameras and the target was 1.2 metres, whereas the distance between the two imaging pods was 1.6 metres.

- 21 Inch Trinitron monitor
- CD re-writer (HP CD-RW 9100 series, read speed 32x, write speed 12x, rewrite speed 8x) for backing up patients' records.

The following basic software were installed:

- Windows 98 (Microsoft, Washington, USA)
- Java™ Standard Edition Runtime Environment version 1.2.2 (Sun Microsystems, Inc., California, USA)
- GL View version 4.4 (freeware developed by Holger-Grahn, Berlin, Germany) for viewing 3D files.
- Irfan-View version 3.1 (freeware developed by Irfan Skiljan, Austria) for viewing 2D images and screen captures.
- Open Graphic Library (OpenGL) version 2.1.

The specialist software programmes for this project were:

- C3D® software version 3 beta (last update in May 2001)
- Facial Analysis Tool® (last update in Nov. 2002)

C3D™ software was written and developed by the Turing Institute and Faraday Partnership at the Department of Computing Science, University of Glasgow. The main functions of this software included: system calibration, image acquisition and model building.

3.1.2 Calibration

In order that the detailed geometric configuration of all of the cameras could be determined, a calibration process was required. A calibration target comprising discs on contrasting background and of accurately known dimensions and location was captured by the cameras for a variety of target poses (Figure 3.4). Images of the target from all the cameras were processed to find the central location of the discs and these coordinates were used to fit an approximate geometric model of each camera and its respective relative orientation to the target. Calibration takes into account the following camera parameters: sensor pixel pitch, lens focal length, camera baseline and, importantly, the principal point on each imaging plane (where the projective centre of each camera projects onto each respective imaging plane) (Figure 3.5). In addition to computing intrinsic camera parameters, the procedure calculates extrinsic parameters such as relative camera-target orientation. This procedure is followed by giving an estimate of the overall calibration error in pixel units.

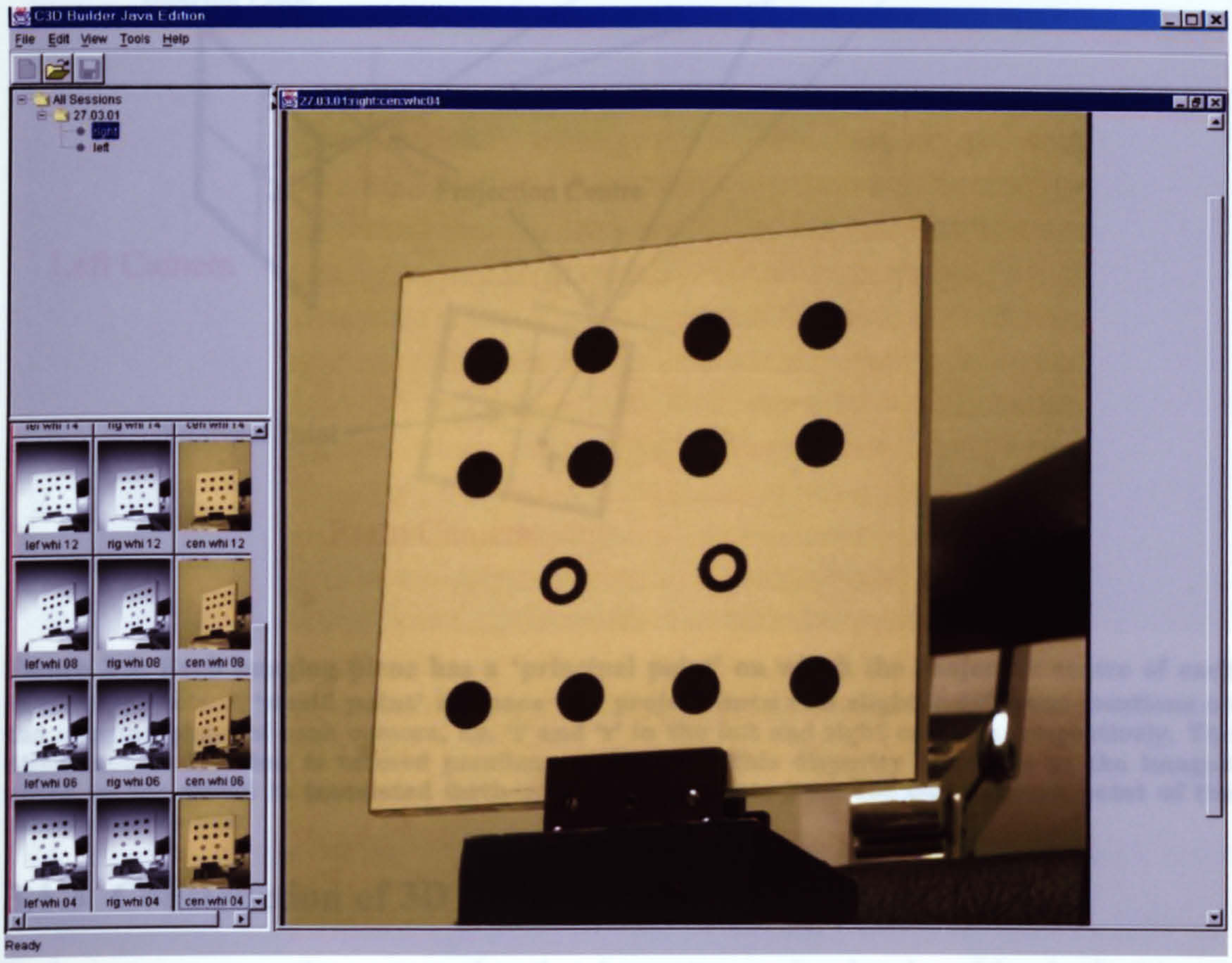


Figure 3.4: Calibration target. The calibration target is imaged several times in different positions. Images taken from the 6 cameras are processed to find the central location of the discs and used to fit a geometric model of each camera and its respective orientation to the target.

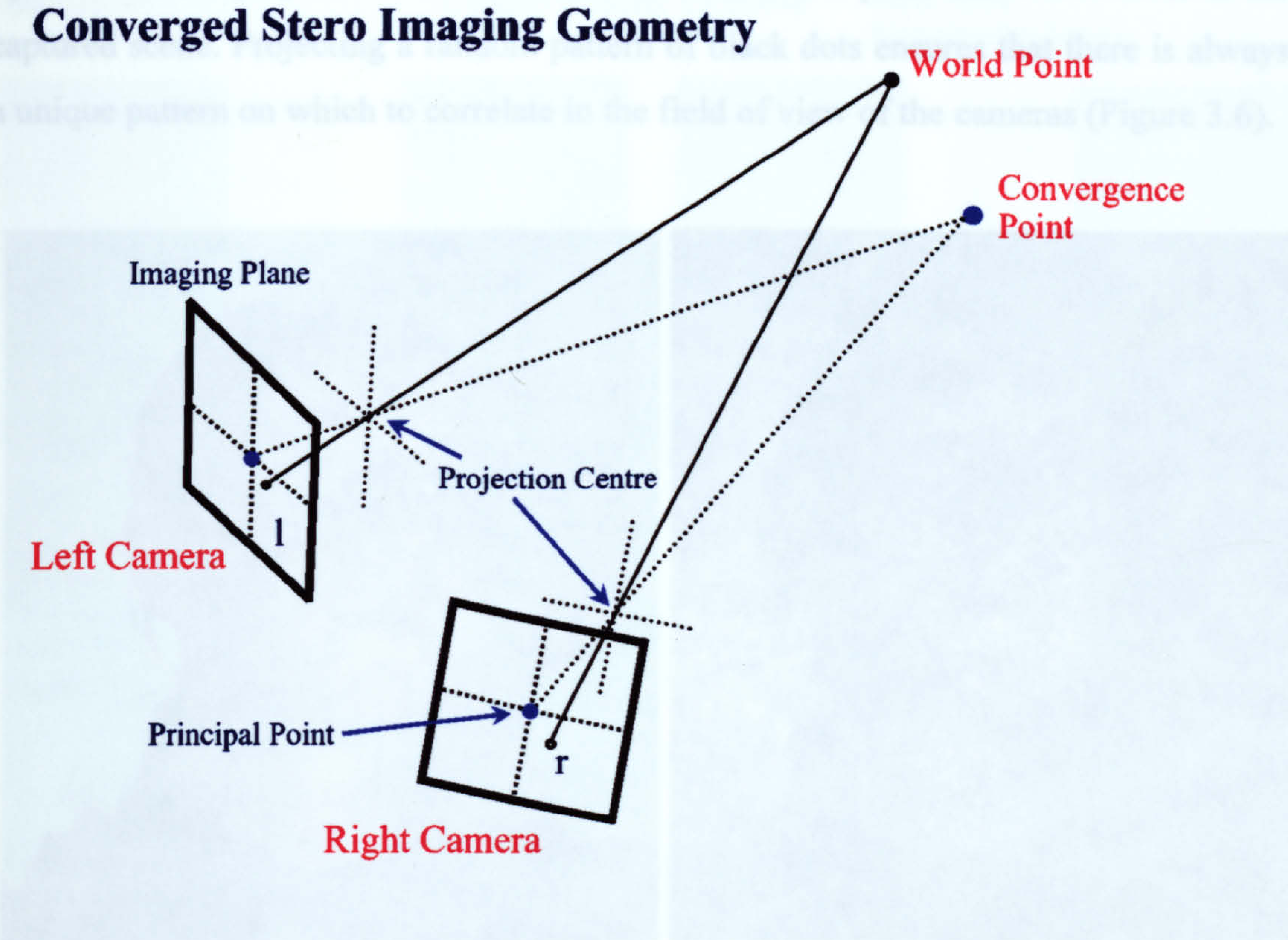


Figure 3.5: Each imaging plane has a 'principal point' on which the projective centre of each camera projects. A 'world point' in space will project onto two slightly different locations on the imaging plane of each camera, i.e. 'l' and 'r' in the left and right cameras, respectively. The difference in location is termed parallax or disparity. This disparity increases as the imaged point in the world is translated further in the depth axis from the convergence point of the camera stereo-pair

3.1.3 Construction of 3D facial models

Before any capture, the operator has the chance to monitor head position by looking at the six previewing windows and adjusting the head position so it can be seen from the six different views. However, by experience, the operator can bypass this step.

Each capture was acquired within 50 milliseconds and was made up of 6 images representing the two pods. The sequence was as follows:

- Four monochrome images, illuminated with speckle texture projection flash, were captured first within 10 milliseconds (for the two pods) (Figures 3.6 and 3.7a).
- A gap of 30 milliseconds existed before the following capture.
- Two colour images, illuminated with white light flash, were captured in 10 milliseconds (Figure 3.6).

Speckle-texture projection flash is used in order to avoid plain untextured areas in the captured scene. Projecting a random pattern of black dots ensures that there is always a unique pattern on which to correlate in the field of view of the cameras (Figure 3.6).

Figure 3.6: White light illumination versus 'speckle' texture illumination projected onto patient's face (both images were taken from one side).

The complex nature of the stereo-matching process is to determine, for each point imaged in the left camera, the corresponding point in the right camera. The output of this process is (x, y) disparity maps and a confidence map (Figure 3.7b). This process is termed 'space intersection' and results in the computation of a point cloud in X, Y, Z space[155]. The point cloud captured by a single stereo-pair of cameras comprises only 2.5D information and is called a *range model* (Fig 3.7c). An implicit surface is computed that merges together the point clouds into a single triangulated polygon mesh, using a variant of the Marching Cubes algorithm. This mesh can be further decimated to any arbitrarily low resolution for display purposes[155]. The final 3D output can be seen as a solid (green and red), shaded, or wireframe model (Figure 3.7d). By finding the correspondence between each 'vertex' (or 'node') in the 3D polygonal mesh and each pixel in the colour texture map, the system creates a photorealistic rendered model that can be viewed from any direction (Figure 3.8).

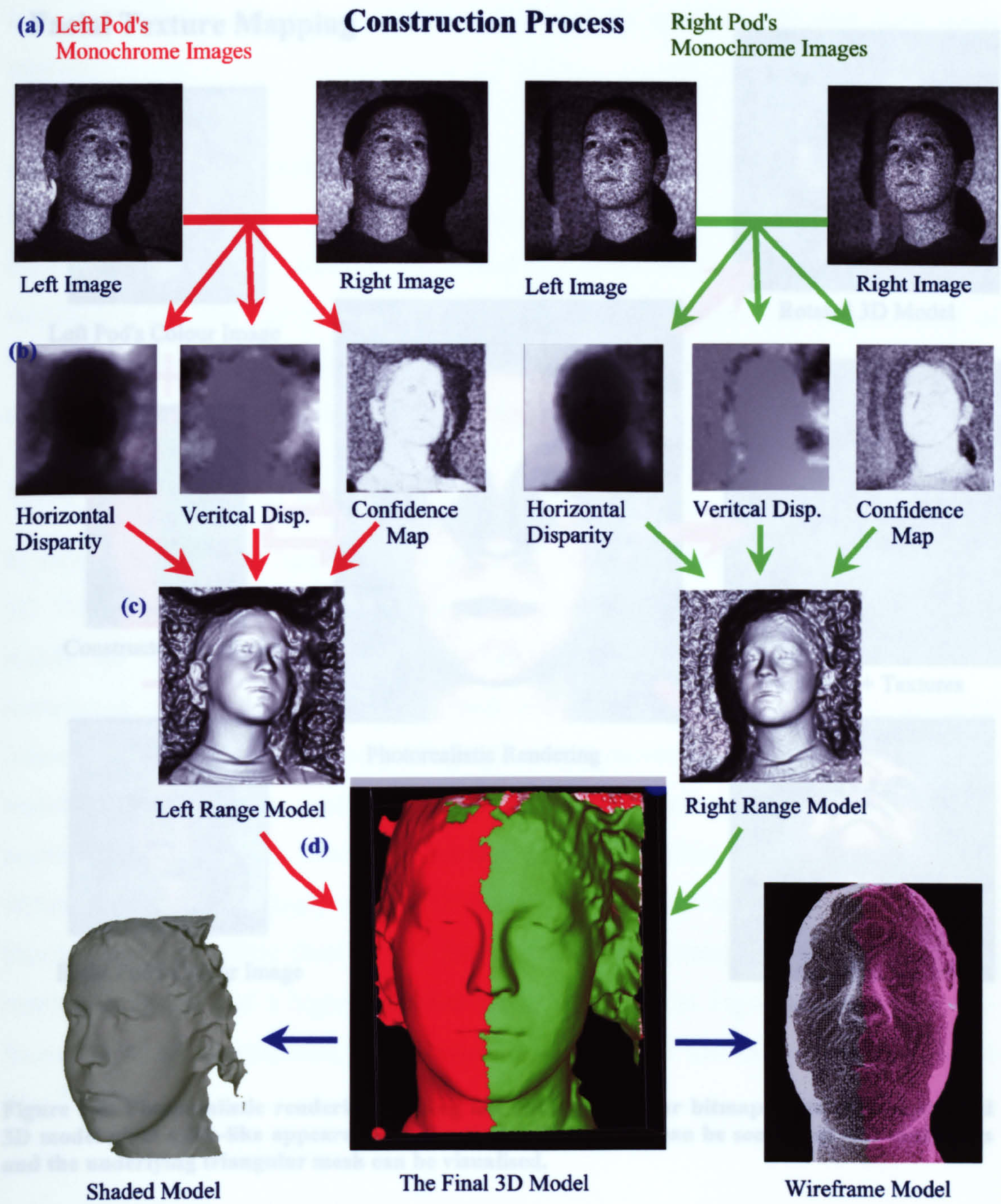


Figure 3.7: The construction procedure. Monochrome raw images captured (a), disparity maps and confidence maps built (b), range models recovered (c) and the final output seen in different ways (d).

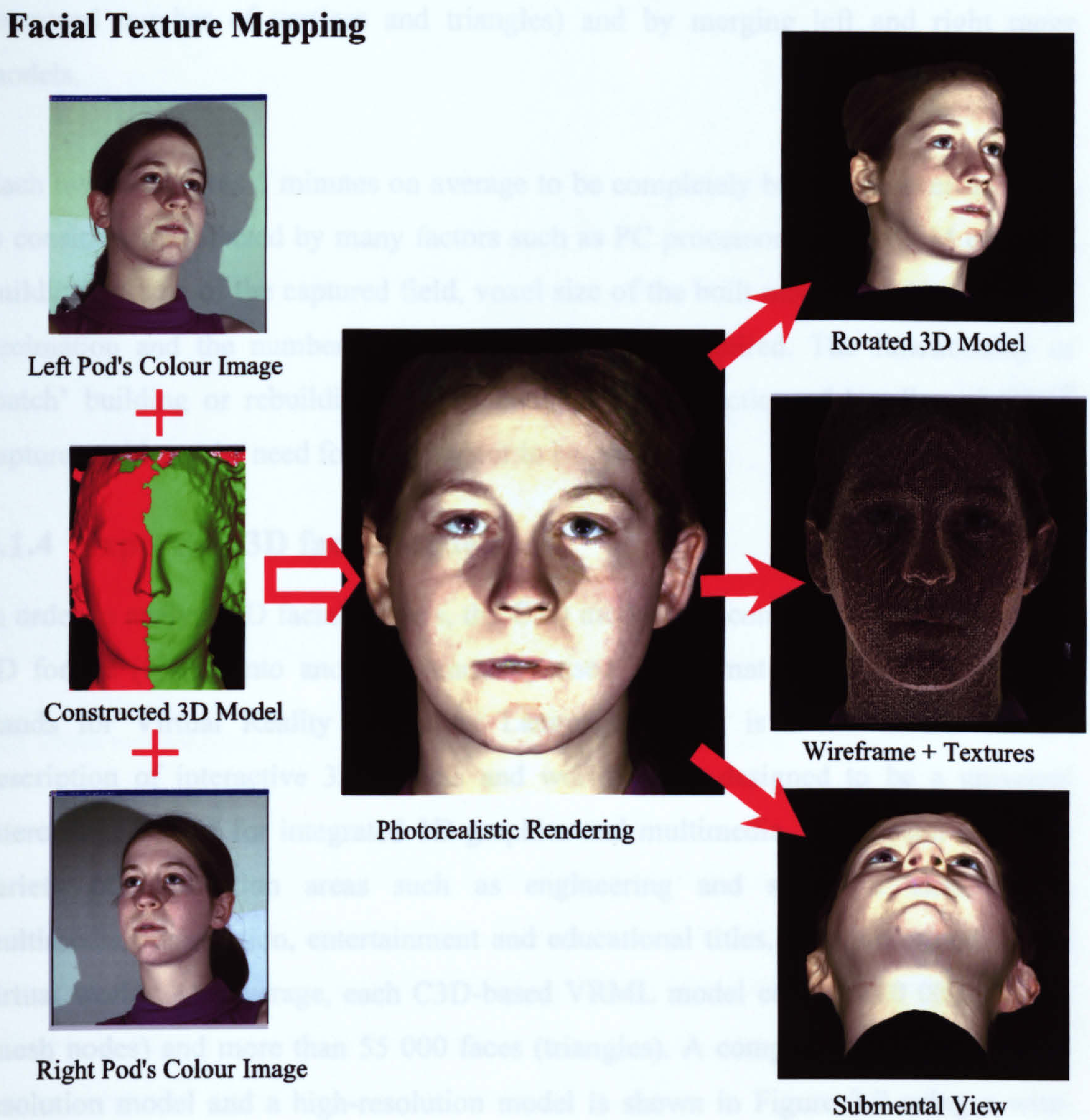


Figure 3.8: Photorealistic rendering: adding left and right colour bitmaps onto the constructed 3D model gives a life-like appearance to the model. This model can be seen from different views and the underlying triangular mesh can be visualised.

Since, the C3D system is a 'full-field' imaging technique, some unnecessary objects or areas might appear and should be discarded before reaching the file output. This discarding minimises model file size and accelerates further model manipulation and analysis. It is facilitated by building the model in two steps. The first step produces a low-resolution 3D model in which the point cloud is dependent on one stereopair (without merging left and right range models). The building volume defined by a white box surrounding the model can be reduced through a specific dialogue box. This is followed by building the model with a higher resolution (reduced voxel size, increased number of vertices and triangles) and by merging left and right range models.

Each model requires 5 minutes on average to be completely built. However this time is considerably affected by many factors such as PC processor speed, RAM capacity, building volume of the captured field, voxel size of the built model, the magnitude of decimation and the number of smoothing iterations required. The functionality of 'batch' building or rebuilding enables automatic construction of bundles of C3D® captures, without the need for the operator to be present.

3.1.4 Exporting 3D facial models

In order to analyse 3D facial models, the C3D models are converted from their native 3D format (*.c3d) into another commonly used 3D format called VRML. VRML stands for Virtual Reality Modelling Language and it is a file format for the description of interactive 3D objects and worlds. It is designed to be a universal interchange format for integrated 3D graphics and multimedia. It has been used in a variety of application areas such as engineering and scientific visualisation, multimedia presentation, entertainment and educational titles, web pages and shared virtual worlds. On average, each C3D-based VRML model contains 30 000 vertices (mesh nodes) and more than 55 000 faces (triangles). A comparison between a low-resolution model and a high-resolution model is shown in Figure 3.9 using a wire-frame mode of visualisation. This format is required for use in the Facial Analysis Tool®.

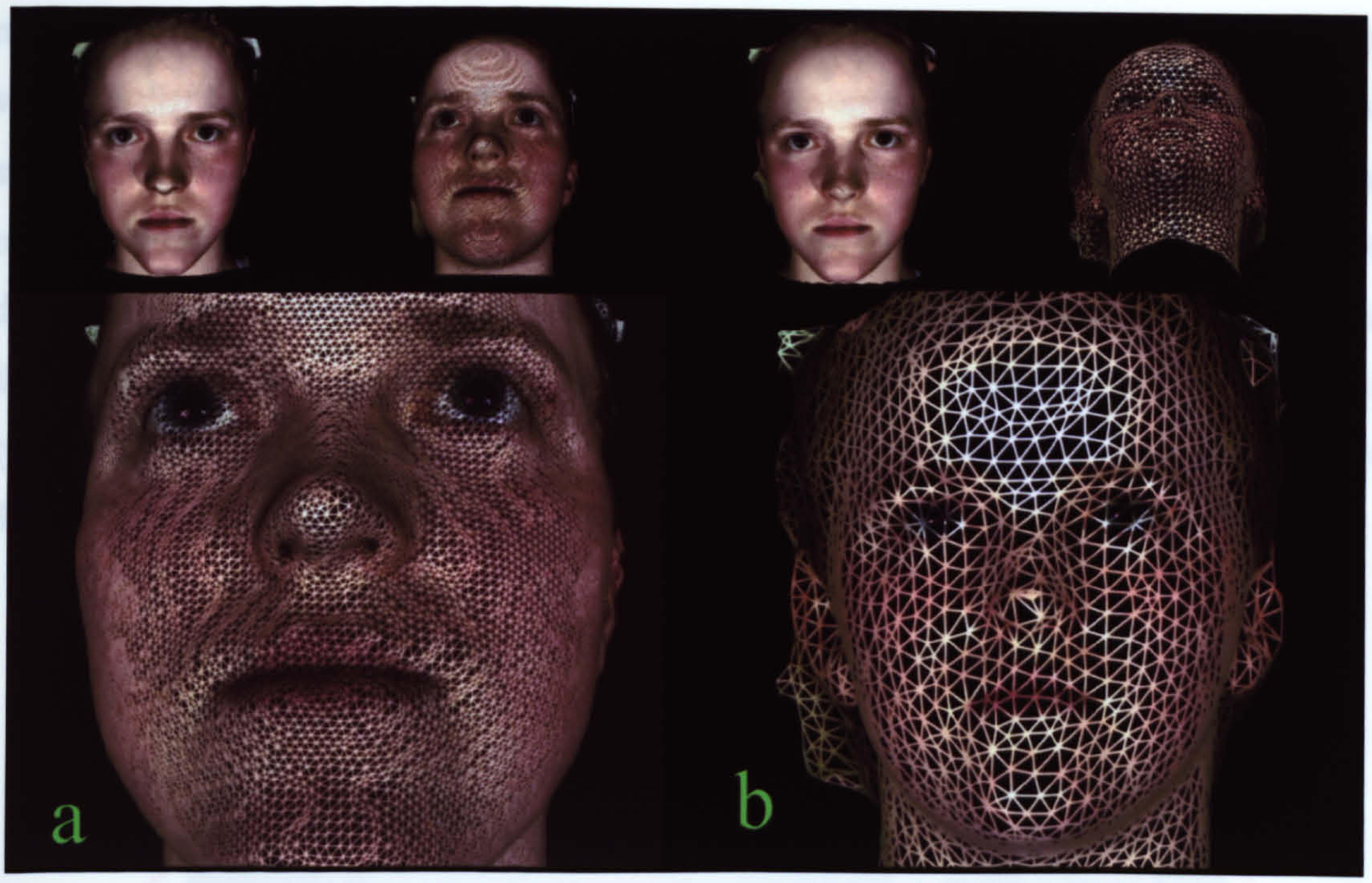


Figure 3.9: High-resolution models versus low-resolution models. (a) A VRML model with more than 30000 vertices compared with (b) VRML model with less than 2000 vertices

3.2 3D Facial Analysis software

The Facial Analysis Tool® (FAT) has been developed within a collaborative project to assess facial clefts in babies and infants. The software has undergone several upgrades from the first version, which was revealed in April 2000. The main functions of this software in its current version (version 5) are:

- Landmark identification on 3D models
- Landmark editing and pseudo-landmark construction
- Landmark-based linear and angular measurements
- Surface curve extraction
- Surface area and volumetric assessment
- Facial asymmetry assessment

3.2.1 Facial Analysis Tool® Interface

Each VRML model is loaded to the FAT, where the operator can manipulate the model from any direction through the use of 'magnification', 'translation' and 'rotation' buttons (Figure3.10). The model can be seen as a solid surface, a triangular mesh or a life-like model (on which the colour textures are mapped). The triple-view interface enables the operator to examine the model in 3 perpendicular views. The main window displays the 3D facial model in the full-face view. The first smaller window displays the model at 90 degrees rotation around the y-axis and the second smaller window displays it at 90 degrees rotation around the x-axis relative to the original position of the model in the main window. The operator has a choice of 6 different predefined positions to standardize the orientation of the head provided that three landmarks are located on the facial model to establish reference planes. Different types and directions of lighting are available in the 'menu bar' if required (Figure 3.10). Two models can be loaded simultaneously if a comparison is required.

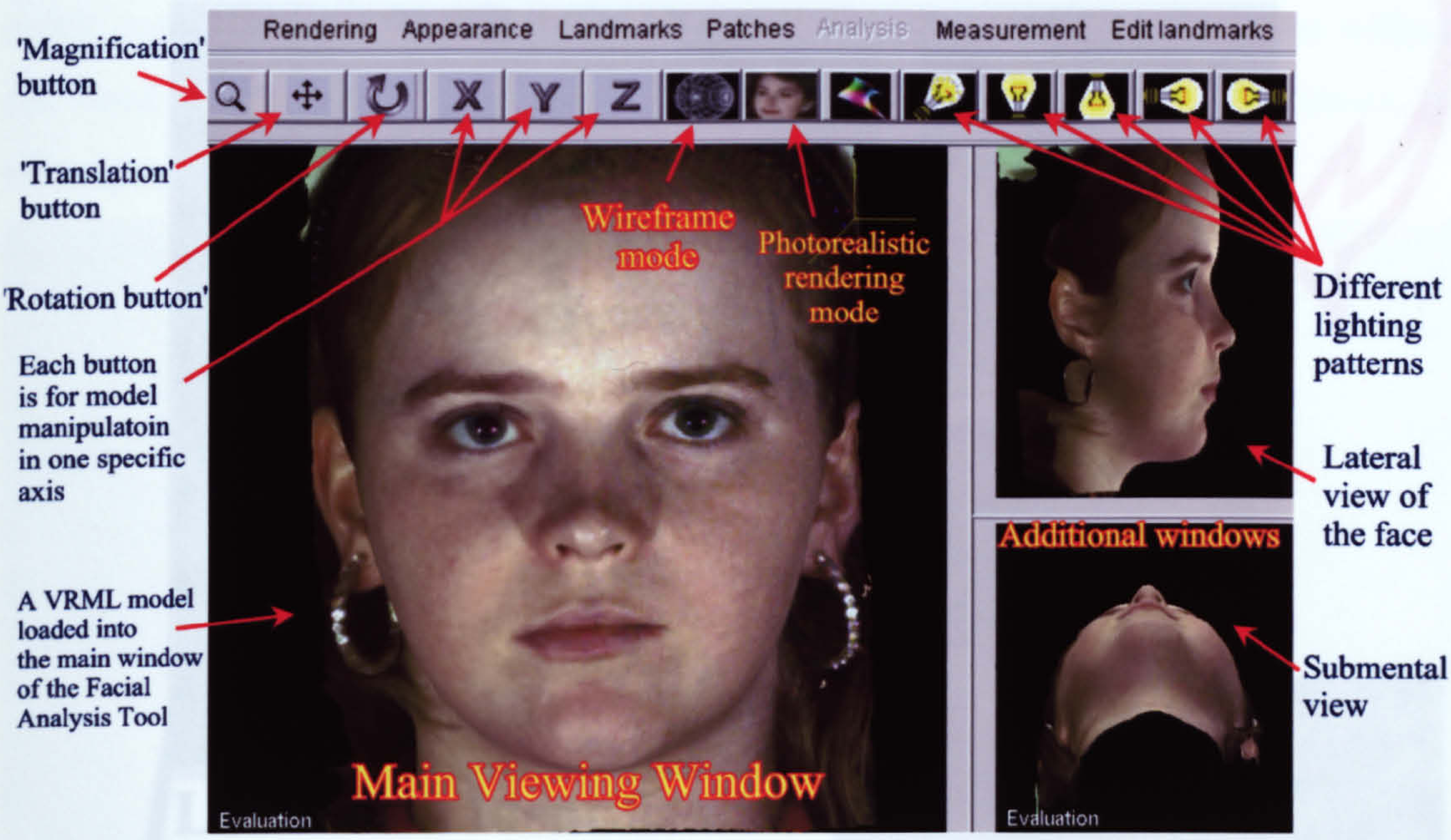


Figure 3.10: Facial Analysis Tool interface. Main window enables the operator to see the full-face view of the patient in the same position in which he/she has been captured. Lateral and submental views give additional information, and are located beside the main view. Manipulation of the 3D model can be performed via 'magnification', 'translation' or 'rotation' buttons. Different modes of visualisation are available, i.e. wireframe mode and photorealistic mode.

3.2.2 Landmark identification and editing

Before identification of landmarks, a file containing a group of landmarks along with their abbreviations (codes) and definitions (if desired) is constructed. This file is then used to tell the software about the number and sequence of landmarks that will be digitised. Identification of landmarks is enhanced by the ability to see the mouse cursor in three viewing windows. Each landmark is digitised by clicking on its accurate position in the main window and a red dot appears indicating that this point has been registered. Once landmarks have been digitised, their 3D coordinates are exported and saved as a text file (ASCII code) for further statistical analysis (Figure 3.11).

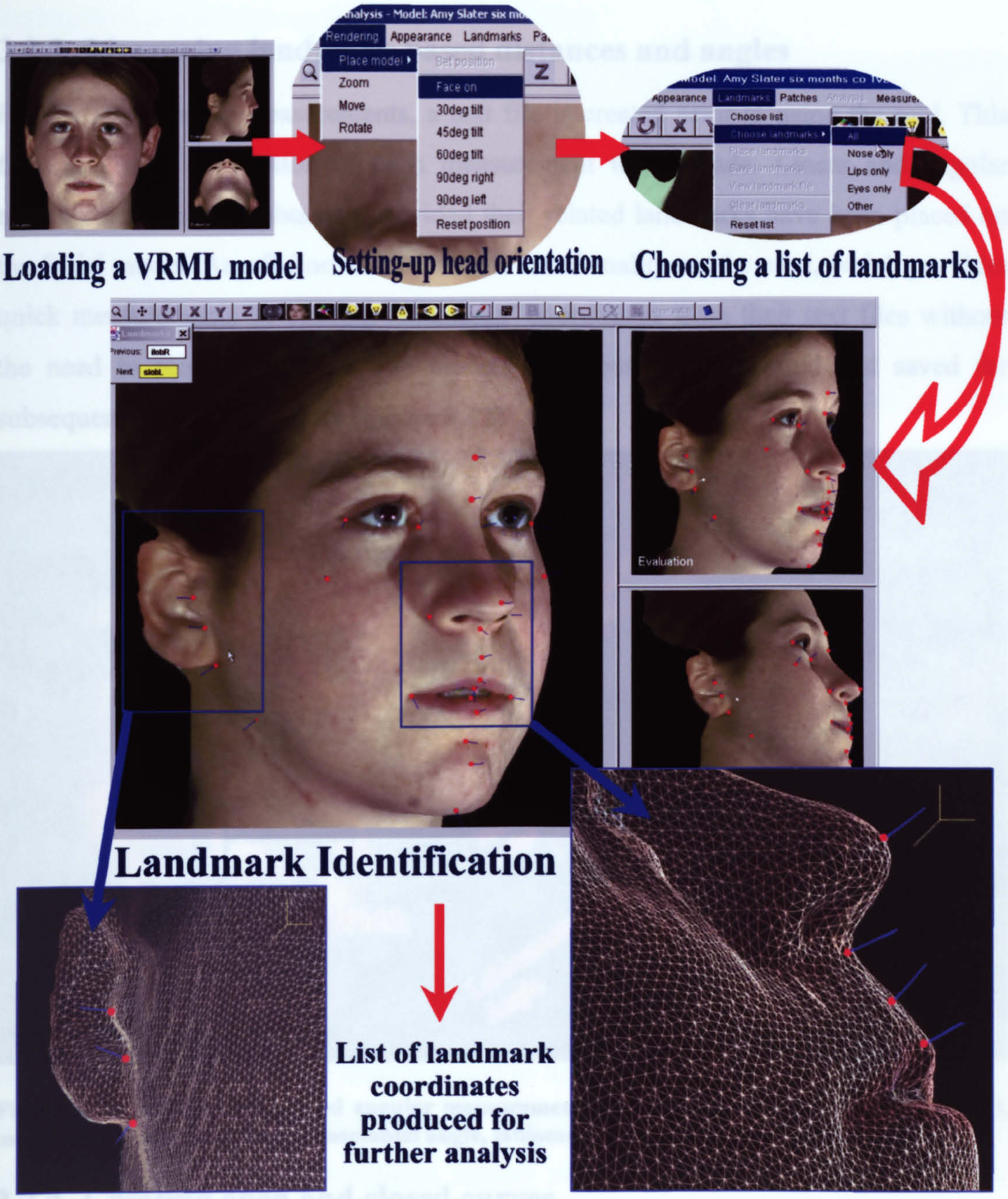


Figure 3.11: Landmark identification in the Facial Analysis Tool. Landmarks are digitised in a sequential manner. Once identification has been performed, landmarks' coordinates are exported and saved for further analyses.

Editing of landmarks is achieved by highlighting the landmark first, followed by translating its position or deleting it (if required). The software provides the researcher with the ability to construct any pseudo-landmark as a mid-point between any two anatomical landmarks. The saved x, y, z-coordinates of landmarks can be retrieved and read-back at any time for accuracy checking, location editing or FAT-based analysis.

3.2.3 Measuring landmark-based distances and angles

For landmark-based measurements, a text file is created prior to using the tool. This file contains a description of each measurement to be made. Linear and angular measurements can be obtained provided their related landmarks have been placed on the facial model. An off-line version of this functionality can be used, which provides quick measurements by reading landmarks' coordinates from their text files without the need to reopen or reload the models. The output is exported and saved for subsequent statistical analysis (Figure 3.12)

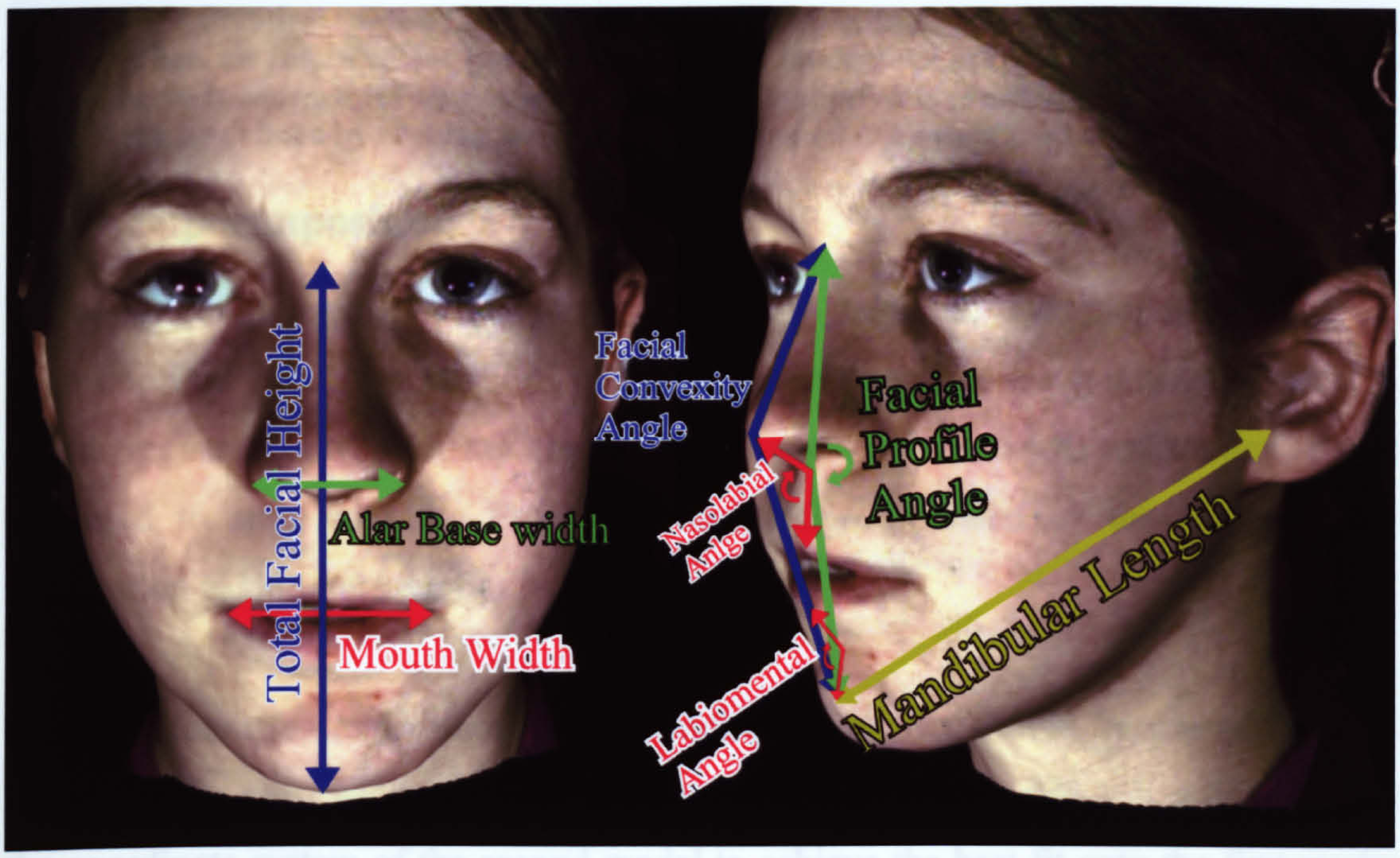


Figure 3.12: Different linear and angular measurement can be obtained, e.g. total facial height, mouth width, alar base width, nasolabial angle, labiomental angle and facial profile angle.

3.2.4 Creating open and closed curves

To produce an open curve, two or more 'boundary' landmarks are highlighted and connected together to from an open surface curve. The curve consists of the original chosen landmarks as well as many intermediate points constructed (on triangles' edges and faces' centres) on the surface of the underlying polygonal mesh (Figure 3.13a). The coordinates of the produced points are saved in a file for later analysis. These perimeter points are saved in the order in which they trace the curve and not the order in which they are calculated. Another functionality in the FAT connects the last identified boundary landmark to the first one creating a closed curve (Figure 3.13b). If a surface 'patch' is required, clicking inside the region surrounded by the closed curve highlights it as a red triangular mesh (Figure3.13c).

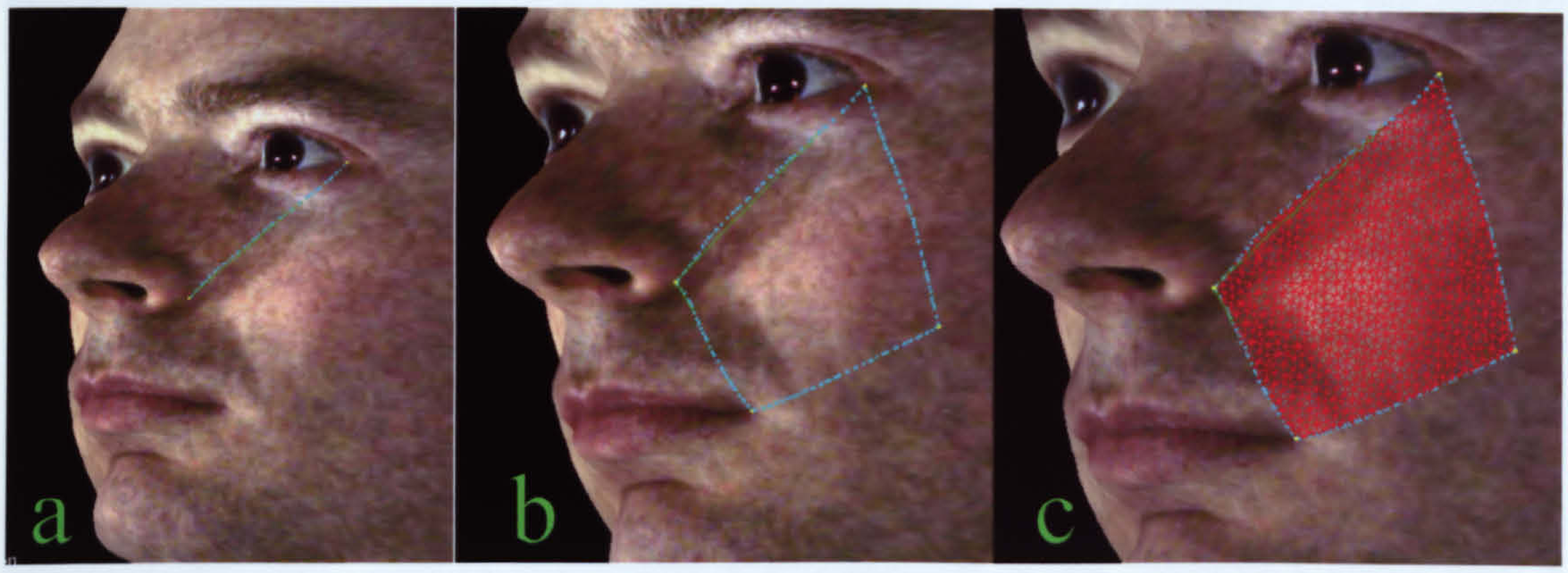


Figure 3.13: Creating curves. (a) To create a simple curve, two boundary landmarks need to be chosen. Then all intermediate points between both landmarks are created and displayed. (b) Closed curve is constructed when the last boundary landmark is connected to the first one. (c) A 'patch' can be defined by clicking inside the area surrounded by the closed curve.

3.2.5 Superimposition

When a comparison between two models is required, the models should be superimposed first. Two methods of model superimposition are available: landmark-based registration (Procrustes registration) and surface-based registration. It is preferred to start with the Procrustes registration followed by the surface-based registration to fine-tune the fit.

For the Procrustes registration, corresponding landmarks should be placed on both models in the same sequence. The software translates, rotates and scales (if required) the coordinate system of the second model to achieve the best fit onto the first model using the principle of the least squares. The result is then displayed visually along with a report of the transformations carried out. An example of a landmark-based superimposition is shown in Figure 3.14.

The second step is to superimpose on surfaces or 'patches' through the use of Iterative Closest Points (ICP) technique. In ICP registration, corresponding patches are highlighted on both models. ICP registration establishes correspondence between data sets by matching points in one data set to the closest points in the other data set, in an iterative procedure. The result is also shown visually accompanied with a report of the transformations performed.

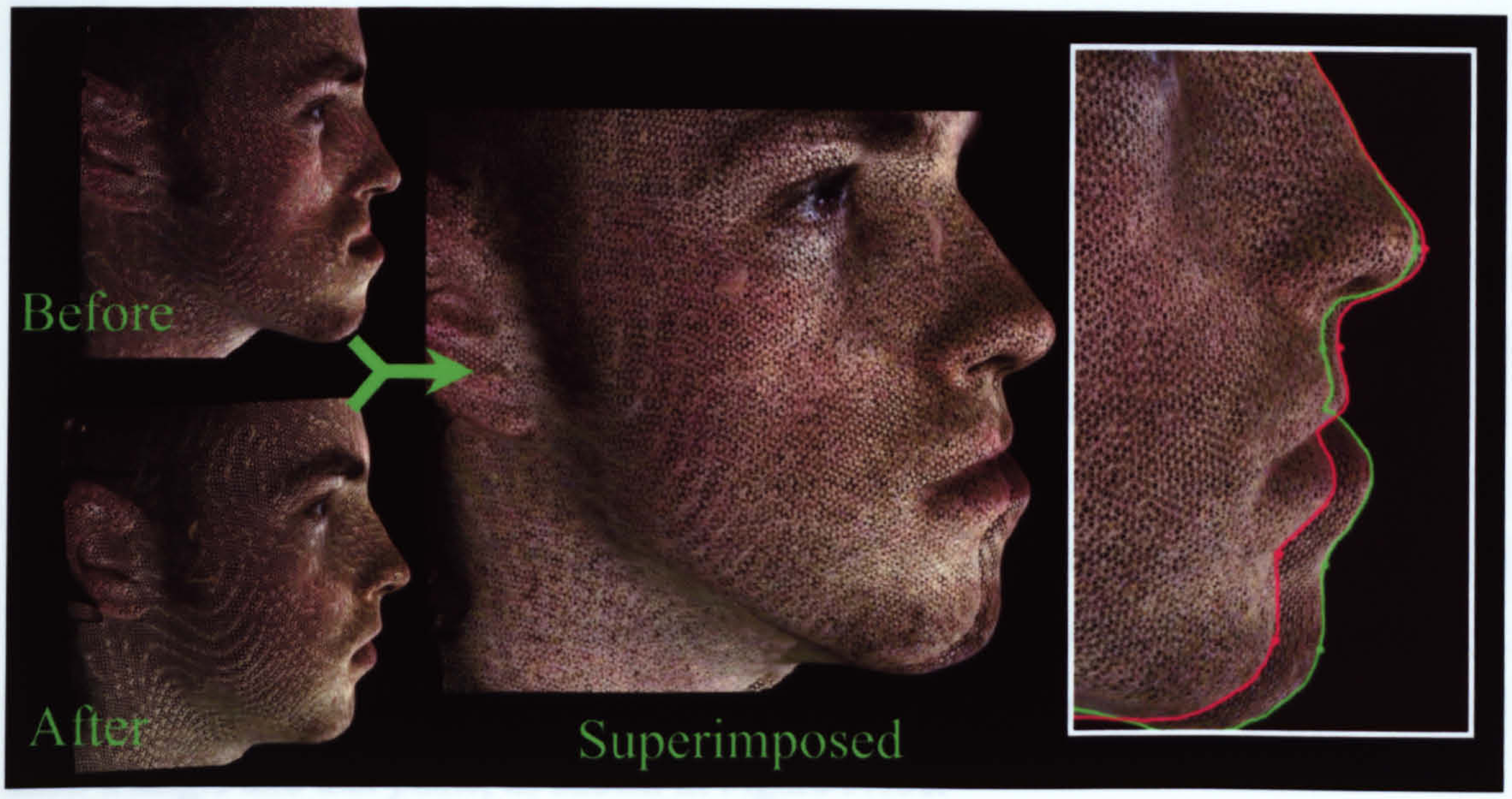


Figure 3.14: Landmark-based superimposition between two facial models of a Class III patient. A close-up view (in the right illustration) reveals the soft-tissue changes that occurred at the nose, the lips and the chin in the midsagittal plane. The green and red outlines have been drawn by hand to increase clarity.

3.2.6 Surface areas and volumes

Surface areas can be calculated by defining patches on the 3D facial model. Difference in surface areas of two corresponding patches on two models can be obtained. For volumetric assessment, three methods of calculating the enclosed volume between two corresponding patches are available:

- Back-plane construction method
- Tetrahedron formation method
- Projection method

The original method projects each of the surface patches of interest onto a back plane to produce a volume (Figure 3.15a). The position and orientation of the back plane, however, can be chosen arbitrarily so that the absolute volume of either patch is totally meaningless. In this algorithm, the back plane is placed parallel to x-y plane and behind the model. It assumes that the facial orientation is standardised (patient facing positive z-direction) and the volume change is mainly along the z-axis.

Recently, two additional algorithms have been developed and implemented to improve the accuracy of the measured volume. The addition is related to the final step, in which a closed form (triangular mesh) between the two patches is created and its volume is computed. The two patches are first divided into different regions, according to the relative position of each region to the other one (above it or below it) (Figure3.15b). If the second patch lies completely above or below the first patch, one region is created. After that, every two corresponding regions in the two patches are connected or 'stitched' together to construct a closed form, as shown in Figure3.15c. The 'tetrahedron formation' method calculates the volume of this closed form by projecting each triangle (in the mesh) to the origin point to construct a tetrahedron and calculating the volume of each tetrahedron (Figure 3.15d). In the 'projection method', each triangle is projected to an arbitrary plane and the volume is calculated between each triangle and that plane, as shown in Figure 3.15e.

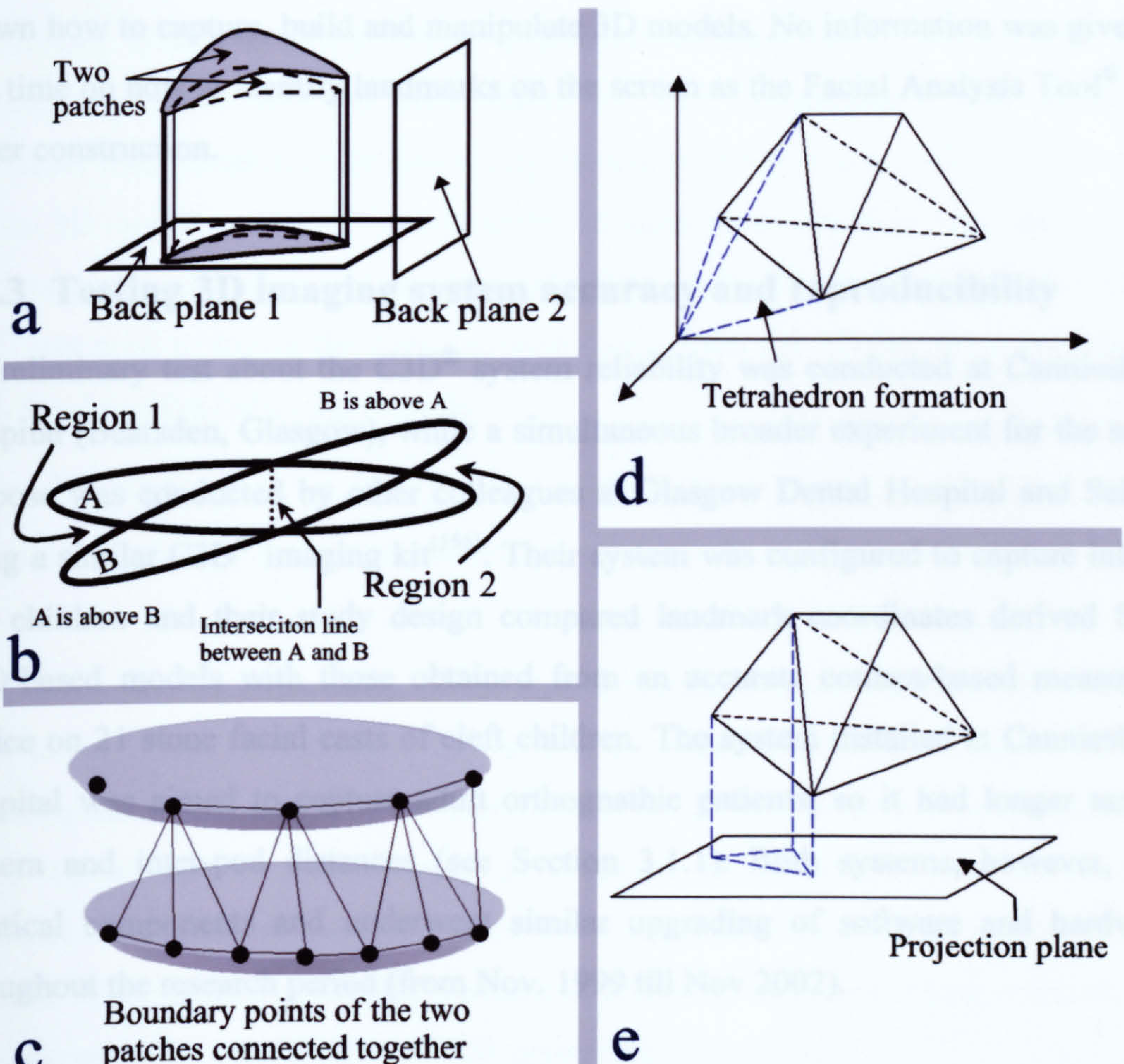


Figure 3.15: Algorithms used to calculate volumes in the Facial Analysis Tool. (a) Back plane construction method. (b, c) the new method of creating enclosed volumes and connecting boundary points of patches for each region. (d) The tetrahedron method. (e) The projection method.

3.3 Preliminary work

3.3.1 Aims of preliminary work

- To become familiar with the 3D imaging system
- To determine the accuracy and reproducibility of the captured and built 3D models

3.3.2 Training course

A one-day training course at the 3D MATIC Research Laboratory (previously known as: Turing Institute / Faraday partnership) was undertaken. The course included a lecture about the principles of 3D imaging with C3D system, the theoretical basis of it, followed by a 3-hour practical session in which instructions were given. Three adult volunteers were captured and their 3D models were built. The participants were shown how to capture, build and manipulate 3D models. No information was given at that time on how to identify landmarks on the screen as the Facial Analysis Tool® was under construction.

3.3.3 Testing 3D imaging system accuracy and reproducibility

A preliminary test about the C3D® system reliability was conducted at Canniesburn Hospital (Bearsden, Glasgow), while a simultaneous broader experiment for the same purpose was conducted by other colleagues at Glasgow Dental Hospital and School using a similar C3D® imaging kit[156]. Their system was configured to capture infants and children and their study design compared landmark coordinates derived from C3D-based models with those obtained from an accurate contact-based measuring device on 21 stone facial casts of cleft children. The system installed at Canniesburn Hospital was aimed to capture adult orthognathic patients, so it had longer target-camera and inter-pod distances (see Section 3.1.1). Both systems, however, had identical components and underwent similar upgrading of software and hardware throughout the research period (from Nov. 1999 till Nov 2002).

Several anthropometric landmarks (10 in the midsagittal plane and 9 on each side of the face) were marked on the surface of the dummy head using a black pen with a diameter of 0.4 mm (superfine Staedtler® lumocolor permanent, Staedtler®, Germany).

Table 3.1 illustrates the definitions of the employed anthropometric landmarks. An illustration of the dummy head is shown in Figure 3.16. (Additional 'boundary' landmarks were marked on the dummy' head for use in the further validation study about the volumetric assessment; see Section 3.5.3.4.4).

Table 3.2 illustrates the ten inter-landmarks distances, which were measured directly on the dummy head using electronic digital callipers (Mitutoyo Digimatic Calliper, 500 series, Japan; precision in the order of 0.01 mm) and indirectly on 3D models using the Facial Analysis Tool® (FAT). The dummy head was placed on a tripod resting on a rigid chair and 3D images of the dummy head were then taken by the C3D imaging system. These were built into the final stage and a VRML file was exported for each 3D model.

For testing system accuracy, direct measurements using the digital callipers were repeated ten times and the mean value for each measurement was calculated. Landmark identification of the previously marked points was also performed ten times on one 3D model on-screen. Consequently, 10 linear measurements were obtained and the mean value for each variable was calculated. A built-in measuring utility in the FAT was used to obtain the linear measurements from the 3D landmark coordinates with the aid of the following formula:

$$\text{Distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

Where (x_1, y_1, z_1) and (x_2, y_2, z_2) are the coordinates of landmarks 1 and 2, respectively

To evaluate the reproducibility of 3D model production, the standard deviation for each mean linear measurement of the ten measurements were evaluated first by repeating landmark identification on one model ten times. This step was undertaken to reveal the amount of inconsistency in landmark identification. In a second step, landmark identification was performed on ten 3D models generated from ten 3D captures of the dummy head. The standard deviation of each mean linear measurement was also used as a measure of the C3D system reproducibility.

Table 3.1	Landmarks definitions according to Farkas et al[61]
Landmark	**Definition**
Alar curvature (or alar crest) (ac)	The most lateral point in the curved base line of each ala, indicating the facial insertion of the nasal wingbase.
Cheilion (ch)	The point located at each labial commissure.
Endocanthion (enc)	The point at the inner commissure of the eye fissure and is located lateral to the bony landmark used in cephalometry
Exocanthion (exc)	The point at the outer commissure of the eye fissure and is located slightly medial to the bony exocanthion.
Glabella (gla)	The most prominent midline point between the eyebrows and is identical to the bony Glabella on the frontal bone
Gonion (go)	The most lateral point on the mandibular angle close to the bony Gonion.
Inferior Labial Sulcus (ils)= Sublabiale*	The deepest midline point on the labiomental fold, which determines the lower border of the lower lip or the upper border of the chin.
Labiale inferius (li)	The midpoint of the lower vermilion line
Labiale superius (ls)	The midpoint of the upper vermilion line.
Menton (men)	The lowest median landmark on the lower border of the mandible and is identical to the bony Menton.
Nasion (na)	The point in the midline of both the nasal root and the nasofrontal suture. The point is always above the line that connects the two inner canthi and is identical to the bony Nasion.
Otobasion inferius (obi)	The most inferior point on the ear lobe located at the attachment (junction) of the lobe to the face.

Table 3.1 Contd.

Landmark	Definition
Pogonion (pog)	The most anterior midpoint of the chin, located on the skin surface in front of the identical bony landmark of the mandible.
Pronasale (prn)	The most protruded point of the apex nasi identified in lateral view of the rest position of the head.
Stomion inferius (stmi)†	The most superior midpoint of the vermilion border of the lower lip.
Stomion superius (stms)†	The most inferior midpoint of the vermilion border of the upper lip when the lips at rest. If the lips are closed, this point will fall over Stomion inferius (stmi).
Subnasale (sn)	The midpoint of the angle at the columella base where the lower border of the nasal septum and surface of the upper lip meet. This point is not identical to the bony point ANS or 'nasospinale'.
Subtragion (sbtr)†	The most anterior inferior point on the anterior inferior margin of the helix attachment to the face, just above the ear lobe.
Superior Labial Sulcus (sls)†	The deepest midline point on the upper lip, which is located usually halfway between subnasale and Labiale superius
Tragion (tr)	The notch on the upper margin of the Tragus.
Zygion (zyg)†	The most prominent point on the cheek area beneath the outer canthus and slightly medial the vertical line passing through it. It is different from the bony Zygion point.

(*) We preferred to use the first term instead of the second term chosen by Farkas et al[61].

(†) Points defined by the researcher.

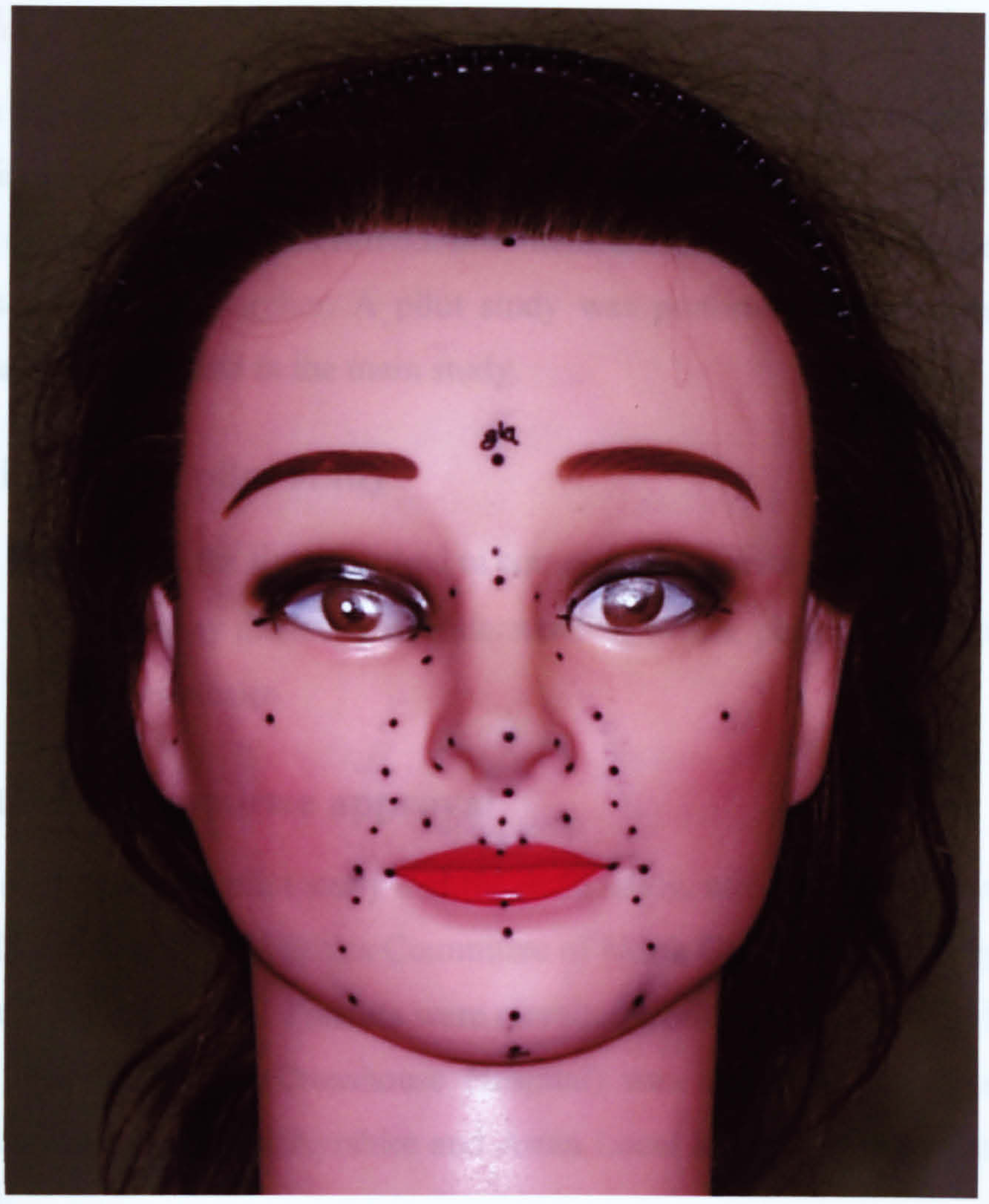


Figure 3.16: The dummy head used with 28 anthropometric landmarks and several non-anatomic 'boundary' landmarks marked on the face.

Table 3.2	**Inter-landmark distances used for the preliminary system accuracy test**		
No.	Measurement	Landmarks used	
1	Inter-canthal width	excR	excL
2	Inter-malar width	zygR	zygL
3	Total facial width	trR	trL
4	Alar base width	acR	acL
5	Mouth width	chR	chL
6	Inter-gonial width	goR	goL
7	Total facial height	gla	men
8	Lower facial height	sn	men
9	Columellar length	sn	prn
10	Mandibular length	trL	pog

3.4 Pilot Study

To assess psychosocial aspects of patients undergoing orthognathic surgery, a package of questionnaires was developed from several psychological standardised and validated questionnaires in the orthodontic literature, one modified questionnaire and one devised by the researcher. A pilot study was performed before applying these questionnaires on patients in the main study.

3.4.1 Aims of the pilot study

- To explore the time required to complete the questionnaires
- To detect any difficulty in understanding words, phrases, or sentences in the questionnaire.

3.4.2 Ethical Committee approval

Before commencing the pilot study and the main study, ethical approval was obtained from the Local Area Dental Ethics Committee of North Glasgow University Hospitals NHS Trust in January 2000. Patients were recruited from Canniesburn and Monklands Hospitals. A third centre (Crosshouse Hospital) was added afterwards and ethical approval was obtained from Ayrshire and Arran Local Research Ethics Committee in June 2001.

3.4.3 Inclusion and exclusion criteria

The following inclusion criteria were considered for the pilot study:

- Patients with dentofacial deformities
- Caucasian origin
- Age greater than 16 years
- In the presurgical phase, with the surgery planned within 12 weeks

Exclusion criteria were not as strict as those in the main study

- Patients with a history of facial trauma
- Patients with craniofacial defects and syndromes
- Patients planned for distraction osteogenesis

3.4.4 Sample characteristics in the pilot study

Ten patients (six males; four females) were recruited from Canniesburn Hospital, and were not included in the main study, which commenced in June 2000 (three months following the pilot study). Each subject was given an information sheet, which explained the purpose of the study (Appendix I) and his/her informed consent was obtained (Appendix II). Their age ranged from 17 to 39 years. Seven cases were diagnosed as skeletal Class III and three were diagnosed as skeletal Class II. Seven cases had presurgical orthodontic treatment. No psychological problems were reported in their case notes.

3.4.5 Design

The time for completing the whole package of questionnaires was recorded. Subjects were encouraged to ask for clarification of any difficult question or obscure phrase. After completing the forms, they were asked to give their general opinion about them. The psychosocial assessment package included the following questionnaires:

1- Rosenberg's Self Esteem[453] (Appendix V).
2- Motives for treatment[408] (Appendix VI).
3- Facial Body Image (a modified version of the questionnaire used by Kiyak et al[430]; Appendix VII).
4- Self-rating of required facial change (drawing-based questionnaire devised by the researcher; Section 3.5.5.3.1).
5- Self-rating of facial profiles[410,440].
6- Multi-dimensional Health Locus of Control[454] (Appendix VIII).
7- EPQ-R Short Scale[455] (Appendix IX).
8- Hospital Anxiety and Depression Scale (HADS)[456] (Appendix X).

A detailed description of each questionnaire is given in the psychosocial analysis section of this chapter (Section 3.5.5).

3.5 Main Study

3.5.1 Power calculation

Estimation of the sample size is dependent on the following factors:

- The level of desired power, which is the probability of finding a difference to be statistically significant when this difference actually exists[457]
- The type of the intended statistical test (including the level of significance)
- The smallest clinically significant difference that needs to be detected
- The variability in the observed data

The smallest clinically significant difference requiring detection was set to 1 mm, although there is no consensus on this issue. Lack of previous studies in the context of 3D soft-tissue changes following orthognathic surgery did not provide a clear indication of the variability of such data. Time limitation of the research programme did not allow another pilot study to assess the amount of variability, but, it was inferred from a previous report that the standard deviation was approximately 1.2 mm in data gathered from 3D laser-scanned facial models[458]. Applying two-tailed paired t tests with a significance level of 0.05 and a power of 80% revealed that a sample size of 12 subjects is required (for a calculated standardised difference of about 0.85 mm)[459]. The diversity of surgical interventions, however, indicated that for each surgical-intervention-based homogenous subgroup, 12 subjects are required under the previous assumptions. Reviewing the case notes of the accomplished orthognathic treatment at Canniesburn Hospital in the last three years indicated that more than 70 cases should be obtained to obtain the minimal sample size required for each specific surgical intervention.

3.5.2 Inclusion and exclusion criteria

Subject inclusion criteria were similar to those of the pilot study:

- One or more dentofacial deformity
- Caucasian origin
- Age greater than 16
- Within one week prior to orthognathic surgery

The following subjects were excluded:

- Those of non-Caucasian origin
- History of facial trauma
- Craniofacial defects and syndromes
- Concomitant or previous soft-tissue surgery

- Concomitant osseous surgery of the facial skeleton
- Intra-oral or extra-oral distraction osteogenesis

Each subject was given an information sheet to read (Appendix III), followed by a discussion about the intended appointments for assessment. Patients were assured that their post-surgical appointments would coincide with the routine follow-up visits at one month, three months and six months following surgery. Then, informed consent was obtained from each subject (Appendix IV).

3.5.3 3D imaging of the face

Details about the 3D imaging system have been given in Section 3.1. Here, a description of the workflow during data collection is given.

3.5.3.1 Conditions of the 3D capture

Patients were seen at the following times

- T1: within one week before surgery
- T2: one month after surgery
- T3: three months after surgery
- T4: six months after surgery

If a follow-up appointment of a patient was not attended, or it did not coincide with the research schedule, he/she was contacted and asked to come on a planned day. If a patient failed to attend within five days of the postsurgical appointment, the intended acquisition session was cancelled and related data were considered missing.

A calibration procedure was performed prior to image acquisition. On all occasions, one calibration procedure was performed before any acquisition session (usually in the morning) and an additional one at the end of the day. The second calibration served as back up if any problem appeared when building the models attached to the first calibration.

Images of patients were taken according to the following criteria:

- Head in natural head position (NHP)
- Teeth in centric occlusion (CO)
- Lips in repose

The natural head position was established using the 'mirror' method[99,460,460,461]. A mirror was fixed to the wall in front of the patient at a distance of 5 feet and at head height. In order to confirm consistency in achieving centric or habitual occlusion, an examination of occlusal relationships was performed prior to capture, especially in skeletal Class II cases where patients tended to mask the original deformity by posturing the mandible forward. Three captures where performed. Patients were given 3 minutes between each capture, to avoid any strained facial expression. The total acquisition session was 15 minutes at each visit.

3.5.3.2 Building, exporting, and landmark identification

Models were built in batches and their quality was checked on another day. Although great attention was paid to standardise patients' head position and facial expression, one model was chosen subjectively from each of the three captures to be exported and analysed. The main criteria for inclusion of a model in the subsequent analysis were:

- The face was aligned without any tilt, although this was not achievable in cases with marked facial asymmetry
- Facial expression at rest with or without lip seal
- Eyes open
- Brightness and contrast satisfactory
- Smooth model without incomplete areas or 'holes'

Chosen models were exported as VRML models to be inserted into the Facial Analysis Tool© (FAT). In the FAT, one model was loaded at a time, a list of landmarks was recalled and landmarks were identified in a specific sequence. The definition of each landmark is given Table 3.1. Figure 3.17 illustrates positions of landmarks according to their definitions. Landmark identification was performed under standardised conditions regarding monitor brightness, contrast, Red-Green-Blue (RGB) balance as well as surrounding room illumination. Upon finishing, a text file containing x-, y-, z-coordinates of each landmark was produced and saved.

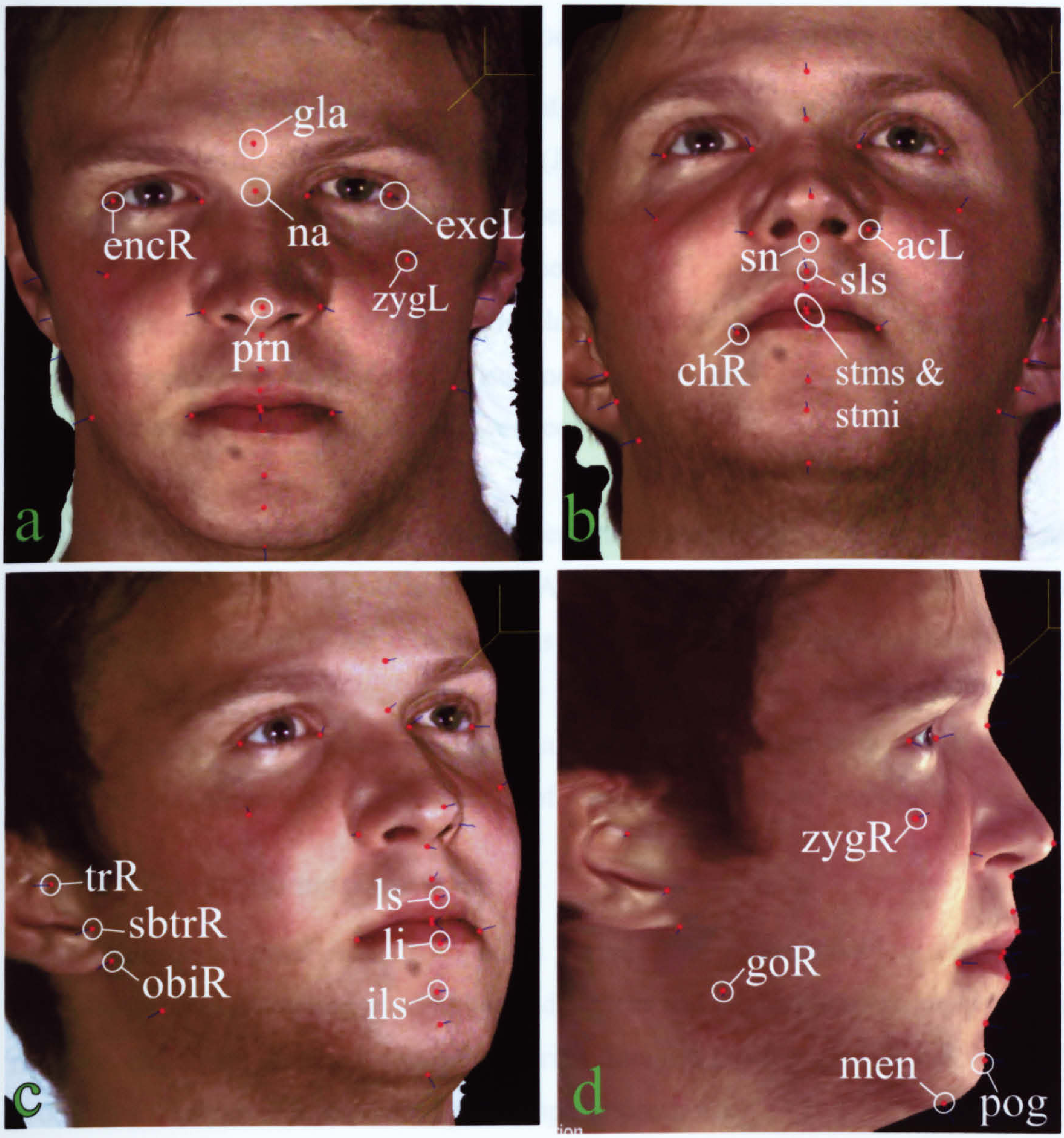


Figure 3.17: Landmarks' locations on a 3D model of an orthognathic patient.

During the data collection period, landmark identification was accomplished in stages, with a group of patients' records digitised at each stage. All the landmarks mentioned in Table 3.1 were employed and identified in the first group. However, based on the results of landmark identification reproducibility, some landmarks were no longer identified in the subsequent groups of patients' records.

3.5.3.3 Landmark identification reproducibility: error of the method

- Ten 3D facial models were chosen at random from the available records in the middle of the data collection period (July 2001).
- Landmarks were digitised three times, one week apart to avoid memory bias, and their 3D coordinates were obtained.
- Standard deviations of repeatedly placed landmarks' coordinates around their centroids were calculated. Also mean x-, y- and z- absolute differences between repeated digitisations were computed.

This experiment was performed to differentiate between three levels of landmark reproducibility: high, moderate and poor. A cut-off limit between high and moderate reproducibility was set at 0.5 mm, whereas a cut-off limit of 1 mm was set between moderate and poor reproducibility. Any point showing an inconsistency in its identification above 1 mm was deemed unsuitable to be included in the main study of facial changes, particularly in the analysis of 3D displacements of landmarks.

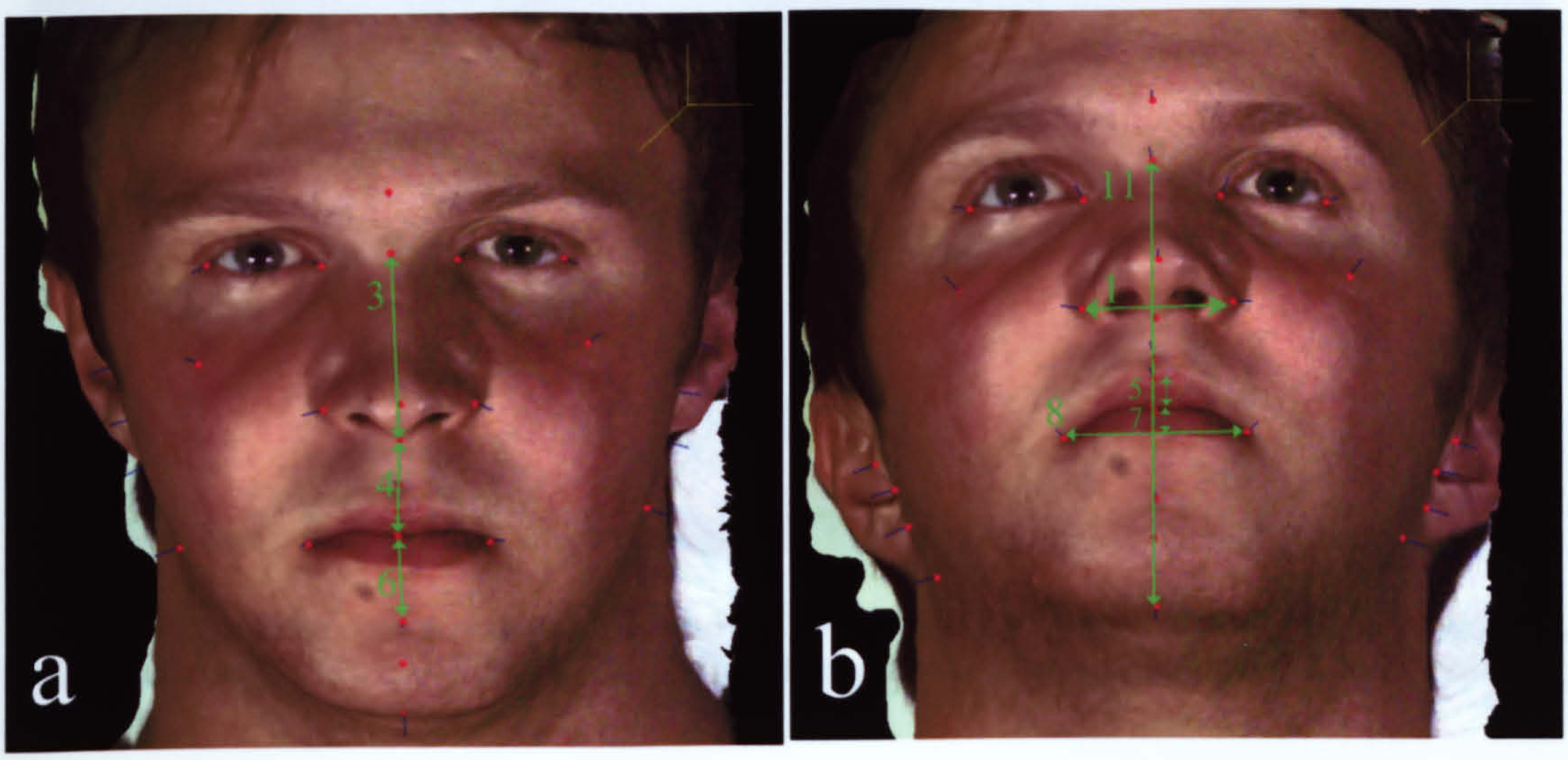
3.5.3.4 3D morphometric analyses

Measurements obtained from 3D models varied from conventional morphometric methods (such as extracting interlandmark distances and angles) to more sophisticated methods employing geometric morphometric principles (such partial or full Ordinary Procrustes Analysis and ICP-based patch superimposition).

3.5.3.4.1 Interlandmark distances and angles

Thirteen linear and six angular measurements were obtained. Table 3.3 and Figure 3.18 illustrate linear measurements, whereas Table 3.4 and Figure 3.19 illustrate angular measurements.

Table 3.3	3D linear measurements		
No.	Distance	Landmarks used	
1	Alar base width	acL	acR
2	Columella length	sn	prn
3	Nasal bridge length	na	prn
4	Upper lip height	sn	stms
5	Upper vermilion height	ls	stms
6	Lower lip height	ils	stmi
7	Lower vermilion height	li	stmi
8	Mouth width	chL	chR
9	Lower facial height	sn	men
10	Upper facial height	na	sn
11	Total facial height	na	men
12	Mandibular length right side	pog	sbtrR
13	Mandibular length left side	pog	sbtrL



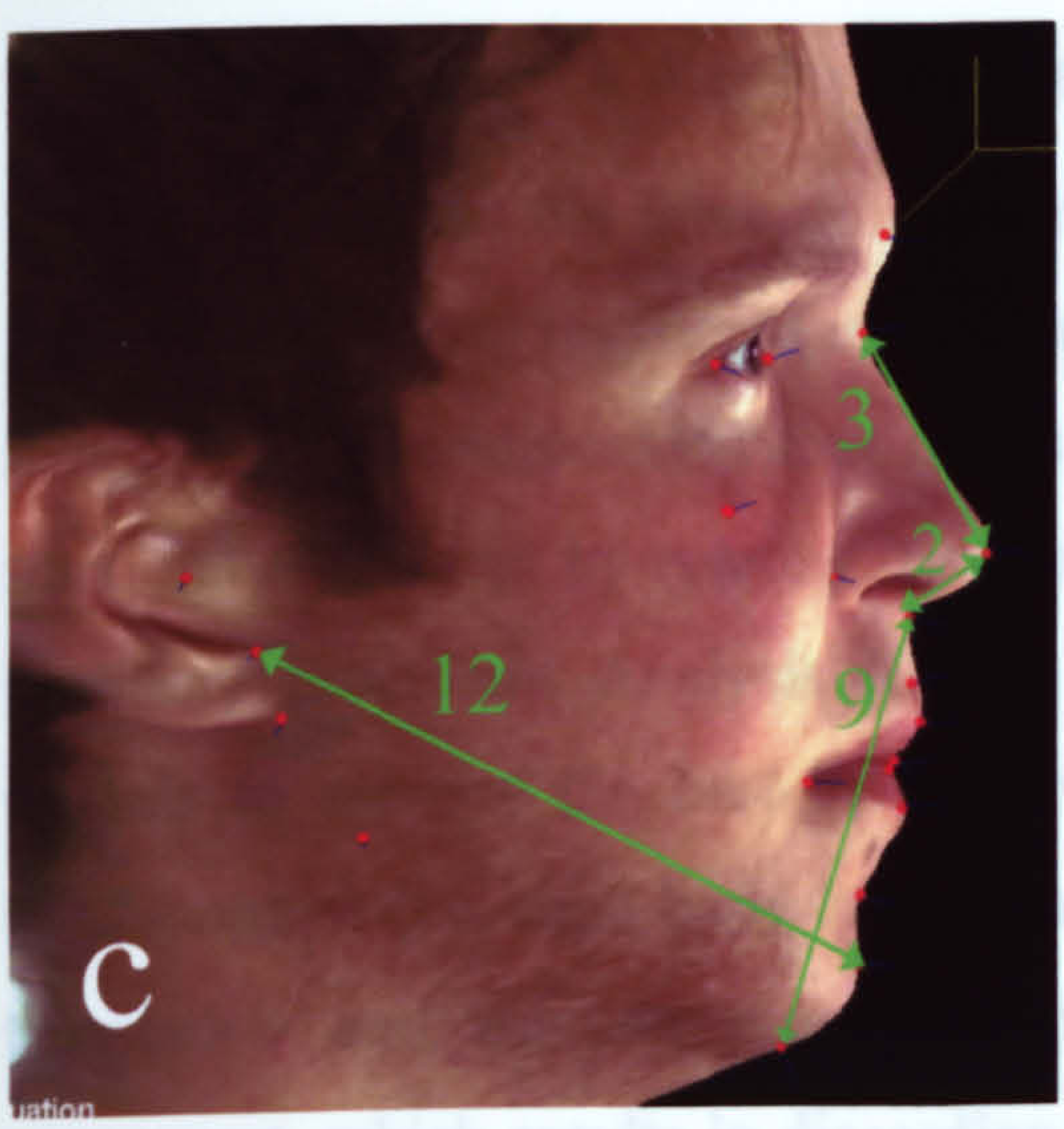


Figure 3.18: Interlandmark distances on 3D facial models. In illustration 'a': nasal bridge length (3), upper lip height (4) and lower lip height (6). In illustration 'b': alar base width (1), upper vermilion height (5), lower vermilion height (7), mouth width (8) and total facial height (11). In illustration 'c': columellar length (2), lower facial height (9) and right mandibular length (12).

Table 3.4		3D angular measurements		
No.	Angle	Landmarks used for each angle		
1	Facial convexity angle	na	sn	pog
2	Facial profile angle	na	prn	pog
3	Nasolabial angle	prn	sn	ls
4	Nasal tip angle	na	prn	sn
5	Labiomental angle	li	ils	pog
6	Chin angle	ils	pog	men

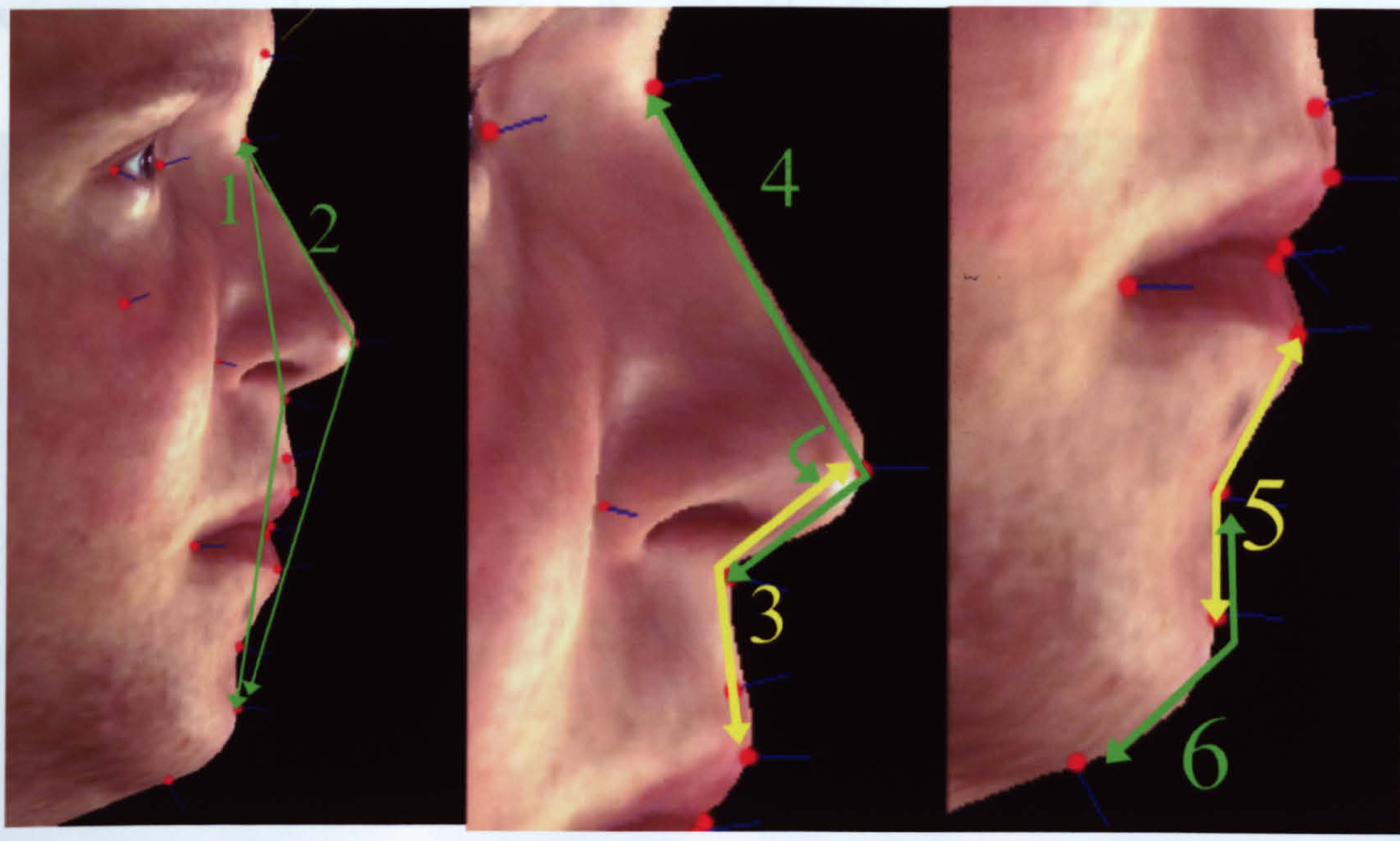


Figure 3.19: Interlandmark angles measured on 3D models. These were facial convexity angle (1), facial profile angle (2), nasolabial angle (3), nasal tip angle (4), labiomental angle (5) and chin angle (6).

3.5.3.4.2 Landmark displacements

In order to assess the three dimensional landmark displacements following surgery, facial models were registered in a three dimensional manner. Procrustes Analysis is a method of superimposition that aligns configurations of landmarks to a position of maximal agreement by rotating, translating and scaling the configurations[212]. Partial Ordinary Procrustes Analysis (OPA) translates and rotates the coordinates of two models to achieve the best-fit preserving the shape and size information of each configuration (i.e. rigid-body transformations). Full OPA adds a scaling process to the translation and rotation processes of both coordinates to achieve the maximal agreement, which results in discarding size information. The word 'Ordinary' is used when the procedure is applied on two objects. If more than two objects are aligned, the term 'Generalised' (GPA) is used instead[212].

According to the results of the reproducibility study (Section 4.2.3), seven points were found to be highly reproducible and they were located in areas not affected by surgery (Figure 3.20). They were used in a partial OPA superimposition and the software was programmed to produce the x-, y- and z- displacements of landmarks. An example of superimposed models using partial OPA is shown in Figure 3.21 for a skeletal Class II case. Positives values of displacements were assigned for forward and upward movements of landmarks in the z- and y-axes, respectively. Positive values in the x-axis were assigned to movements to the right side of the patient's face.

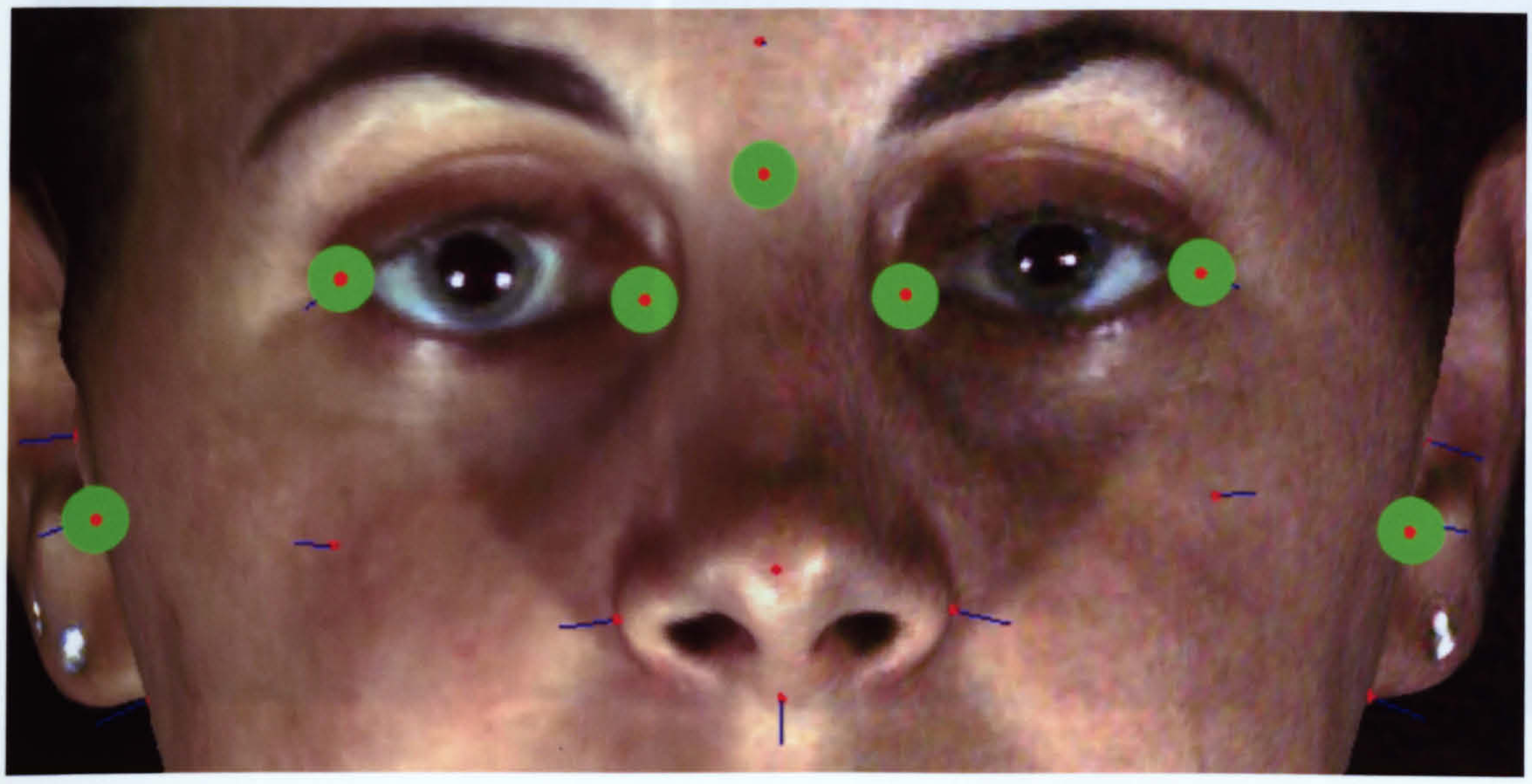


Figure 3.20: Seven landmarks used in the Procrustes registration across the eyes and the ears

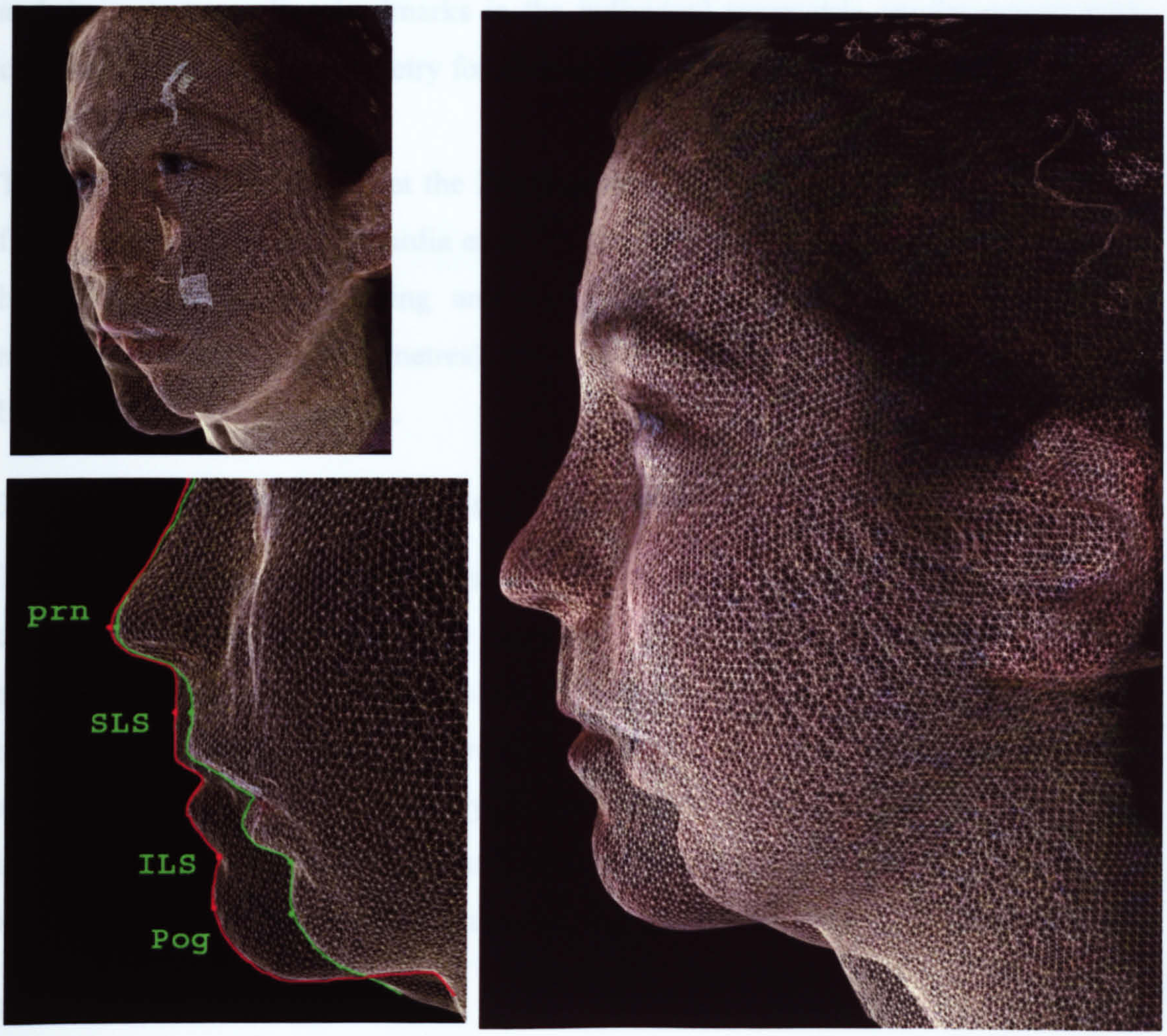


Figure 3.21: Procrustes-based superimposition of pre- and post-operative 3D models of a Class II patient treated surgically by double-jaw correction. The registration employed seven reproducible and stable facial landmarks.

3.5.3.4.3 Facial asymmetry scores

Each configuration of landmarks for each patient at each assessment time was scaled to a common size. Each of the configurations was reflected around an arbitrary plane and landmarks forming pairs were re-labelled by swapping the labelling (e.g. if the 1st and 2nd points formed a pair, after reflection the 1st point became the 2nd and the 2nd became the 1st). The individual symmetric configuration was created by calculating simply the average of the original configuration and the reflect-relabelled version after aligning using partial OPA. This was followed by superimposing the original configuration on the created individual symmetric configuration (using partial OPA again). The mean squared distances between landmarks in the original configurations and their corresponding landmarks in the individual symmetric configurations were expressed as scores of asymmetry for each subject at each time of assessment.

This method was developed at the Department of Statistics (University of Glasgow) from the original ideas of Mardia et al[(462)]. The calculated asymmetry scores did not have an interpretable meaning and could not be expressed using the ordinary measurement units (e.g. millimetres). However, they have been scaled (by multiplying by 1000) for better readability.

3.5.3.4.4 Validating the volumetric algorithms

Three algorithms are available in the FAT for pairwise comparisons. The back plane construction method of calculating volumetric changes appeared unsatisfactory in a previous investigation on the volumetric facial changes following Twin-Block treatment[(463)]. It was decided, therefore, to validate the newly added algorithms of assessing facial change. The study was conducted in two stages: the first stage involved adding specimens on a dummy head (Figure 3.16, Section 3.3.3), while the second stage of the experiment was applied on a live adult male head (Figure 3.24).

3.5.3.4.4.1 In vitro validation

Twenty-eight anthropometric landmarks were previously marked on the dummy head using a black pen with a diameter of 0.4 mm (superfine Staedtler® lumocolor permanent, Staedtler®, Germany). Definitions of these landmarks have been given before (Table 3.1; Section 3.3.3). Additional non-anatomical landmarks were used around the nose, the lips and the chin. These points served, in a later stage, as additional 'boundary' landmarks for the creation of patches on the constructed 3D models (Figure 3.16; Section 3.3.3).

Thirty polyvinylsiloxane (addition-type silicone elastomer of high viscosity, Coltene President putty soft, Coltene AG, Switzerland) specimens were mixed according to the manufacturer instructions and applied onto the external surface of the dummy head. Specimens were applied in three main areas: the nose, the lips and the chin with 10 specimens created for each area. Different shapes and configurations were created in an attempt to simulate different facial configurations and deformities (Figure 3.22). Adhesion of specimens was checked and no adhesive was required to maintain tight contact between each specimen and the facial surface. After each facial surface addition, the model was captured by C3D, and a 3D model was constructed for each capture.

Figure 3.22 Different designs of facial explants on the dummy head

The true volume of each specimen was obtained employing Archimedes principle based on water displacement. Each specimen was first immersed in a water container at room temperature (≈21°C) and the weight of the displaced water after immersion was calculated using a 4-figure analytical balance (Model AC210S, Sartorius AG, Goettingen, Germany). The volume was then calculated using the appropriate water density value. This measurement was considered as the gold standard.

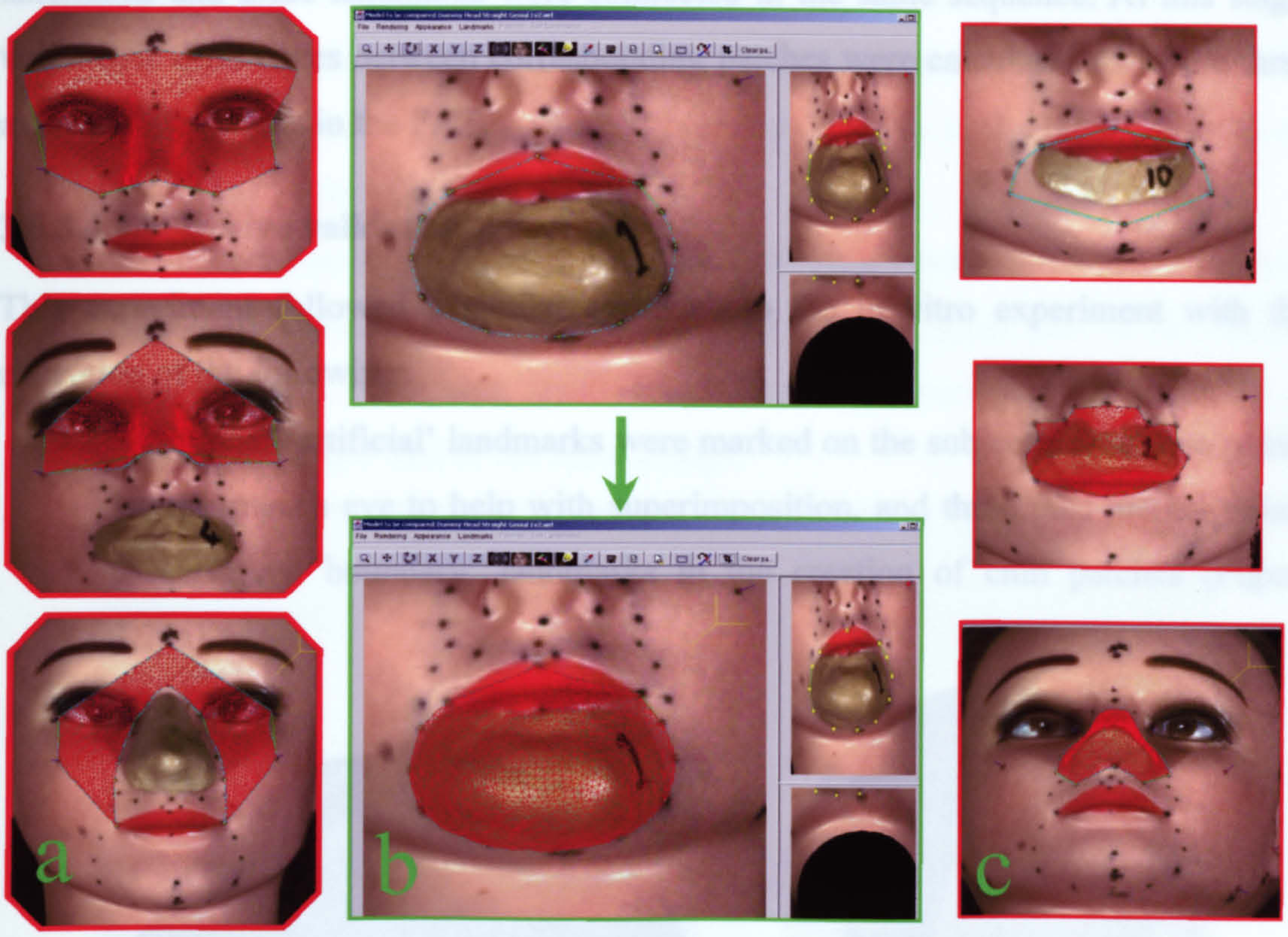


Figure 3.23: Calculating volumes of specimens using the FAT. (a) Patches used for ICP registrations. (b) Before and after highlighting a chin patch. (c) Labiomental, upper labial and nasal patches.

To obtain the 3D-based volume of each specimen, modified models were compared with the original dummy head model. Registration of models was performed through Procrustes alignment followed by H-weighted ICP (Iterative Closest Point) registration. A previous investigation using the Facial Analysis Tool recommended the use of this two-step method when two models are to be compared[(464)]. The landmark-based registration procedure employed 12 anthropometric landmarks (goR, sbtrR, zygR, excR, encR, na, gla, encL, exL, zygL, sbtrL, goL). Superimpositioning patches were created across the eyes, the nose and the cheeks for labial and labiomental specimens, while they followed other designs when the specimens were located on the nose (Figure 3.23). Since a non-animated object was used, there was no intention to restrict the superimpositioning method to the eyes and forehead.

With regard to the dummy head, a specific patch was first created on the second model (with the added material) around the specimen, and a similar patch was created on the first model (original). Both models had the same number of boundary landmarks and these landmarks were connected in the same sequence. At this stage, volumetric differences between corresponding patches were calculated using the three available algorithms in the FAT.

3.5.3.4.4.2 In vivo validation

This experiment followed a similar approach to the in vitro experiment with the exception of the following:

- Additional 'artificial' landmarks were marked on the subject's face; two points lateral to each eye to help with superimposition, and three post-mental points to serve as 'boundary' landmarks in the creation of chin patches (Figure 3.24a).

Figure 3.24: Photographs of the volunteer's face. (a) A frontal photograph of the face with all the landmarks marked. (b) An example of a nasal specimen seen laterally. (c) An example of a chin specimen seen frontally.

- Images were taken in natural head position with the lips in repose. Zachrisson's method was used to establish rest position in the lower facial parts[(465)].
- More visual inspection was required to ensure that each specimen was firmly in contact with the subject's face (Figure 3.24b&c). No adhesive was required.

- For Procrustes registration, nine anthropometric landmarks were used: zygR, excR, encR, gla, encL, excL, zygL as well as two non-anatomical points lateral to Exocanthion. Nasion (na) was not used because it was covered in some occasions by the nasal specimens.
- For ICP registration, the main superimpositioning patches used with nasal and labial specimens were located at the eyes and the upper part of the cheeks (Figure 3.25). With chin specimens, the patches were slightly extended to include the upper half of the nasal bridge.

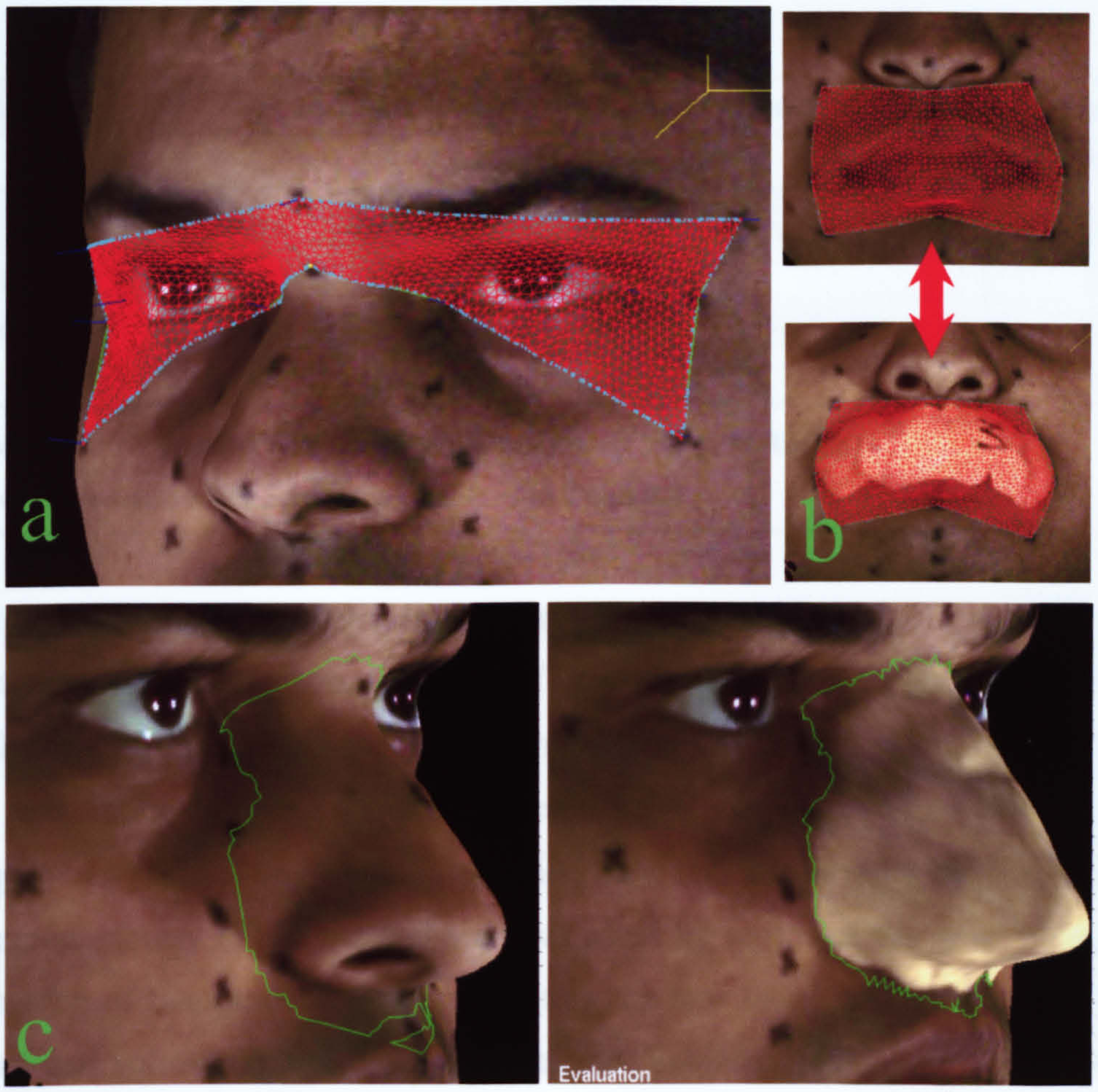


Figure 3.25: 3D-based procedures to calculate the enclosed volume between each couple of corresponding patches. (a) Defining a patch across the eyes and the nasal root for ICP superimposition. (b) Corresponding labial patches to calculate the enclosed volume after superimposition due to the added labial specimen. (c) Patch boundaries are modified in a further step to exclude areas of no change after the alignment of the two models.

Statistical tests were applied to detect significant differences in volumes obtained by water displacement and by 3D models. The percentage error was calculated by dividing the measurement error (the difference between the actual volume and the 3D-based volume) by the actual volume.

3.5.3.4.5 Facial volumetric changes

Four surface patches representing four facial regions were constructed on each 3D model. The volumetric change following surgery at each facial region was calculated for patients in subgroup A (skeletal Class III patients treated by bimaxillary surgery). Table 3.5 illustrates the boundary landmarks required for each patch. Two constructed points were required on both sides for creating the lower lip and the chin patches. The definitions of these constructed points are given in Table 3.6. Figure 3.28 illustrates some examples of facial patches (highlighted in red) on 3D models.

Table 3.5	**Assessment of volumetric changes following orthognathic surgery**	
Patch	**Boundary landmarks**	N
Nasal	na, encL, acL, sbalL, sn, sbalR, acR, encR	8
Upper lip	acR, sn, acL, chL, stms, chR	6
Lower lip	chR, stmi, chL, sbchL*, ils, sbchR*	6
Chin	sbchR, ils, sbchL, pmenL*, men, pmenR*	6

Abbreviations: N= number of boundary landmarks; R: Right; L: Left.
(*) These non-anatomical points are explained in Table 3.6.

Based on the results of the validation experiments (see Section 4.2.4), the 'tetrahedron formation' method was chosen because of its minimal error compared with the other two algorithms. 3D models were superimposed in two stages, using the landmark-based registration followed by the ICP registration. The enclosed volumes between corresponding patches were calculated when their boundaries were stitched together. The reproducibility of the method was evaluated by repeating the whole procedure (registration of two models, then highlighting the four facial patches and calculating the enclosed volumes) on ten randomly selected subjects from subgroup A after one month of the first assessment.

Table 3.6	**Definitions of the constructed bilateral points**	
Landmark	**Code**	**Definition**
Subcheilion	Sbch	This point is constructed at one fourth of the surface distance between Pogonion and Subtragion and closer to Pogonion.
Paramenton	Pmen	This point is constructed at one fourth of the surface distance between menton and obi (Otobasion inferius) and closer to Menton.

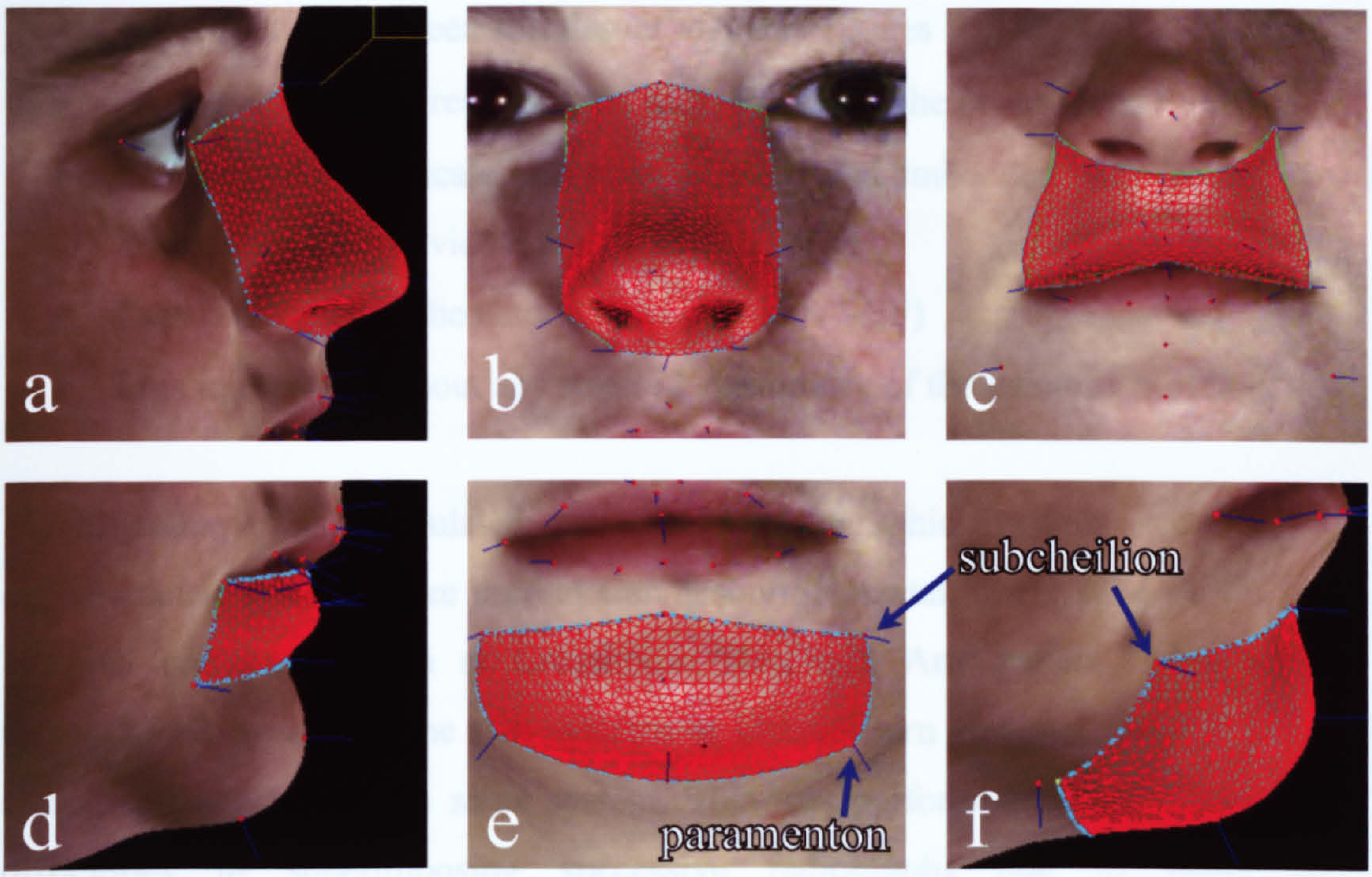


Figure 3.26: Four facial patches highlighted on a 3D model for use in the analysis of volumetric changes. (a) Lateral view of a nasal patch. (b) Nasal patch from front. (c) Upper lip patch. (d) Lower lip patch. (e) Chin patch from front. Constructed points required for the chin patch are shown in (e) and (f).

3.5.4 2D imaging of the face: lateral cephalograms

Lateral cephalograms for each patient were obtained from three centres: Canniesburn, Monklands and Crosshouse Hospitals in the West of Scotland. The taking of all radiographs was not under the direct control of the researcher. However, the method used to obtain each radiograph at each centre was standardised by well-trained personnel. In addition, the conditions for including lateral cephalograms in the study were clarified to the staff beforehand. Lateral cephalograms were taken at the following time intervals:

- T1: within one week before surgery
- T2: within one week following surgery
- T3: at six months post-surgery (± one week).

3.5.4.1 Conditions of including an radiograph

Each radiograph was examined subjectively before inclusion in the study, to ensure that the following criteria were met:

- High quality films without any scratches, pinholes or artificial shadows which obscured any landmark required for the analysis.

- Good contrast between soft tissues and hard tissues
- All facial features present on the film, especially the lower facial third
- The presence of a scale or a ruler captured and embedded with the radiograph to calculate the individual magnification factor
- Face positioned in the natural head position (NHP)
- Lips in repose, without any stressed appearance of the mentalis muscles.

Magnification was calculated for each radiographic system (two different cephalometric systems were used at Canniesburn Hospital, one system at Monklands Hospital and one system at Crosshouse Hospital). Any patient, who had been radiographed by one of the two systems at Canniesburn Hospital, was followed up radiographically using the same system. This was performed intentionally to avoid difficulties in superimposing successive radiographs due to magnification discrepancies. An individual magnification factor was computed for each cephalogram at each time (despite being produced by the same system) to ensure accuracy and to account for any error in head positioning or unintentional change in the distance between the film and the midsagittal plane of the face.

Ideally, all the cephalograms should have been taken in centric occlusion (or habitual occlusion). Most of the patients in the immediate postoperative period, however, had interocclusal splints (acrylic wafers) between the upper and the lower dentition, which resulted in approximately 2-mm distance between the upper and lower molars on the cephalograms.

In order to minimise vertical changes of mandibular landmarks upon splint removal or jaw closure(243), a simulation of this movement was performed and the new position of the mandible was traced, which will be explained in the following section.

3.5.4.2 Tracing of cephalograms

Cephalometric radiographs were traced using high-quality acetate tracing paper with Steadtler Mars-Macrograph pencil (9H). A lead pointer (Hitenlik 1110) was used to create a very fine tip identical in diameter to the cross-hair cursor of the digitiser. The tracing procedure was performed in a darkened room using an orthodontic radiograph viewer (H. A. West (Radiograph) Ltd., Edinburgh, UK).

The presurgical, the immediate postsurgical and the six-month postsurgical radiographs were traced in sequence. The tracing workflow started with a careful drawing of the soft-tissue drape starting from the forehead and finishing at the chin area. Then, skeletal structures were drawn starting from the cranial base details, through the orbits and the maxilla and finishing at the mandible, the ramus and the condyles.

On the presurgical radiograph tracing, two landmarks were identified: Nasion (N) and Sella turcica (S). A line was drawn between these points to create the anterior cranial base line. A third point was constructed, called (S2), 7 degrees upward from this line. So a corrected horizontal plane was created[86] as if the cranial base line (S-N) was rotated 7 degrees clockwise around point N. This line was considered as the x-axis in the coordinate system for each patient. The y-axis (the vertical axis) was constructed perpendicular to this line and passing through Nasion, which resulted in a coordinate system with an origin at Nasion (0,0) (Figure 3.27).

Following construction of the coordinate system, each of the postoperative tracings (immediate and six-month radiographic tracings) was superimposed on the presurgical radiographic tracing. The superimposition was performed manually to achieve the best-fit using cranial base structures as well as point Nasion[466,467]. Once the maximal agreement was achieved, the presurgical coordinate system was transferred to the postsurgical tracings.

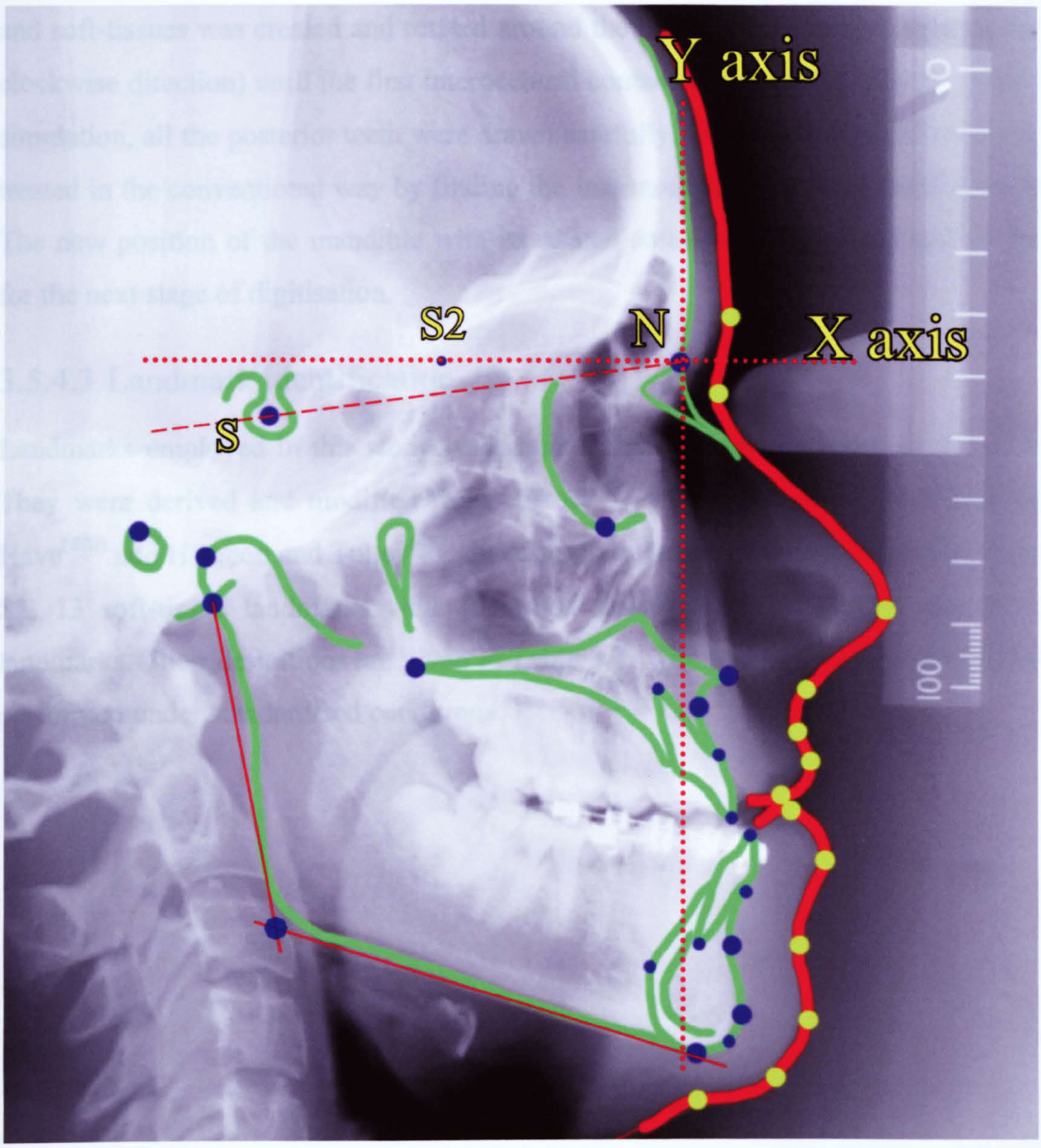


Figure 3.27: Construction of the x- and y-coordinate system. Soft- and hard-tissue contours have been thickened for illustrative purposes.

On the postsurgical radiographs, some landmarks were of poor definition due to the surgical intervention (such as ANS or PNS). In order to solve this problem, components of the presurgical tracing were used to reconstruct missing or poor anatomical landmarks. ANS was reconstructed on the postsurgical tracing from the presurgical tracing by superimposing both on the maxillary outlines, especially the palatal vault[247,467,467], followed by transferring ANS to the postsurgical tracing.

In cases where interocclusal digitations were not seen in the cephalograms (because of the presence of the acrylic wafer), a template of the traced mandible including hard-and soft-tissues was created and rotated around the centre of the condyles (in an anti-clockwise direction) until the first interocclusal contact was achieved. For this kind of simulation, all the posterior teeth were drawn carefully. Double shadows of teeth were treated in the conventional way by finding the intermediate outlines of these shadows. The new position of the mandible with its related soft-tissues was fixed and secured for the next stage of digitisation.

3.5.4.3 Landmark identification

Landmarks employed in this study with their definitions are illustrated in Table 3.6. They were derived and modified from Rakosi(468), Phillips et al(469), Kerr and Ten Have(470) and Houston and Tulley(467). In addition to locating Nasion (N), Sella (S) and S2, 13 soft-tissue landmarks were identified followed by 19 skeletal and dental landmarks. Their definitions are given in Table 3.7. The identification procedure was performed under standardised conditions.

Table 3.7	Landmarks used in the cephalometric study	
Name of landmark	Code*	Definition
Glabella	gla	The most anterior point on the soft-tissue forehead
Nasion (soft-tissue)	na	The most concave point of the soft-tissue outline of the nasal root between the eyes
Pronasale	prn	The most anterior point on the nasal tip
Subnasale	sn	The junction point between the columella and the upper cutaneous lip
Superior Labial Sulcus	sls	The most posterior point on the concavity between the upper lip and the nose
Labrale superius	ls	The most anterior point on the convexity of the upper lip
Stomion superius	stms	The most inferior point of the anterior portion of the upper lip when the lips are apart, or the point of the upper lip at which i merges with the lower lip when the lips are in contact.
Stomion inferius	stmi	The most superior point of the anterior portion of the lower lip when the lips are apart, or the point of the lower lip at which it merges with the upper lip when the lips are in contact.
Labrale inferius	li	The most anterior point on the convexity of the lower lip
Inferior Labial Sulcus	ils	The most posterior point on the concavity between the lower lip and the chin, or the deepest point on the labiomental groove.
Pogonion (soft-tissue)	pog	The most anterior point on the convexity of the soft-tissue chin
Gnathion (soft-tissue)	gn	The midpoint on the curvature between soft-tissue pogonion and soft-tissue menton
Menton (soft-tissue)	men	The most inferior point of the soft-tissue outline of the chin
Nasion (hard-tissue)	N	The most anterior point of the nasofrontal suture in the midsagittal plane.
Sella (S)	S	The centre point of the hyperphysial fossa.
Orbitale	Or	The lowest point on the average of the right and left orbital margins
Porion	Po	The most superior point on the average of bony external acoustic meatus
Anterior Nasal Spine	ANS	The tip of bony anterior nasal spine
Point A (subspinale)	A	The deepest midline point in the curved bony outline of the maxillary alveolar process.
Prosthion	Pr	The most inferior anterior point of the maxillary alveolar process between the upper central incisors in the midsagittal plane
Incision superius	IS	The edge of the crown of the most anterior maxillary central incisor
Incision inferius	II	The edge of the crown of the most anterior mandibular central incisor
Infradentale	Id	The most superior anterior point of the mandibular alveolar process between the lower central incisors in the midsagittal plane
Point B (supramentale)	B	The most posterior point in the outer contour of the mandibular process in the midsagittal plane
Pogonion (hard-tissue)	Pog	The most anterior point of the bony chin
Gnathion (hard-tissue)	Gn	The midpoint on the curvature between hard-tissue pogonion and hard-tissue menton.

Table 3.7 Contd.

Name of landmark	Code*	Definition
Menton (hard-tissue)	Men	The most inferior point in the outline of the symphysis.
Genion	Ge	The most posterior point on the lingual cortical aspect of the symphysis above the genial tubercles and usually one to two millimetres below the level of the lower incisor apex
Gonion	Go	The point of intersection of the lines tangent to the posterior border of the ascending ramus and mandibular body.
Articulare	Ar	The point of intersection of the posterior margin of the ascending ramus and the inferior margin of the posterior cranial base (the inferior margin of the sphenoid body.
Condylion	Cd	The most superior and posterior point in the average outline of the condylar heads.
Posterior Nasal Spine	PNS	The point of intersection of a continuation of the anterior wall of the pterygo-maxillary fissure and the floor of the nose. Thi point marks the posterior limit of the maxilla.
Apex of the upper incisor	UIA	The root apex of the most anterior maxillary central incisor
Apes of the lower incisor	LIA	The root apex of the most anterior mandibular central incisor

(*) Small letters have been used in all soft-tissue landmarks abbreviations to distinguish them from hard-tissue landmarks abbreviations.

3.5.4.4 Landmark digitisation

PC-DIG©[471] is a computer programme for 2D image digitisation. A list of the landmarks required for digitisation was created in the programme. Using a digitisation tablet, landmarks were digitised in a sequence. The software stored x and y native coordinates of these landmarks. Through a list of command lines, the software was programmed to rotate the matrix of coordinates around the N point so that the horizontal axis (x-axis) would be the line passing through N and S2 and the vertical axis (y-axis) would be perpendicular to it passing through N. Then x and y distances for each landmark from the reference planes were computed. Interlandmark distances, angles and ratios were also calculated. Data were stored in a text file (ASCII code) for further data manipulation and analysis.

3.5.4.5 Reproducibility of landmark identification: error of method

Thirty cephalograms were chosen at random from the whole groups of radiographs regardless of their imaging time. Cases that required additional effort in tracing by simulating mouth closure (to bring the teeth into maximum inter-cuspidation) were treated separately, and the reproducibility of such a procedure was assessed later (see Section 3.5.5.6).

The selected radiographs were retraced, landmarks re-identified and digitised in the same way described before. The assessment of landmark identification error was performed one month following the initial identification. Landmarks' x and y coordinates were obtained (horizontal and vertical landmarks' distances from the origin at nasion, respectively). In addition, linear and angular measurements (explained in the Section 3.5.4.7) were calculated. Mean differences between the two measurements were obtained and student paired t tests were applied to detect statistically significant differences between the two data sets (original measurements versus the repeated measurements)[472,472]. Houston's coefficient of reliability [472] was calculated for each variable in order to evaluate random errors. Dahlberg's formula[473] was also used to evaluate the combined random and systematic error for each landmark.

3.5.4.6 Reproducibility of simulated mandibular closure

Thirty lateral cephalograms were selected at random from a group of radiographs in which simulation of mandibular closure was performed. In addition to retracing and re-identification of landmarks, rotation of the mandible was performed applying the same method described earlier. The coordinates of seventeen landmarks likely to be affected by the mandibular rotation were obtained. Eleven were hard-tissue landmarks and six were soft-tissue landmarks. Student paired t-tests were applied to evaluate systematic errors. Random errors were examined by calculating the coefficient of reliability(472) for each landmark coordinate. Dahlberg's method in error estimation was also used for each landmark coordinate(473).

3.5.4.7 Two-dimensional measurements

Although a considerable amount of data was collected, the 2D analysis included the following:

3.5.4.7.1 Soft-and hard-tissue landmark displacements

Since landmark coordinates for the three cephalograms taken at T1, T2 and T3 had the same coordinate system, x and y displacements of landmarks were obtained by calculating differences in coordinates between each two assessment times, i.e. T1-T2 (surgical change), T2-T3 (follow-up relapse) and T1-T3 (the overall change). Positive values were assigned for forward movement and upward movements in the x and y axes, respectively. Statistically significant changes were detected by student's paired t tests. If the conditions of using student's t tests were not met, non-parametric tests (Wilcoxon matched-pairs signed-rank tests) were used instead.

3.5.4.7.2 Interlandmark distances and angles

Interlandmark distances and angles were obtained for the three assessment times (T1, T2 and T3). The employed soft-tissue distances and angles are illustrated in Table 3.8. Hard-tissue distances and angles are illustrated in Table 3.9. Soft-tissue thickness measurements at seven soft-tissue levels were also obtained (see Table 3.10). Figure 3.28 gives some examples of soft- and hard-tissue distances, while angular measurements are shown in Figure 3.29. Figure 3.30 illustrates the locations of soft-tissue thicknesses measured.

Table 3.8	2D soft-tissue measurements (distances and angles)		
No.	Measurement	Landmarks used	Type*
1	Upper lip height (ULH)	sn-stms	Dv.
2	Upper vermilion height (LVH)	ls-stms	Dv.
3	Lower lip height (LLH)	stmi-ils	Dv.
4	Lower vermilion height (LVH)	stmi-li	Dv.
5	Lower facial height (LFH)	sn-men	Dv.
6	Interlabial distance (ILD)	stms-stmi	Dv.
7	Total vermilion height (TVH)	ls-li	Dv.
8	Columellar length (ColumL)	sn-prn	Dh.
1	Nasal tip angle	na-prn-sn	A
2	Nasolabial angle	prn-sn-ls	A
3	Labiomental angle	li-ils-pog	A
4	Chin angle	ils-pog-men	A
5	Facial profile angle	na-prn-pog	A

*** Type of measurement: 'D' for distances and 'A' for angles. The letter 'v' was added to distances measured parallel to the y-axis (vertical distances) and 'h' was added to distances measured parallel to x-axis (horizontal distances).**

Table 3.9	2D hard-tissue measurements (distances and angles)		
No.	Measurement	Landmarks used	Type*
1	Total anterior facial height (TAFH)	N-Men	Dv.
2	Upper anterior facial height (UAFH)	N-ANS	Dv.
3	Lower anterior facial height (LAFH)	ANS-Men	Dv.
4	Posterior facial height (PFH)	S-Go	Dv.
5	Mandibular length (MdL)	Cd-Gn	D
6	Mandibular ramus height (MdRmH)	Cd-Go	D
7	Mandibular body length (MdBL)	Go-Pog	D
8	Maxillary length 1 (MxL1)	Cd-A	D
9	Maxillary length 2 (MxL2)	Cd-ANS	D
10	Maxillary length 3 (MxL3)	ANS-PNS	D
11	Facial axis length (FAL)	S-Gn	D
12	Posterior cranial base length (PCB)	S-Ar	D
13	Overbite (OB)	Ii-Is	Dv.
14	Overjet (OJ)	Ii-Is	Dh.
15	Incisal show	Is-stms	Dv.
1	SNA	S-N-A	A
2	SNB	S-N-B	A
3	ANB	A-N-B	A
4	SNPog	S-N-Pog	A
5	Maxillary plane to SN plane (MxSN)	ANS-PNS-S-N	A
6	Mandibular plane to SN plane (MdSN)	Men-Go-S-N	A
7	Maxillo-mandibular planes angle (MxMd)	ANS-PNS-Go-Men	A
8	Mandibular plane incisor angle (MPIA)	Go-Men-Ii-LIA	A
9	Upper incisor to SN plane (UISN)	S-N-Is-UIA	A
10	Interincisal angle (IIA)	Ii-LIA-Is-UIA	A

(*) Type of measurement: 'D' for distances and 'A' for angles. The letter 'v' was added to indicate distances measured parallel to the y-axis (vertical distances) and 'h' to indicate distances measured parallel to x-axis (horizontal distances).

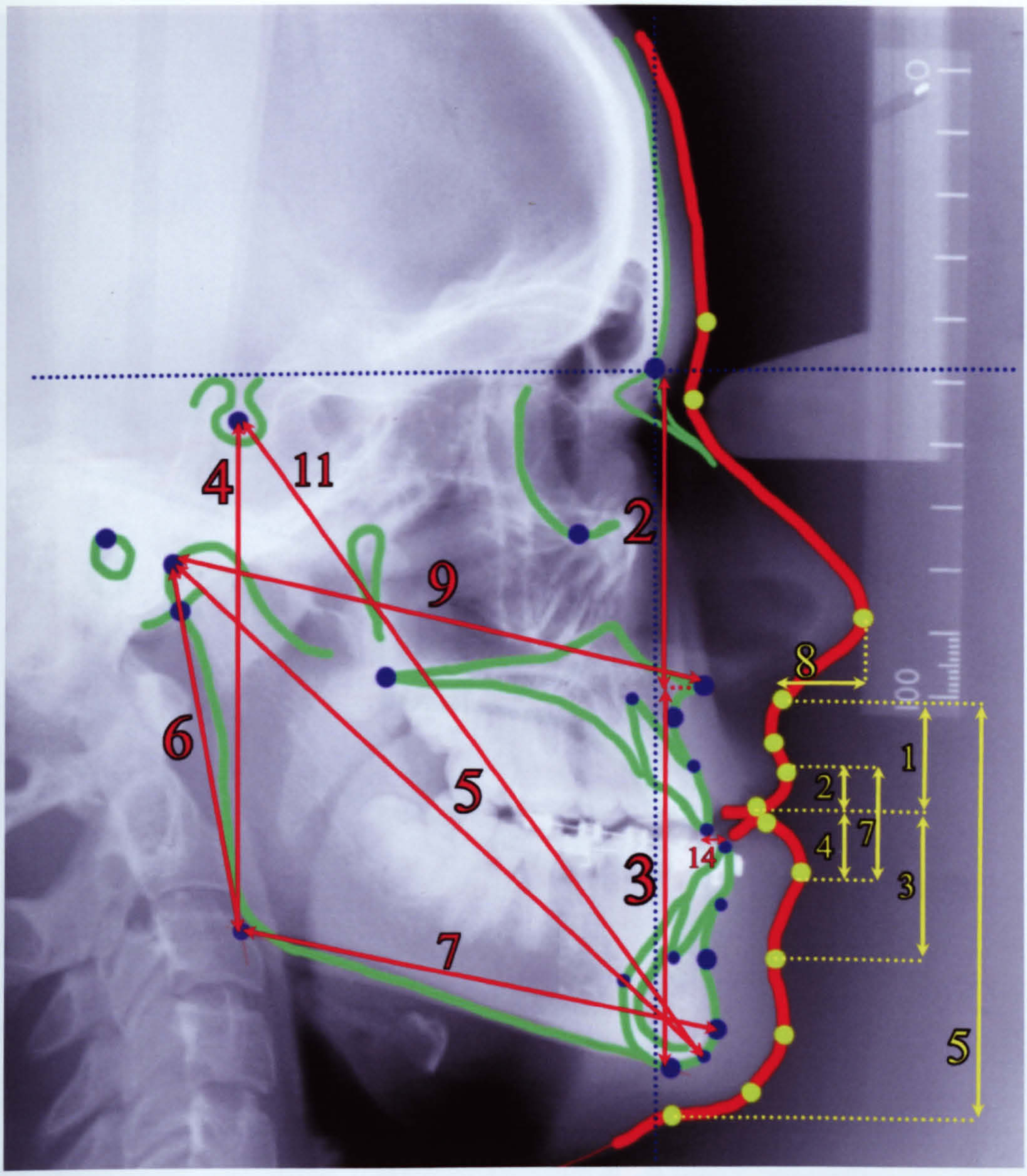


Figure 3.28: Distances calculated on the cephalogram. The numbers of distances on soft tissues (shown in yellow) are explained in Table 3.8 and the numbers of distances on hard-tissues (shown in red) are explained in Table 3.9. Soft- and hard-tissue contours have been thickened for illustrative purposes.

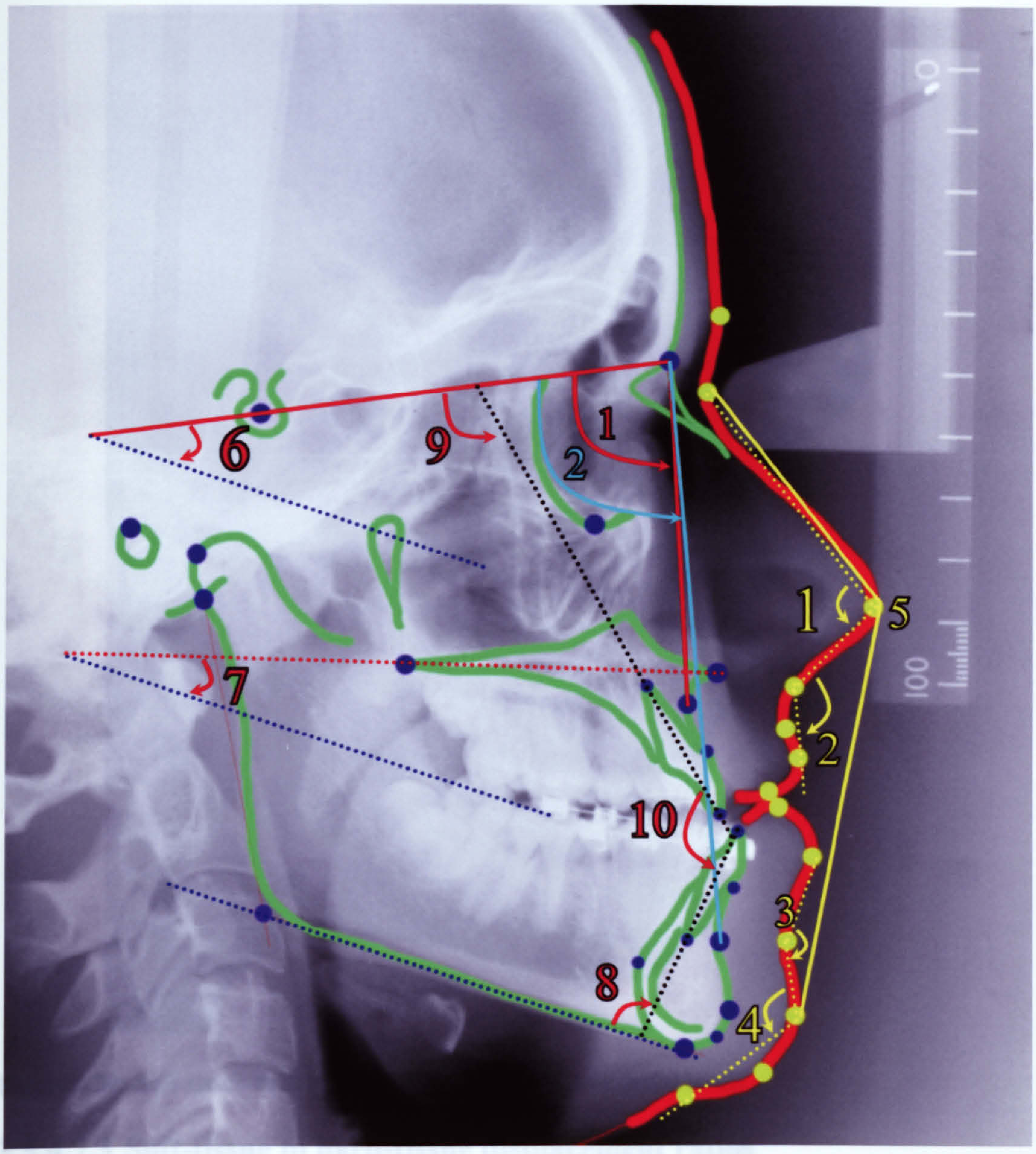


Figure 3.29: Angles calculated on the cephalogram. The numbers beside the angles on soft tissues (marked in yellow) are explained in Table 3.8. The numbers beside the angles on hard tissues (marked in cyan) are explained in Table 3.9. Soft- and hard-tissue contours have been thickened for illustrative purposes.

Table 3.10	**Soft-tissue thickness at seven facial levels**		
No.	**Level of soft-tissue thickness**	**Landmarks used**	
		Hard-tissue point	**Soft-tissue point**
1	Nasal base	ANS	sn
2	Upper lip – cutaneous portion	A	sls
3	Upper lip – vermilion border	Pr	ls
4	Lower lip – vermilion border	Id	li
5	Labiomental fold	B	ils
6	Chin – prominent point	Pog	pog
7	Chin – inferior point	Men	men

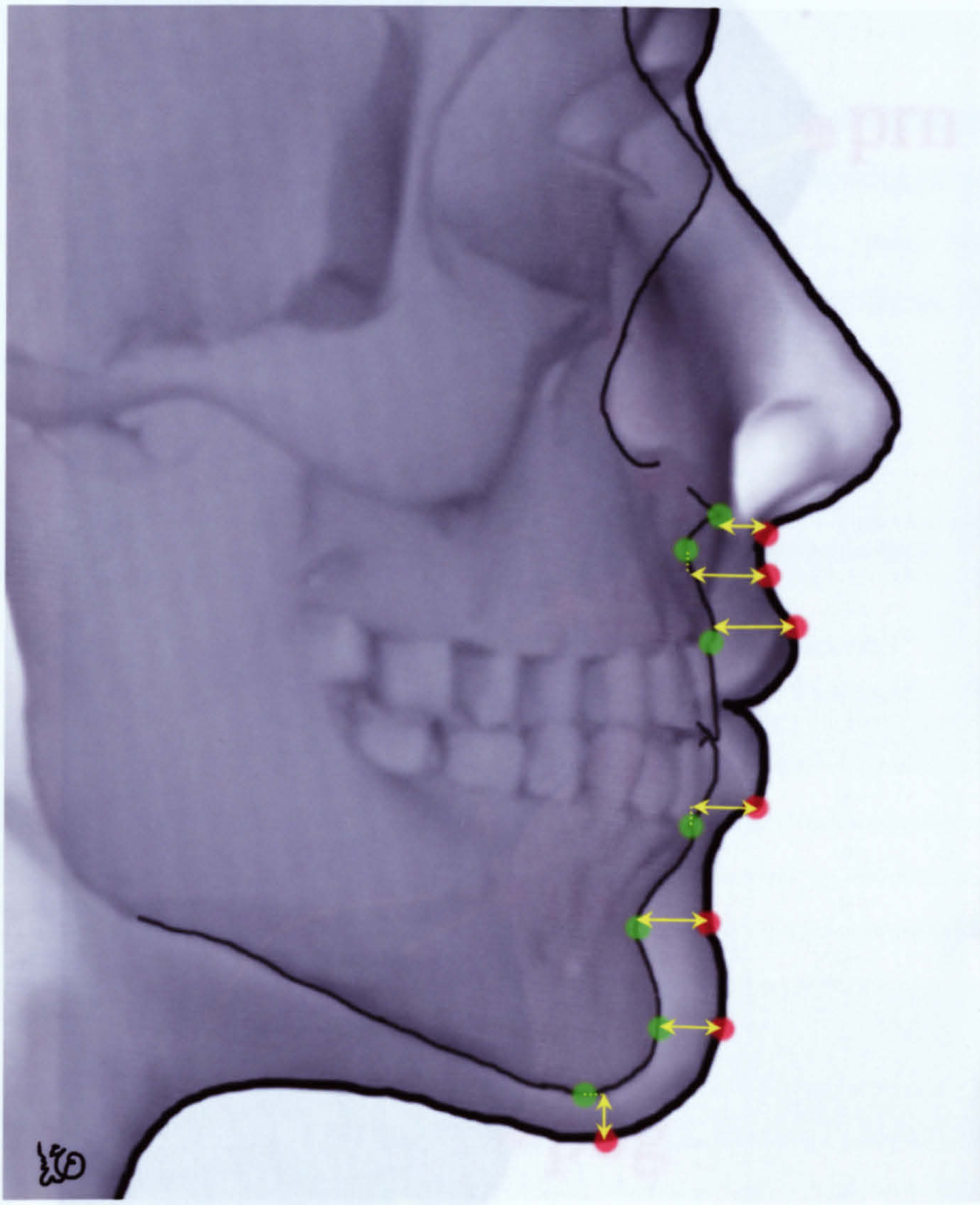


Figure 3.30: Soft-tissue thickness at seven different lower facial levels

3.5.4.7.3 Soft-tissue to hard-tissue displacement ratios

Between T1 and T3, soft-tissue to hard-tissue displacement ratios were calculated simply by dividing the soft-tissue change of a landmark by the hard-tissue change of another corresponding landmark. Twenty-two possible combinations of soft-tissue to hard-tissue displacement ratios were considered as shown in Figure 3.28. Median values were considered rather than mean values because of the presence of outliers in several ratios(378). Significantly different median ratios from zero were detected using non-parametric tests (Wilcoxon one-sample signed-rank tests).

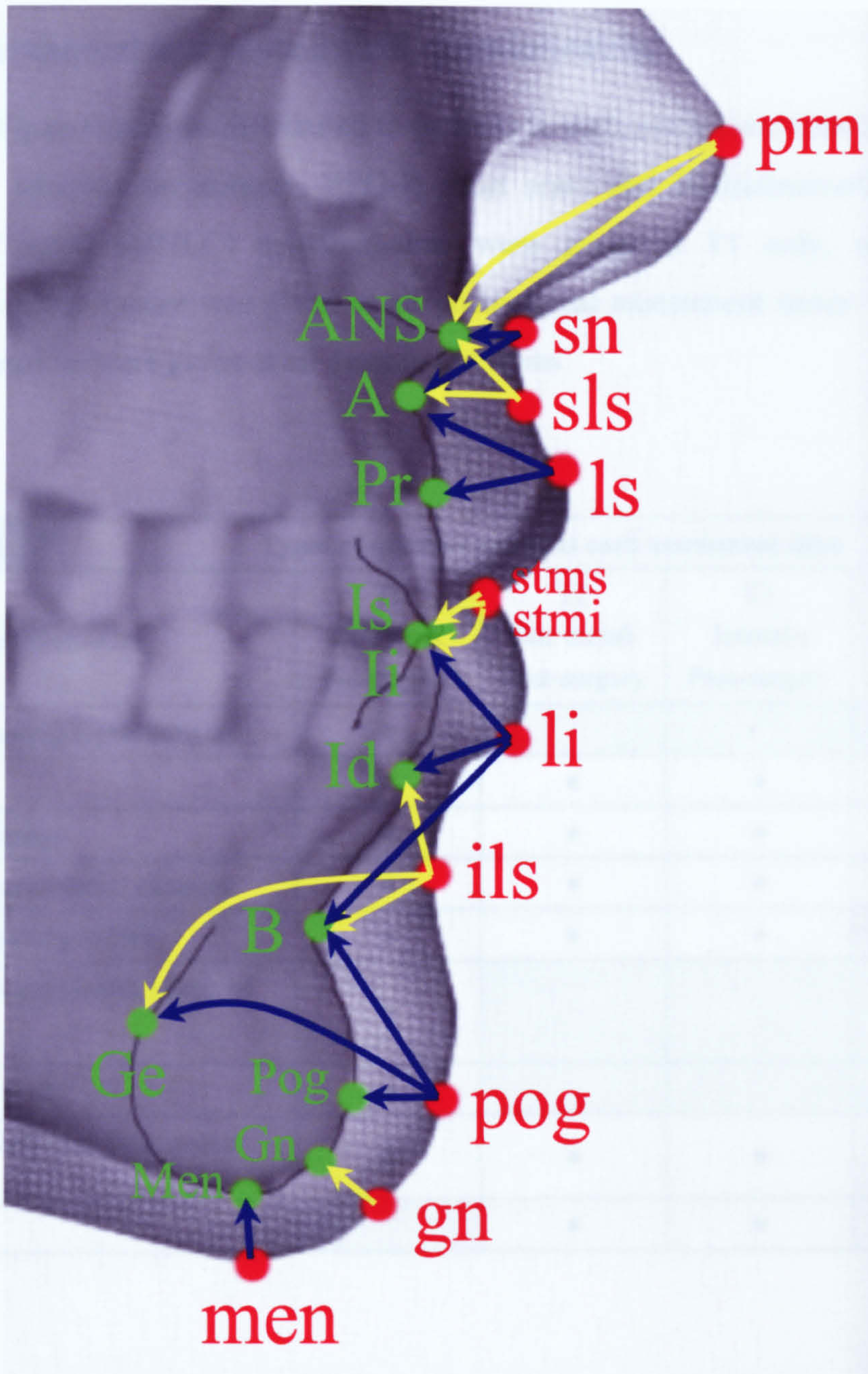


Figure 3.31: Twenty-two soft-tissue to hard-tissue displacements ratios calculated.

3.5.5 Psychosocial analysis

The timing of the psychosocial assessment was coincidental with the timing of the 3D capture, i.e. four assessment times:

- T1: within one week before surgery
- T2: at one month post surgery
- T3: at three months post surgery
- T4: at six months post surgery

3.5.5.1 Presurgical and postsurgical questionnaires

The types of questionnaires distributed to patients at each assessment time are given in Table 3.11. Motives for surgery, EPQ-R short scale and Multidimensional Health Locus of Control (MHLC) questionnaires were given at T1 only, whereas the satisfaction questionnaire was given at all postsurgical assessment times. The rest of the questionnaires were given at all assessment times.

Table 3.11	Types of questionnaires at each assessment time			
Questionnaire	T1 One week Pre-surgery	T2 One month Post-surgery	T3 3months Post-surgery	T4 Six month Post-surgery
Motives for orthognathic surgery	•			
Self esteem	•	•	•	•
Facial Body Image	•	•	•	•
Self-perception of facial changes	•	•	•	•
Self-perception of profiles	•	•	•	•
Multidimensional Health Locus of Control	•			
EPQ-R short scale	•			
Hospital Anxiety and Depression Scale	•	•	•	•
Satisfaction		•	•	•

3.5.5.2 Motivation for surgery

Assessment of motivation was undertaken at T1 only. A 13-item questionnaire was used to assess patient's motivation to undergo orthognathic surgery (Appendix VI). This questionnaire was developed by Kiyak et al[408]. Patients were asked to give their opinion about each motive using a 4-point Likert response scale from (0) 'not at all a motive' to (4) 'so much a motive'. This questionnaire required one minute to complete. The scale was converted in a further analysis into a binary variable, i.e. the answer would be (1) 'little or no motive at all' or (4) 'moderate or so much a motive'. This enabled chi-squared tests to be performed to detect significant differences between Class II and Class III patients, females and males and younger and older patients in their motivational[474] patterns. When the validity of a chi-squared test was in doubt, a Fisher's exact test was used instead[474].

3.5.5.3 Patient's perception of facial change

Three different designs were used to assess patients' perception of facial appearance in the presurgical and post-surgical periods.

3.5.5.3.1 Facial Body Image

This questionnaire was based on a list of facial features in which patients were asked to determine their feelings towards these facial features (Appendix VII). This questionnaire, titled 'Facial Body Image' (FBI), was modified from the one used by Kiyak et al (1982)[430]who in turn modified it from the original work of Secord and Jourard[475]. The FBI's list included 13 facial features: hair, forehead, eyes, ears, nose, upper lip, lower lip, cheeks, teeth, chin, upper part of the neck, profile and shape of the face. A 5-point Likert scale was used and the response scale varied from (1) 'have strong feelings and wish change could somehow be made' to (5) 'consider myself fortunate'. The FBI questionnaire took two minutes to complete. Although it was an ordinal scale, the mean value of each score was used as a summary measure under the implicit assumption that a change from score 1 to 2, for example, is the same as a change from score 2 to 3 or 3 to 4[476]. Wilcoxon matched-pairs signed-rank tests were used to detect whether the postsurgical differences were significantly different from zero.

3.5.5.3.2 Self-perception of required or achieved facial change (SPFC)

The second design was based on lateral and frontal facial drawings (Figures 3.32 and 3.33). This design was developed by the researcher and its applicability was tested in the pilot study. The presurgical questionnaire requested each subject to indicate facial regions that required maximum change (using the letter 'M'), minimal or no change (using the letter 'N') according to their perception. The face was sectioned into four midsagittal facial regions (the nose, the upper lip and philtrum, the lower lip and the chin) and four bilateral regions (the infra-orbital region, the upper part of the cheek, the lower part of the cheek and the paranasal region). This questionnaire required two to three minutes to complete. Some patients required some assistance and clarification. Kappa statistics were used to assess the level of agreement in perception between lateral- and frontal-view questionnaires.

Please indicate with letters (M or N) on the drawings of the face:
- Areas that require maximum change with surgery (M)
- Areas that require little or no change with surgery (N)

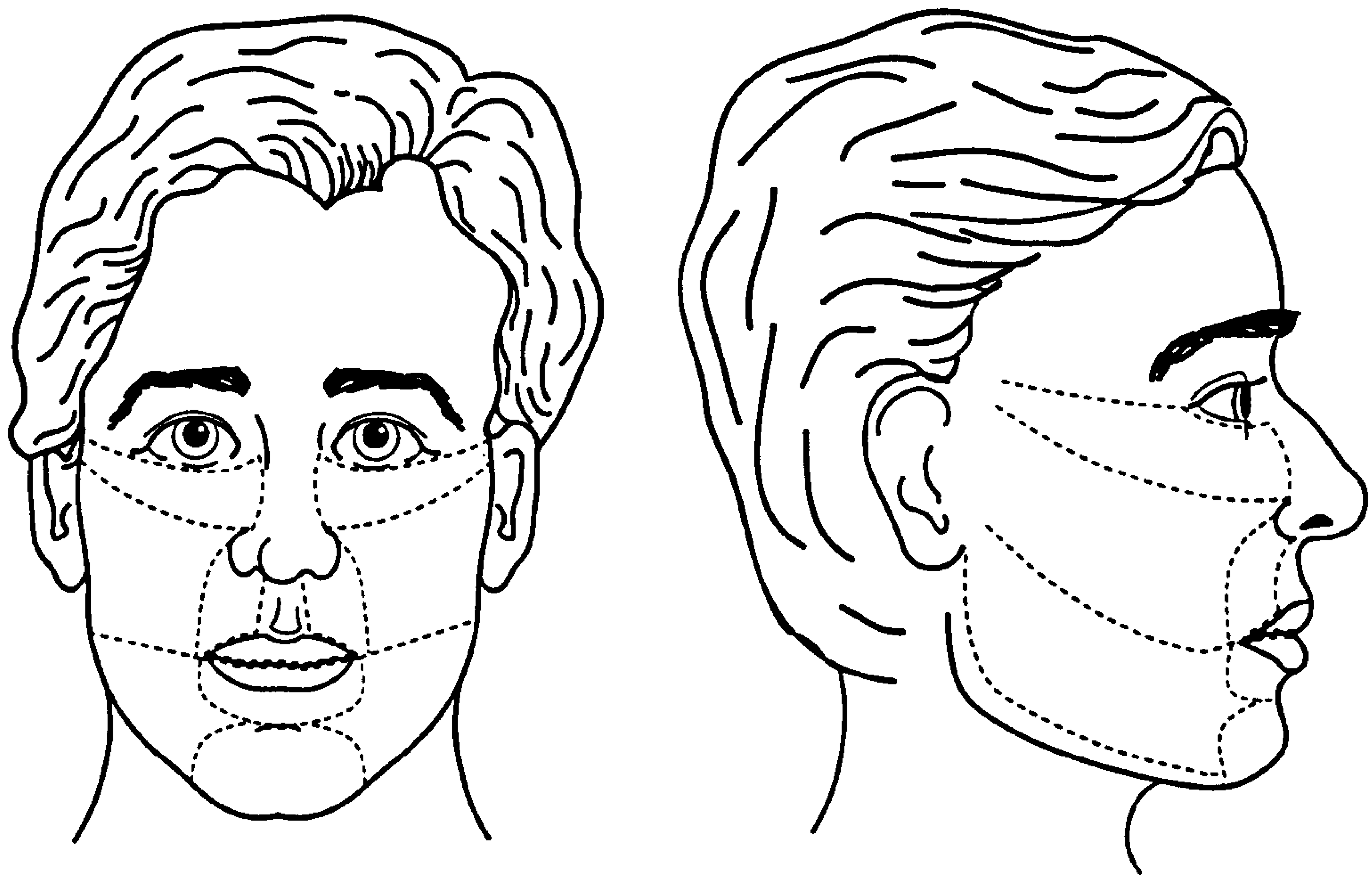


Figure 3.32: Patient's perception of facial change – male drawings

Please indicate with letters (M or N) on the drawings of the face:
- Areas that require maximum change with surgery (M)
- Areas that require little or no change with surgery (N)

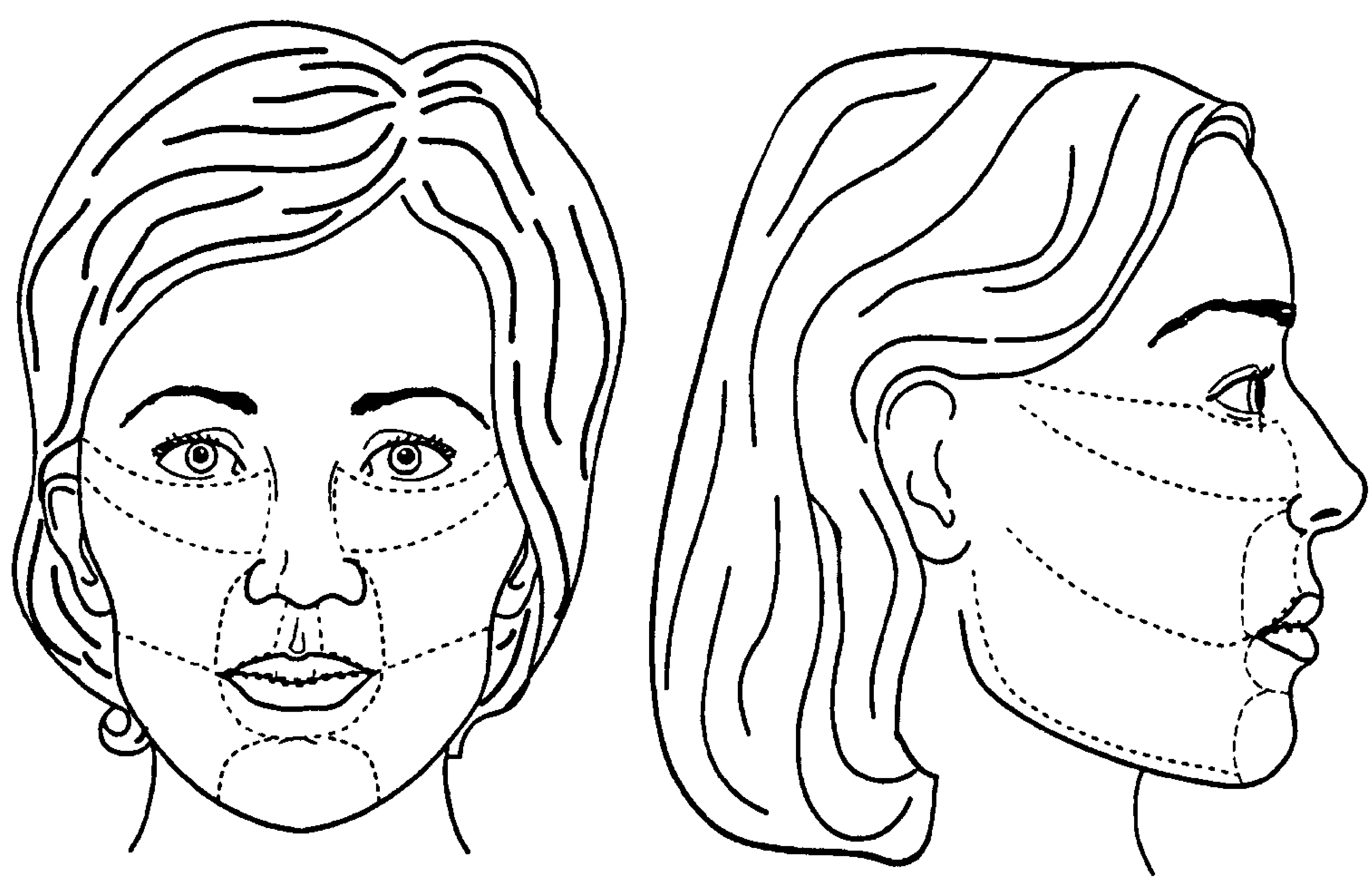


Figure 3.33: Patient's perception of facial change –female drawings

3.5.5.3.3 Self-perception of facial profile (SPFP)

The third design was a drawing-based questionnaire and was developed by Bell and Kiyak[410] to assess self-perception of facial profile. This questionnaire was constructed from 4 sets of drawings of facial profiles with different types of simulated dentofacial deformities. The first question requested each subject to identify the profile which best resembled the lateral view of their face vertically on a 9-point scale starting from a long-face profile (number 1) transforming gradually into a short-face profile (number 9). Choice number 5 was considered the perfect face vertically. Questions two and three, enabled each subject to self-rate their profile in the anteroposterior direction regarding the upper and the lower jaw, respectively. The final question, about the relationship between the teeth and the face, aimed to reveal patients' understanding and perception of the relationship between the dentoalveolar complex and the lips.

3.5.5.4 Personality characteristics

Four questionnaires were employed for this part of the study; with two of them being applied at the four assessment times, and the other two at the presurgical assessment only.

3.5.5.4.1 Rosenberg self-esteem (RSE)

Rosenberg self-esteem[453] is a simple questionnaire for the assessment of self-esteem or perceived self-worth (Appendix V). It consists of 10 items to which the subject responds on a four-point scale of agreement. Half of the items are expressions of positive self-esteem, and half are negative. The scale is self-administered and takes about five minutes to complete. The total score ranges from 10 to 40. Low scores indicate high self-esteem. Little data are available on the psychometric properties of the RSE scale even though it is widely used. The scale does not provide any information about state and trait indices of self-esteem. The scale is clinically useful in showing changes in self-esteem due to a therapeutic intervention. Patients' scores before the operation were compared to their scores at one, three and six months postoperatively. Student t-tests were applied to detect statistically significant differences over time (paired t tests) and between Class II and Class III subjects, younger and older subjects and males versus females at each assessment time (two-sample t tests). Non-parametric tests were applied when asymmetric distributions were noticed.

3.5.5.4.2 Hospital anxiety and depression scale (HADS)

This common 14-item self-administered questionnaire has been used to assess levels of anxiety and depression in patients admitted for orthognathic surgery[456] (Appendix X). It takes five minutes to complete. For each of the subscales, anxiety and depression, there are seven statements. Each subject was asked to give his or her opinion about each statement using a 4-point response scale. The total score for each subscale ranges from 0 to 21. Low scores indicate low depression or anxiety. This questionnaire was administered at T1, T2, T3 and T4. Changes over time were assessed using paired t tests for the whole group as well as for the subgroups. Sex- and age-differences were statistically tested using two-sample t-tests. Non-parametric tests were carried out when the assumptions for parametric tests were not met.

3.5.5.4.3 Multidimensional Health Locus of Control (MHLC)

The Multidimensional Health Locus of Control Scale (MHLC)[454] is designed to determine the way in which people view certain important health-related issues (Appendix VIII). It provides measures of three dimensions of health locus of control: (1) Internality (IHLC) – measuring the extent to which an individual believes the locus of control for health is internal and hence under his or her control; (2) Chance (CHLC) – measuring the belief in chance or external factors in determining health outcomes; and (3) Powerful others (PHLC) – measuring the belief in the control over one's health of powerful others, particularly health professionals. Two equivalent versions of the scale are available: Form A and Form B with 18 items in each. Each item is a belief statement. The patients are asked to give their opinion with regard to each item using a 6-point scale, which ranges from strongly disagree (1) to strongly agree (6). The scale has three subscales measuring the three dimensions of control mentioned above. The score of each subscale ranges from 6 to 36. The higher the score is for a subscale, the stronger the belief. The three subscales are not combined into a single overall score[454]. This questionnaire was given once. Comparisons based on Class of deformity, subjects' sex and age were performed using the conventional statistical methods mentioned earlier.

3.5.5.4.4 EPQ- Short Scale

This questionnaire is designed to measure the levels of four characteristics: neuroticism, psychoticism, extroversion and a 'lie' scale to detect those who may not be responding honestly[455] (Appendix IX). It consists of 48 questions, with 12 questions for each dimension. Subjects are asked to answer 'yes' or 'no' for each question. A specific scoring system is used in order to obtain the final score for each subscale. The higher the score, the higher the level is on the given subscale. Answers should be considered with caution for those patients who scored high in the 'lies' subscale as they may be attempting to present 'ideal' or socially acceptable personalities. This questionnaire was given to patients in the presurgical assessment to obtain an idea about their personality regarding these aspects. It is known that factors such as neuroticism are predictors of anxiety before surgery, while extroversion can be predictive of good post-operative outcome. Psychoticism is not a measure of pathological personality, but indicates those who tend to be socially withdrawn and have little need of social interaction.

3.5.5.5 Satisfaction following surgery

The satisfaction questionnaire developed by Kiyak et al[432] was employed and administered at the three postsurgical assessments, i.e. T2, T3 and T4 (Appendix XI). Satisfaction was defined in four different ways: (1) willing to undergo orthognathic surgery again, (2) likelihood of recommending this surgery to others, (3) satisfaction with the recovery from surgery and (4) the overall satisfaction with the results of the operation.

Patients were asked to respond on 7-point Likert scales, ranging from 1 (indicating no satisfaction) to 7 (indicating very high satisfaction). The results from the four subscales were obtained and analysed separately. A combined score was obtained by averaging the four subscales. Change in satisfaction over time was analysed using Wilcoxon matched-pairs signed-rank tests. Deformity-type, sex and age differences at each assessment time were analysed using Mann-Whitney U tests.

3.5.6 Compatibility between 3D and 2D records

Although the stereophotogrammetric facial soft-tissue records were not obtained simultaneously with lateral cephalograms, measurements calculated by both methods were compared to assess the extent of compatibility.

Thirty lateral cephalograms were chosen from the preoperative and the six-month postoperative lateral cephalograms (Table 3.12). The corresponding thirty presurgical 3D facial models were retrieved and the equivalent linear and angular measurements were calculated. Correction for magnification was performed on all 2D linear measurements. Paired t-tests were applied to detect statistically significant differences.

Table 3.12	**Linear and angular measurement obtained from 2D and 3D databases**	
No.	Measurement	Soft-tissue landmark used
1	Nasal tip angle	na-prn-sn
2	Nasolabial angle	prn-sn-ls
3	Labiomental angle	li-ils-pog
4	Facial profile angle	na-prn-pog
5	Lower facial height	sn-men
6	Nasal height	na-sn
7	Total upper lip height	sn-stms

3.5.7 3D facial change versus perception of change

Using self-perception of facial change (SPFC) questionnaires (both versions: 'full-face view' and the 'lateral-face view'), it was possible to examine the differences in 3D facial soft-tissue changes based on patients' perception of facial change at six months postsurgery. This part of the study was an exploratory trial about the possible link between the collected 3D and psychosocial data.

This investigation was conducted on Class II and Class III patients. The results from frontal and lateral drawings of the face given at T4 (six months following surgery) were obtained regarding the upper lip, lower lip and chin regions. Anteroposterior displacements of the related landmarks between T1-T4 were also obtained. For each facial region, patients were divided into two subgroups: those who perceived maximum change, and those who perceived little or no change for that particular region. Two-sample t tests were applied to detect statistically significant differences in the magnitude of z-displacements of each landmark between the two subsets of change perception.

3.6 Statistical methods and analyses

A summary of all the statistical tests employed in the current study is shown in Table 3.13. The rationale for using each method has been given before in the relevant sections. It is worth mentioning that Anderson-Darling normality tests[(477)] were applied on all continuous 3D, 2D and discrete psychosocial variables to detect asymmetric distributions, in which the application of standard parametric tests was inappropriate. The mean value of each variable was used, generally, as a measure of central tendency, whereas median values were used for non-normally distributed variables.

Basic descriptive statistics, Anderson-Darling normality tests, significance tests (parametric and non-parametric), as well as Houston's coefficient of reliability and Dahlberg's error estimation were carried out using Minitab™ Version 13 software (Minitab Inc., USA). 3D displacements of facial soft-tissue landmarks, facial asymmetry scores and Kappa statistics were calculated using custom-made scripts employed in the S-PLUS 2000 Professional Release 3 software (Statistical Sciences Corporation, MathSoft, USA). Interlandmark distances and angles on 3D facial models and volumetric differences following surgery were obtained through the Facial Analysis Tool functions.

Table 3.13	Overview of the statistical tests employed in the current study		
Statistical test	**3D variables**	**2D variables**	**Psychosocial variables**
One-sample t test	• Landmark x-, y- and z-displacements. • Volumetric changes in subgroup A.		
Wilcoxon one-sample signed-rank test	• Landmark x-, y- and z-displacements.	• Soft-tissue to hard-tissue displacement ratios.	
Paired t test	• 3D imaging system accuracy. • Volumetric calculation accuracy of three algorithms in vivo and in vitro. • Changes in linear and angular measurements.	• Systematic error in linear, angular measurements, x- and y-coordinates of landmarks. • Changes in x- and y-coordinates of landmarks as well as in linear and angular measurements over time (in the main study).	• Changes in self-esteem, anxiety and depression over time.
Wilcoxon matched-pairs signed-rank test	• Changes in linear and angular measurements over time. • Changes in facial asymmetry scores over time.	• Changes in x- and y-coordinates of landmarks over time. • Changes in linear and angular measurements over time. • Changes in soft-tissue thickness over time.	• Changes in FBI score over time • Changes in self-perception of facial profile over time. • Changes in self-esteem, anxiety, depression and satisfaction over time.
Two-sample t test		• Magnitude of z-displacements of landmarks based on patients' perception of facial change	• Sex- and age-comparisons in self-esteem, anxiety and depression
Mann-Whitney U test			• Sex- and age-comparisons in self-esteem, anxiety and depression • Satisfaction comparisons (type of deformity, sex, age)
One-way ANOVA			• EPQ-R and MHLC subscales between subgroups A – C.
Chi-squared test			• Motivational patterns comparisons (type of deformity, sex and age)
Fisher's exact test			• Motivational patterns comparisons (type of deformity, sex and age)

Abbreviations used: FBI= facial body image; MHLC= multidimensional health locus of control; ANOVA= analysis of variance

Chapter Four
Results

4 Results

4.1 Sample characteristics

Over a period of two years, 107 patients were screened. Seventy-eight patients met the inclusion criteria. Twenty-nine patients were excluded from the study for the following reasons:

- Non-Caucasian origin (9 cases: six were of Asian decent and three of African decent)
- Dentofacial deformities caused by traumatic injuries (5 cases)
- Cleft lip and/or palate deformities (6 cases)
- Distraction osteogenesis treatments, intra- or extra-orally (4 cases)
- Craniofacial syndromes (other than cleft lip and palate patients) such as hemifacial microsomia or Treacher-Collins syndrome (5 cases)

Over the course of the study, two subjects moved elsewhere in the United Kingdom and one moved abroad leaving a final group of 75 patients.

This sample comprised 46 skeletal Class III cases, 24 skeletal Class II cases and five skeletal Class I cases with marked facial asymmetry (Figure 4.1). Diagnosis was made following careful clinical examination of each subject with the aid of patients' presurgical case notes and records. In both Class II and Class III subgroups (n=70), facial asymmetry was clinically obvious in 19 subjects (≈27%), of whom 15 cases fell in the Class III subgroup (almost one third) and 4 cases in the Class II subgroup (≈17%).

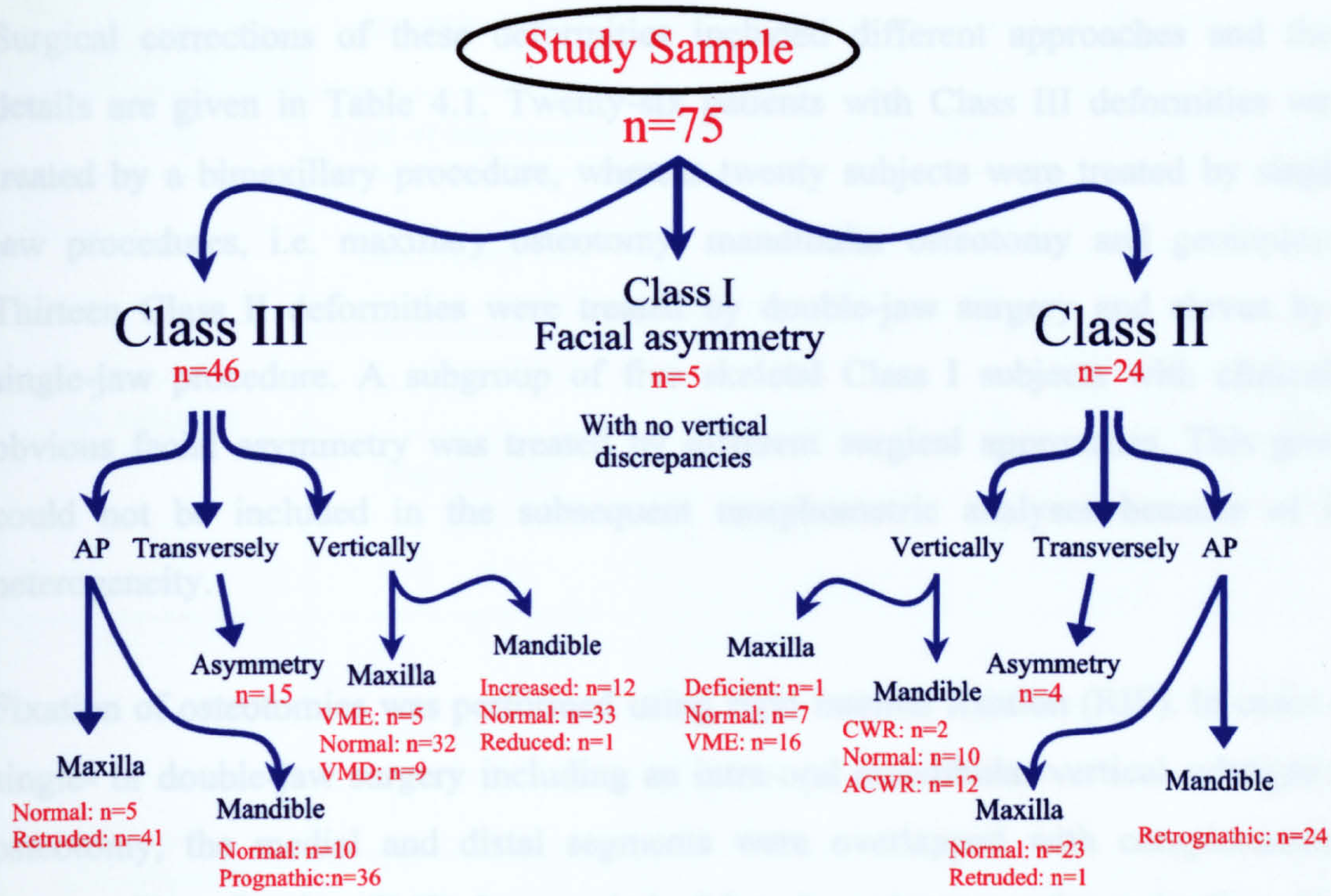


Figure 4.1 Dentofacial diagnosis of the recruited patients based on clinical examination.

The clinical-based diagnosis of patients' facial appearance in the Class III subgroup (n=46) revealed different underlying skeletal characteristics. In the anteroposterior direction, the maxilla was judged to be normal in 5 cases (≈11%), and retruded in 41 cases (≈89%); the mandible was in a normal position in ten cases (≈22%) and prognathic in 36 cases (≈78%). In the vertical direction, vertical maxillary excess (VME) was observed in five cases (≈11%) and the opposite deformity (i.e., vertical maxillary deficiency (VMD)) was observed in nine cases (≈19%), while the remaining 32 subjects appeared vertically normal (≈70%). Increased lower facial height was detected in 12 cases (≈26%), whereas 33 cases did not show any specific vertical deformity (≈72) and one case presented with obvious anterior mandibular rotation and a reduced lower facial height.

In the Class II subgroup (n=24), the clinical examination disclosed that 23 cases exhibited normal position of the maxilla anteroposteriorly and the maxilla was retruded in one case; the mandible was judged retrognathic in all cases. Vertically, the maxilla appeared deficient in one case, in excess in two thirds of the subgroup and normal in the remaining 7 cases (≈29%).

Surgical corrections of these deformities included different approaches and their details are given in Table 4.1. Twenty-six patients with Class III deformities were treated by a bimaxillary procedure, whereas twenty subjects were treated by single-jaw procedures, i.e. maxillary osteotomy, mandibular osteotomy and genioplasty. Thirteen Class II deformities were treated by double-jaw surgery and eleven by a single-jaw procedure. A subgroup of five skeletal Class I subjects with clinically obvious facial asymmetry was treated by different surgical approaches. This group could not be included in the subsequent morphometric analyses because of its heterogeneity.

Fixation of osteotomies was performed using rigid internal fixation (RIF). In cases of single- or double-jaw surgery including an intra-oral mandibular vertical subsigmoid osteotomy, the medial and distal segments were overlapped with complementary intermaxillary fixation (IMF) for a period of 2 to 3 weeks to accelerate healing. This period was extended to four weeks in four subjects. Interocclusal splints (acrylic wafers) were used to facilitate proper surgical positioning of the mobilised segments according to the presurgical plan. Guiding elastics were used in the postsurgical jaw rehabilitation phase for a period of time varying from case to case, with an average duration of 3 weeks.

The number of female subjects was greater than the number of males in the whole study group (75% females) as well as in each subgroup, i.e. 60% in the Class I group (3 out 5 cases), 69% in the Class III group (32 out of 46 cases) and 87% in the Class II group (21 out of the 24 cases). The difference in female-male proportions was not statistically significant between Class II and Class III subgroups (chi squared= 2.76; p=0.097).

For the whole study group, sixty-four percent of the subjects were less than or equal to 25 years of age and 37% were greater than 25 years of age. Eighty percent (4 out of five cases) in the 'facial asymmetry only' group were above 25 years of age. Thirteen out of 24 patients (≈54%) fell in the 'older' category in the Class II group, whereas twelve out of the 46 patients (≈26%) fell in that group in the Class III group. The proportional difference between younger and older patients in the Class II and III groups was not statistically significant (chi-squared=2.79; p=0.095).

Table 4.1	Overview of the surgical interventions performed in the study sample (n=75) as well as in subgroups A, B and C*		
Group	**Type of intervention**	**Main surgical procedure**	**Additional notes**
Class III (46 subjects)	**Bimaxillary (26)**	Max. adv. + Md. Setback **(21)**	Subgroup A
		Max adv. + imp. Md setback **(5)**	
	One-jaw (20)	Max. surgery **(13)**	Max. adv. (7) + Max. adv. + inf. (5) → Subgroup B Max. adv. + imp. (1)
		Md. surgery **(5)**	Setback VSSO (3) Setback BSSO (2)
		Genioplasty only **(2)**	Setback + vert. red.
Class II (24 subjects)	**Bimaxillary (13)**	Max. imp. Md. adv. **(5)**	Subgroup C
		Max. adv. + imp. Md. adv. **(7)**	Subgroup C
		Max. adv. + inf. Md. adv **(1)**	
	One-jaw (11)	Max. surgery **(5)**	Upper anterior setback (2) Impaction (3)
		Md. surgery **(4)**	Adv. BSSO
		Genioplasty only **(2)**	Adv. (1) Adv. + vert. aug. (1)
Class I Facial Asymmetry (5 subjects)	**Bimaxillary (1)**	Max. expansion by midpalatal split + symphyseal ost. **(1)**	
	One-jaw (4)	Genioplasty only **(2)** Md. surgery **(2)**	

(*) Surgical interventions comprising subgroups A, B and C are underlined and highlighted in red, blue and green, respectively. Number of subjects treated by each surgical procedure is mentioned between parentheses.

Abbreviations used:

Max= Maxillary; Md= Mandibular; adv=advancement; imp=impaction; inf=inferior repositioning; vert= vertical; red= reduction; aug= augmentation; ost= osteotomy; VSSO=vertical subsigmoid osteotomy; BSSO= bilateral sagittal split osteotomy.

Pre- and post-surgical orthodontics was undertaken in 65% (49 patients) of the whole sample. The percentage of combined orthodontic-surgical cases increased to 70% (49 patients) for the Class II and Class III cases (n=70). Approximately 80% of Class II cases had pre- and post-surgical orthodontics compared with 65% in Class III subgroup. The orthodontic phase was carried out by either a Consultant Orthodontist or by a postgraduate student working under the direct supervision of a Consultant. Because patients were recruited from three different surgical centres with different sources of orthodontic referral, eight Consultant Orthodontists were responsible for the orthodontic treatment provided to the recruited sample. This resulted in different types of orthodontic fixed appliances and different treatment modalities.

Presurgical orthodontics, however, included in general arch levelling, aligning and coordination as well as dental decompensation. Postsurgery, the orthodontic phase was shorter and limited to detailing and finishing of the occlusion. The duration of post-surgical orthodontics was on average 7.8 months (SD=1.2).

Studying facial soft-tissue behaviour following surgery necessitated the presence of homogenous subgroups with consistent vectors of surgical movements. Therefore, recruited patients were divided into the following main subgroups (Table 4.1):

- **Subgroup A**: Twenty Class III patients treated by maxillary advancement with/without inferior repositioning and mandibular setback. One patient was excluded due to the asbsence of his cephalometric radiograph at six month following surgery.
- **Subgroup B**: Twelve Class III patients treated by maxillary advancement with/without inferior repositioning.
- **Subgroup C**: Twelve Class II patients treated by maxillary impaction with/without slight advancement and mandibular advancement.

In addition, other small-sized subgroups were formed from the database:

- **Subgroup D**: Five Class III patients treated by maxillary advancement and impaction and mandibular setback
- **Subgroup E**: Five Class III patients treated by mandibular setback only
- **Subgroup F**: Four Class II patients treated by mandibular advancement only

Because of the small numbers of patients observed in subgroups D, E and F, it was decided to exclude these from the 3D and 2D morphometric analyses.

4.2 Preliminary, pilot and validation studies

4.2.1 3D imaging system accuracy and reproducibility

Table 4.2 illustrates the ten inter-landmark distances measured on the dummy head using digital callipers (direct measurements) and the corresponding distances obtained from 3D models of the dummy head using the Facial Analysis Tool (indirect measurements).

For horizontal distances, the mean error between the mean direct and mean indirect measurements varied between –0.17 mm to +0.22 mm. For vertical distances, the mean error for the total facial height and the lower facial height was +0.12mm and -0.18 mm, respectively. Anteroposterior measurements showed a mean error of +0.26 mm for the nasal projection measurement and +0.14 for the mandibular length measurement. The standard deviation of the error (or the root mean square error 'RMS error') was 0.13 mm for the ten variables assessed. Paired t tests did not reveal that mean errors were significantly different from zero.

Table 4.2		**Evaluating C3D system accuracy**			
Distances (in mm)		**Mean indirect measurements (SD)***	**Mean direct measurements (SD)†**	**Mean error‡**	**P value**
1	Inter-canthal width (excR-excL)	89.66 (0.22)	89.56 (0.33)	**0.10**	**0.455**
2	Inter-malar width (zygR-zygL)	91.88 (0.07)	91.69 (0.26)	**0.19**	**0.343**
3	Total facial width (trR-trL)	131.00 (0.03)	131.15 (0.22)	**-0.15**	**0.456**
4	Alar base width (acR-acL)	26.60 (0.07)	26.38 (0.11)	**0.22**	**0.194**
5	Mouth width (chR-chL)	45.28 (0.12)	45.45 (0.20)	**-0.17**	**0.394**
6	Intergonial width (goR-goL)	103.22 (0.08)	103.02 (0.34)	**0.20**	**0.392**
7	Total facial height (gla-men)	121.81 (0.10)	121.69 (0.44)	**0.12**	**0.288**
8	Lower facial height (sn-men)	59.23 (0.19)	59.41 (0.12)	**-0.18**	**0.147**
9	Columellar length (sn-prn)	16.58 (0.09)	16.32 (0.33)	**0.26**	**0.138**
10	Mandibular length (trL-pog)	115.46 (0.13)	115.32 (0.31)	**0.14**	**0.541**
Standard deviation of the error				**0.13 mm**	

(*) Values presented are the mean of 10 repeated landmark identifications and automatic inter-landmark-distance calculations and they are stated in mm. Standard deviations are presented between parentheses.

(†) Values presented are the mean of 10 repeated measurements using digital callipers and they are stated in mm. Standard deviations are presented between parentheses.

(‡) The error was calculated as the difference between the direct measurement and the corresponding indirect measurement. Differences are stated in mm. Paired t tests were performed to detect statistically significant differences between the two methods.

For testing system reproducibility, the results are displayed in two sections in Table 4.3. In the first section, the standard deviations (shown in red) illustrate the amount of variability in the calculated distances, which were attributed to the inconsistency in landmark identification. It can be seen that the standard deviations ranged from 0.03 to 0.22 mm for the ten measurements. In the second section, where 10 captures and model constructions of the dummy head were performed, the mean linear measurements were very close to the previously obtained figures (in the first section), but the standard deviations were slightly greater. The range of these standard deviations, however, was between 0.06 and 0.27 mm reflecting high reproducibility of 3D model construction.

Table 4.3	**Evaluating C3D system reproducibility**					
Distances (in mm)	**Inconsistency in landmark identification***			**Reproducibility of system†**		
	Mean value	**SD**	**SEM**	**Mean value**	**SD**	**SEM**
Inter-canthal width (excR-excL)	89.66	0.22	0.10	89.56	0.27	0.15
Inter-malar width (zygR-zygL)	91.88	0.07	0.02	91.85	0.11	0.04
Total facial width (trR-trL)	131.00	0.03	0.01	130.80	0.18	0.08
Alar base width (acR-acL)	26.60	0.07	0.02	26.65	0.06	0.02
Mouth width (chR-chL)	45.28	0.12	0.03	45.41	0.16	0.07
Intergonial width (goR-goL)	103.22	0.08	0.02	103.29	0.16	0.07
Total facial height (gla-men)	121.81	0.10	0.03	121.92	0.21	0.11
Lower facial height (sn-men)	59.23	0.19	0.06	58.98	0.27	0.13
Columellar length (sn-prn)	16.58	0.09	0.02	16.77	0.13	0.05
Mandibular length (trL-pog)	115.46	0.13	0.04	115.51	0.22	0.11

(*) Landmark identification on the 3D model of the dummy head was repeated ten times.

(†) Ten 3D models of the same dummy head were constructed from 10 repeated captures.

4.2.2 Applicability of the psychosocial questionnaires

Table 4.4 illustrates patients' responses in the pilot study regarding the following items: time required to complete the questionnaire, difficulties encountered and their comments on the whole package of questionnaires.

Table 4.4	Patients responses in filling the questionnaire in the pilot study (n=10)		
Subject	**Time required in minutes**	**Difficulties encountered or explanations sought**	**Comments**
1	35	SPFC	Repeated questions in some forms and somewhat long
2	26	SPFC & SPFP	Requires a lot of concentration
3	28	SPFC	-
4	30	-	-
5	28	SPFP	-
6	20	-	Many questions related to facial appearance, although it is not his main concern
7	22	SPFC & EPQ-R Short Scale	Repeated questions in some forms
8	25	EPQ-R Short Scale	-
9	33	MHLC	Somewhat long
10	31	SPFP & SPFC	Drawings need more explanation

Abbreviations used in this table: SPFC= Self perception of the required facial change; SPFP= Self perception of facial profile; MHLC=Multidimensional Health Locus of Control

It was noticed that the shortest time to fill in the questionnaires was 20 minutes and the longest was 35 minutes with an average time of 27.8 minutes. No signs of fatigue were observed among the participants, although three of them commented on the length of the questionnaires. Seven patients required explanations and help in completing the illustration-based questionnaires (SPFC and/or SPFP). EPQ-R had some questions, which two subjects felt that they were hesitant to answer by 'Yes' or 'No'. Subjects' comments included the following points: the presence of repeated questions in some forms (two subjects) the irrelevance of facial appearance questions to one subject who was concerned about functional improvement and the need for more clarification for the illustrations in the SPFS and SPFP forms.

Since the main part of the psychological assessment was focused on perception of facial appearance, more explanation and clarification was introduced at the beginning of the SPFC and SPFP questionnaires for the main study. Also, it was obvious that patients seeking orthognathic surgery mainly for functional reasons would not find the facial-appearance-oriented questions applicable to them and, hence, easy to answer. The presence of repeated questions was deemed normal when multiple questionnaires were administered and facial perceptions as well as personality characteristics were explored from different aspects.

4.2.3 Landmark identification reproducibility on 3D models

Table 4.5 illustrates the amount of error in landmark identification for each landmark in the x-, y-, and z-axes for the thirty landmarks included in the study. Considering a mean absolute error of 0.5 mm as a cut-off limit between reproducible and non-reproducible landmarks, five landmarks were above this limit in the x- (transverse) direction, i.e. left and right 'Gonion', left and right 'Zygion', and 'Menton' while 25 landmarks showed high reproducibility. The most reproducible landmarks were left and right 'Subtragion', 'alar crest' points and 'Subnasale'. In the y- (vertical) direction, irreproducibility was limited to left and right 'Gonion' and 'Zygion' as well as 'Glabella', left and right 'Tragion'. 'Menton', however, showed an acceptable amount of reproducibility (0.4 mm). The number of irreproducible landmarks increased to 8 when the mean absolute differences in the z- (anteroposterior) direction were explored. Again, left and right 'Gonion' were the most irreproducible landmarks followed by left and right 'Tragion', 'Menton' and left and right 'Otobasion inferius'. Most of the midsagittal landmarks were highly reproducible in the anteroposterior direction with a landmark identification error varying from 0.05 mm (for superior labial sulcus landmark) to 0.23 mm (for 'Subnasale').

The overall reproducibility of each landmark is shown in Figure 4.3, where standard deviations (SD) of landmarks' coordinates around their centroids were obtained. Twenty landmarks were found to be highly reproducible (standard deviations were in the order of or less than 0.5 mm). Several points, however, showed poor reproducibility such as: 'Gonion', 'Menton', 'Zygion' and 'Tragion'. Figure 4.4 illustrates these landmarks on a subject's 3D facial model. Highly reproducible landmarks are shown in green, whereas poorly reproducible landmarks are shown in red.

For extracting some facial curves and defining some surface patches for the volumetric assessment (as described before in section 3.2.4), an additional four anthropometric landmarks were required to serve as 'boundary' landmarks and their reproducibility was assessed in the same way as the assessment of the original thirty landmarks. Table 4.6 illustrates the x-, y-, z- differences of these landmarks when digitised three times from 10 randomly chosen 3D facial models. The results proved that these points could be used in the main study. Accordingly, the following landmarks were cancelled from the landmark identification protocol for the main study: goR, goL, zygR, zygL, trR, trL and the following landmarks were added: sbalR, sbalL, cphR and cphL.

Table 4.5		**Mean x-, y-, and z- absolute differences of thirty landmarks identified on ten 3D models at three different occasions**		
Landmarks		Mean absolute x-difference in mm (SD)	Mean absolute y-difference in mm (SD)	Mean absolute z-difference in mm (SD)
1	**acL**	0.16 (0.13)	0.36 (0.27)	0.37 (0.29)
2	**acR**	0.12 (0.08)	0.43 (0.24)	0.41 (0.31)
3	**chL**	0.35 (0.20)	0.22 (0.16)	0.21 (0.16)
4	**chR**	0.36 (0.26)	0.24 (0.14)	0.17 (0.13)
5	**encL**	0.48 (0.49)	0.24 (0.17)	0.14 (0.16)
6	**encR**	0.32 (0.21)	0.24 (0.14)	0.14 (0.15)
7	**excL**	0.28 (0.21)	0.28 (0.26)	0.34 (0.33)
8	**excR**	0.19 (0.16)	0.30 (0.24)	0.33 (0.26)
9	**gla**	0.50 (0.23)	0.70 (0.52)	0.14 (0.11)
10	**goL**	1.18 (1.08)	2.89 (2.89)	2.00 (1.70)
11	**goR**	1.06 (0.49)	2.36 (1.86)	2.97 (1.75)
12	**ils**	0.34 (0.16)	0.46 (0.28)	0.12 (0.14)
13	**li**	0.46 (0.19)	0.29 (0.16)	0.10 (0.07)
14	**ls**	0.27 (0.12)	0.33 (0.42)	0.11 (0.10)
15	**men**	0.70 (0.54)	0.40 (0.27)	1.07 (0.56)
16	**na**	0.35 (0.37)	0.42 (0.26)	0.08 (0.05)
17	**obiL**	0.19 (0.13)	0.48 (0.33)	0.62 (0.31)
18	**obiR**	0.32 (0.34)	0.48 (0.35)	0.88 (0.57)
19	**pog**	0.43 (0.27)	0.40 (0.36)	0.06 (0.03)
20	**prn**	0.31 (0.20)	0.39 (0.38)	0.06 (0.05)
21	**sbtrL**	0.07 (0.06)	0.34 (0.23)	0.49 (0.32)
22	**sbtrR**	0.08 (0.05)	0.29 (0.22)	0.48 (0.28)
23	**sls**	0.27 (0.20)	0.45 (0.28)	0.05 (0.03)
24	**sn**	0.13 (0.10)	0.29 (0.24)	0.23 (0.11)
25	**stmi**	0.34 (0.15)	0.29 (0.13)	0.18 (0.11)
26	**stms**	0.22 (0.16)	0.20 (0.13)	0.42 (0.37)
27	**trL**	0.15 (0.17)	1.12 (0.60)	1.24 (0.65)
28	**trR**	0.32 (0.27)	1.12 (1.09)	1.32 (0.71)
29	**zygL**	0.69 (0.65)	0.63 (0.76)	0.44 (0.36)
30	**zygR**	0.66 (0.65)	0.80 (0.79)	0.58 (0.60)

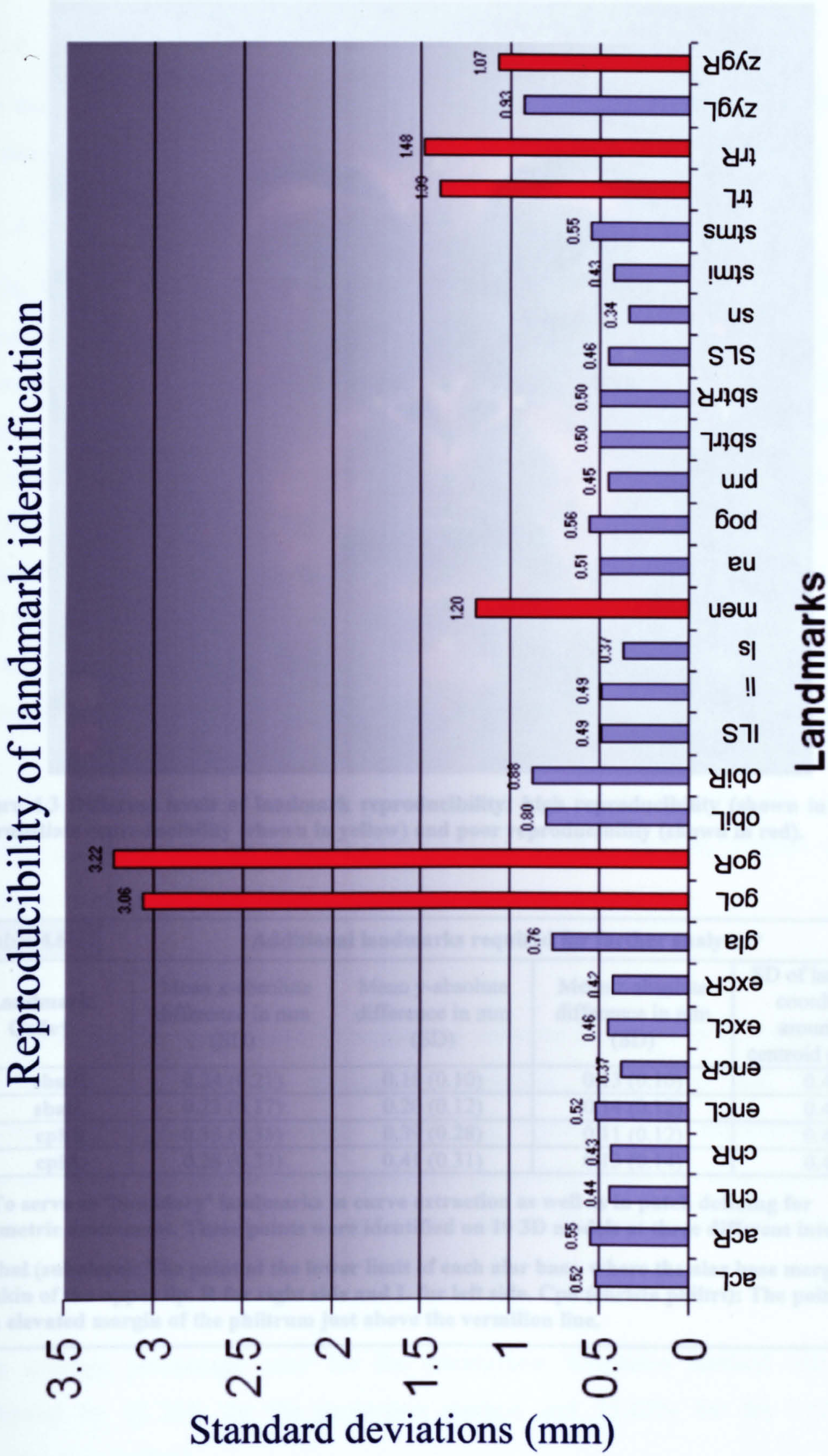


Figure 4.2 Landmark identification reproducibility. Any landmark with a standard deviation greater than 1 mm is highlighted in red. These landmarks were considered inappropriate for use in the 3D displacements analysis.

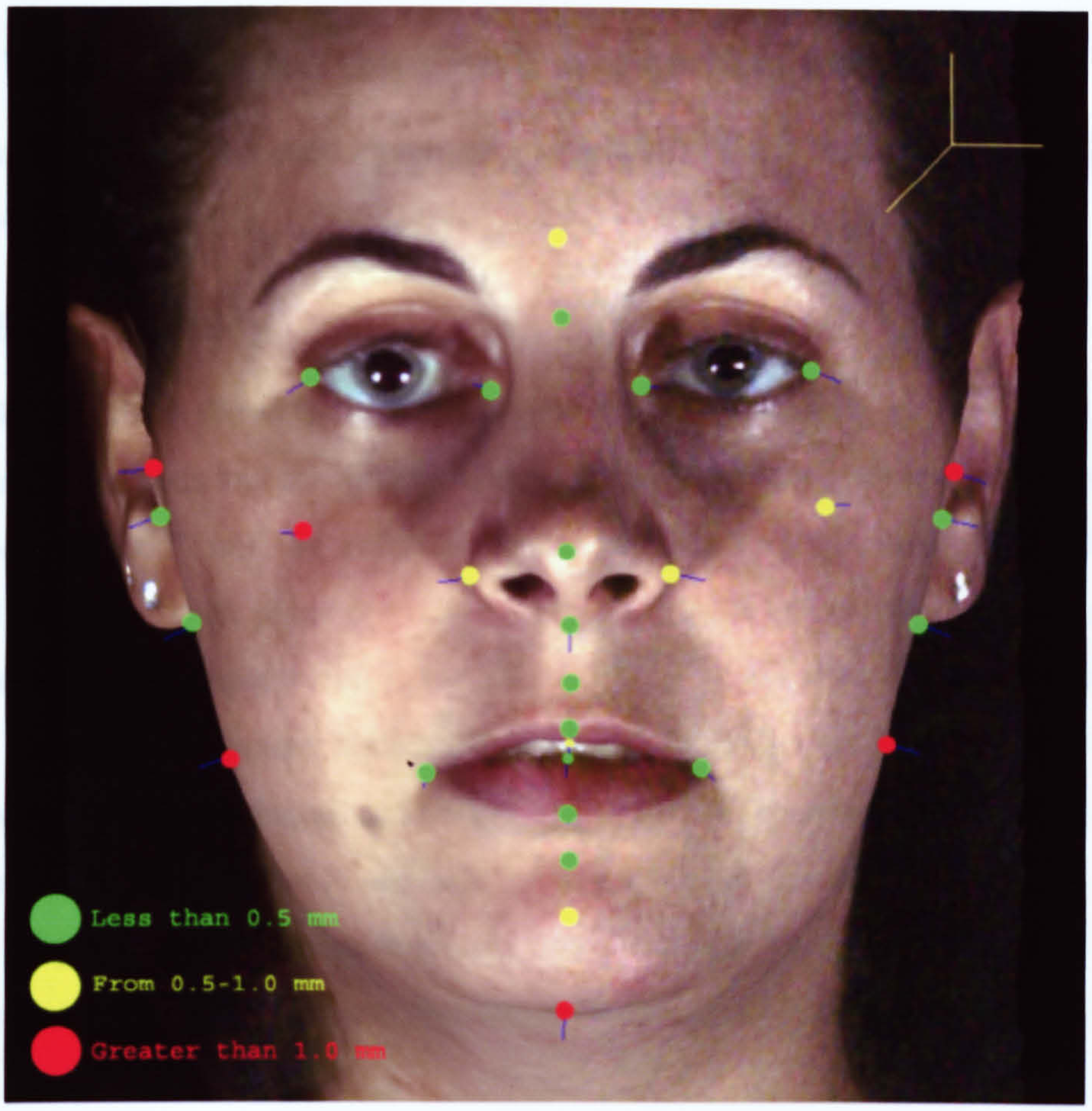


Figure 4.3 Different levels of landmark reproducibility: high reproducibility (shown in green), intermediate reproducibility (shown in yellow) and poor reproducibility (shown in red).

Table 4.6		**Additional landmarks required for further analyses***			
Landmark Code†		Mean x-absolute difference in mm (SD)	Mean y-absolute difference in mm (SD)	Mean z-absolute difference in mm (SD)	SD of landmark coordinate around its centroid (in mm)
1	**sbalR**	0.24 (0.21)	0.18 (0.10)	0.13 (0.10)	0.41
2	**sbalL**	0.23 (0.17)	0.20 (0.12)	0.14 (0.12)	0.42
3	**cphR**	0.33 (0.36)	0.39 (0.28)	0.11 (0.12)	0.48
4	**cphL**	0.28 (0.33)	0.41 (0.31)	0.13 (0.14)	0.49

(*) To serve as 'boundary' landmarks in curve extraction as well as in patch defining for volumetric assessment. These points were identified on 10 3D models at three different intervals.

(†) sbal (subalare): The point at the lower limit of each alar base, where the alar base merges into the skin of the upper lip. R for right side and L for left side. Cph (christa philtri): The point on each elevated margin of the philtrum just above the vermilion line.

4.2.4 Validation of the volumetric assessment on 3D models

The results of the volumetric assessment validation on 3D models are summarised in Tables 4.7 and 4.8.

4.2.4.1 In vitro study

Table 4.7 displays the differences between volumes obtained by the three different algorithmic methods and the actual volumes for the thirty specimens. The 'tetrahedron formation method' will be referred to as the first method, while the 'projection method' and the 'back plane construction method' will be denoted as the second and the third methods, respectively. It was clear that the least mean difference was noticed by the first method (mean difference=0.071 cm^3; 95% CI= -0.074 – 0.2161 cm^3), which was statistically insignificant ($p=0.325$). The mean errors related to the second and third methods were 0.463 cm^3 and 0.442 cm^3 (95% CI= 0.2748 – 0.6512, 0.138 – 0.746), respectively. These were significantly different from zero, which reflected a systematic tendency of these two algorithms to over-estimate specimens' volumes.

The first method showed a mean percentage error of 1.84 % (95% CI: -0.53% - 4.21%) compared to 11.80 % and 8.69 % (95% CI: 5.50% – 18.10%, 2.38% - 15.00%) of the projection and back plane construction methods respectively.

4.2.4.2 In vivo experiment

On a live subject, mean errors in measuring volumes increased to 0.314 cm^3, 1.399 cm^3 and 1.646 cm^3 for the 'tetrahedron formation', 'projection' and 'back-plane construction' methods, respectively (Table 4.8). Again, the error associated with the first algorithm was statistically insignificant ($p=0.114$), while the other two methods showed statistically significant systematic errors by over-estimating specimens' volumes ($p < 0.001$).

The average percentage error for the tetrahedron formation method was 2.82% followed by 13.36% for the projection method and 15.85% for the back plane construction method.

Table 4.7	Differences in volumetric values between each method and the 'gold-standard' method (water displacement method)		
Specimen	3D tetrahedron method in cm^3	3D projection method in cm^3	3D back plane method in cm^3
Nose 1	-0.694	0.077	-0.748
Nose 2	-0.927	-0.653	-0.103
Nose 3	0.120	1.036	0.569
Nose 4	-0.174	0.075	0.594
Nose 5	0.085	0.791	0.424
Nose 6	0.219	0.488	0.704
Nose 7	0.164	0.165	0.297
Nose 8	0.260	0.363	0.838
Nose 9	0.183	0.018	0.141
Nose 10	-0.24	-0.181	-0.428
Lip 1	-0.178	-0.048	-0.831
Lip 2	0.062	0.553	2.173
Lip 3	-0.369	0.361	0.671
Lip 4	0.804	1.512	-0.69
Lip 5	0.817	0.831	1.406
Lip 6	-0.321	-0.133	-0.595
Lip 7	0.018	-0.026	0.401
Lip 8	0.117	0.123	0.092
Lip 9	0.311	1.029	-0.197
Lip 10	0.009	0.035	0.01
Chin 1	-0.139	0.279	0.197
Chin 2	0.480	0.851	1.322
Chin 3	0.168	1.496	1.266
Chin 4	0.299	0.515	0.406
Chin 5	-0.132	0.351	-0.074
Chin 6	0.019	0.512	1.221
Chin 7	0.855	0.938	2.132
Chin 8	0.200	0.925	0.306
Chin 9	-0.074	0.734	1.883
Chin 10	0.186	0.866	-0.124
Mean difference	**0.071**	**0.463**	**0.442**
RMS*	0.274	0.479	0.645
P-value	**0.325**	**<0.001†**	**0.006†**

(*) RMS= root mean square of difference (equivalent to the standard deviation of the error).

(†) Statistically significant difference when paired t test was applied.

Table 4.8	Three methods of calculating specimens' volumes on a live subject		
Descriptive statistics & Hypothesis testing values	3D 'tetrahedron'	3D 'projection'	3D 'back plane'
Mean difference (cm^3)	**0.314**	**1.399**	**1.646**
SD of difference	1.056	1.469	1.264
95 % CI of difference	-0.081 - 0.702	0.853 - 1.947	1.172- 2.113
P value of the difference	0.114	<0.001*	<0.001*
Mean percentage error (%)	**2.82**	**13.36**	**15.85**
SD of percentage error	9.81	13.97	11.73
95 % CI of percentage error	-0.85 - 6.48	8.15 - 18.58	11.47 - 20.23
P value of percentage error	0.127	<0.001*	<0.001*
*** Statistically significant difference from zero (when paired t tests were applied).**			

4.2.5 Error of the method in cephalometric data

4.2.5.1 Measurement error and landmark reproducibility

This analysis considered the three types of data collected, i.e. linear and angular measurements as well as landmark coordinates. Systematic error was assessed by paired t-tests, whereas random error was assessed by the coefficients of reliability (CR) according to Houston[472]. The error of the method of Dahlberg (DEM) was also used to examine the overall error of each variable[473].

Linear measurements (Table 4.9). No systemic errors were observed for most of the variables assessed with the exception of posterior facial height (PFH; p=0.017), maxillary length measured from Condylion to ANS (MxL2; p=0.008), maxillary length measured from PNS to ANS (MxL3; p=0.001) and facial axis length (FAL; p=0.031). All coefficients of reliability were above 90% indicating a random error within the acceptable standards. The error measured according to Dahlberg ranged from 0.27 to 0.87, which was also within the acceptable limits.

Angular measurements (Table 4.10). Systematic errors were detected in the nasal tip angle (p=0.012), nasolabial angle (p=0.042), maxillary-cranial base angle (p=0.003) and maxillary-mandibular planes angle (p=0.004). Other measurements, however, showed a mean difference very close to zero. Coefficients of reliability were above

95% for all the measurements indicating low random error, whereas the standard deviation of the error (DEM) ranged from 0.15 to 1.37.

X-coordinates of landmarks (Table 4.11). Systematic errors were detected in Orbitale (p=0.012), Gonion (p=0.02), Condylion (p=0.049) and PNS (0.002) but the corresponding CRs were still above the 90% cut-off limit. On the other hand, the standard deviation of the error (DEM) was below 1 mm for all landmarks with the exception of Orbitale (1.21) and Prosthion (1.08).

Y-coordinates of landmarks (Table 4.12). Six of the 32 landmarks showed a systematic error. These were Glabella (gla; p=0.012), soft-tissue Nasion (na; p=0.013), Stomion superius (stms, p=0.034), Stomion inferius (stmi; p=0.018), inferior labial sulcus (ils, p=0.033) and soft-tissue Menton (men; p=0.003). Their reliability, however, was acceptable since the coefficients of reliability exceeded 90%. Orbitale, however, showed a coefficient of reliability under this limit (89.1%). The standard deviation of error ranged from 0.29 to 0.66 indicating good reproducibility between 'double determinations', except for Glabella (gla; DEM=1.45).

Table 4.9	Error of the method: soft- and hard-tissue linear measurements (n=30)					
Distance*	Mean	SD	95% CI	P value†	CR ‡	DEM §
TAFH	-0.12	0.58	(-0.336, 0.094)	0.260	0.986	0.41
UAFH	-0.09	0.44	(-0.255, 0.072)	0.261	0.991	0.31
LAFH	0.00	0.54	(-0.200, 0.203)	0.990	0.977	0.38
PFH	-0.21	0.46	(-0.384, -0.041)	<u>0.017</u>	0.982	0.35
MdL	-0.15	0.64	(-0.393, 0.087)	0.202	0.971	0.46
MdRmH	0.12	0.66	(-0.126, 0.369)	0.325	0.974	0.47
MdBL	0.09	0.44	(-0.071, 0.256)	0.260	0.981	0.31
MxL1	-0.06	0.47	(-0.238, 0.116)	0.487	0.983	0.33
MxL2	0.37	0.70	(0.104, 0.630)	<u>0.008</u>	0.982	0.55
MxL3	0.46	0.58	(0.243, 0.673)	<u>0.001</u>	0.983	0.51
FAL	-0.18	0.44	(-0.348, -0.018)	<u>0.031</u>	0.991	0.33
PCB	-0.06	0.59	(-0.282, 0.156)	0.563	0.983	0.41
OJ	0.00	0.42	(-0.154, 0.156)	0.987	0.984	0.29
OB	-0.06	0.41	(-0.213, 0.094)	0.434	0.992	0.29
Incisor Display	0.03	0.57	(-0.181, 0.241)	0.773	0.985	0.39
ULH (s)	-0.09	0.44	(-0.256, 0.071)	0.259	0.974	0.41
UVH (s)	0.09	0.37	(-0.045, 0.231)	0.180	0.965	0.27
LLH (s)	0.06	0.63	(-0.175, 0.297)	0.602	0.967	0.44
LVH (s)	0.12	0.71	(-0.145, 0.386)	0.361	0.973	0.50
UFH (s)	0.27	1.08	(-0.128, 0.672)	0.174	0.975	0.87
LFH (s)	-0.28	0.55	(-0.480, -0.072)	<u>0.010</u>	0.986	0.53
ILD (s)	0.15	0.49	(-0.028, 0.334)	0.096	0.959	0.35
TVH (s)	-0.03	0.56	(-0.240, 0.178)	0.765	0.987	0.39
Nose height (s)	0.00	0.90	(-0.335, 0.336)	0.998	0.989	0.63
Columella length (s)	-0.12	0.40	(-0.269, 0.028)	0.108	0.989	0.29

(*) Abbreviations of some of these measurements have been explained in Tables 3.8 and 3.9. Soft-tissue measurements are denoted by the letter 's' between parentheses.

(†) Testing significant differences from zero using paired t-tests. P values below the level of significance (0.05) are underlined.

(‡) CR= coefficient of reliability calculated according to Houston[472].

(§) DEM= error of the method according to Dahlberg[473].

Table 4.10	Error of the method: soft- and hard-tissue angular measurements (n=30)					
Angle*	Mean	SD	95% CI	P value†	CR ‡	DEM §
SNA	-0.03	0.31	(-0.143, 0.090)	0.644	0.995	0.22
SNB	0.00	0.22	(-0.082, 0.082)	1.000	0.993	0.15
ANB	-0.03	0.26	(-0.130, 0.063)	0.489	0.994	0.18
SNPog	0.00	0.23	(-0.087, 0.081)	0.936	0.991	0.16
MxSN	-0.18	0.31	(-0.304, -0.066)	0.003	0.989	0.25
MdSN	0.09	0.28	(-0.016, 0.189)	0.097	0.979	0.20
MxMd	0.27	0.48	(0.095, 0.452)	0.004	0.966	0.38
MPIA	0.11	0.94	(-0.243, 0.463)	0.528	0.992	0.66
UI-SN	0.23	1.22	(-0.224, 0.684)	0.309	0.982	0.86
Inter-incisor angle	-0.19	1.62	(-0.793, 0.420)	0.534	0.956	1.14
Nose tip angle	0.53	1.09	(0.124, 0.936)	0.012	0.974	0.84
Nasolabial angle	0.51	1.32	(0.019, 1.001)	0.042	0.964	0.98
Labiomental	0.19	1.96	(-0.545, 0.919)	0.606	0.964	1.37
Chin angle	0.13	1.40	(-0.394, 0.654)	0.616	0.974	0.98
Facial profile angle	0.14	0.84	(-0.173, 0.453)	0.367	0.959	0.59

(*) Abbreviations of some of these measurements have been explained in Tables 3.8 and 3.9

(†) Testing significant differences from zero using paired t-tests. P values below the level of significance (0.05) are underlined.

(‡) CR= coefficient of reliability calculated according to Houston[472].

(§) DEM= error of the method according to Dahlberg[473].

Table 4.11	Error of the method: soft- and hard-tissue landmark x coordinates (n=30)					
Landmark*	Mean	SD	95% CI	P value†	CR‡	DEM §
gla	0.03	0.56	(-0.180, 0.240)	0.771	0.982	0.59
na	-0.06	0.78	(-0.2385, 0.1167)	0.589	0.983	0.46
prn	-0.09	0.50	(-0.2783, 0.0947)	0.322	0.991	0.35
sn	0.06	0.47	(-0.1162, 0.2374)	0.489	0.992	0.33
sls	0.09	0.44	(-0.0741, 0.2547)	0.271	0.993	0.31
ls	0.06	0.58	(-0.158, 0.277)	0.580	0.992	0.41
stms	-0.03	0.85	(-0.349, 0.287)	0.843	0.972	0.59
stmi	-0.03	0.82	(-0.334, 0.275)	0.845	0.962	0.57
li	-0.12	0.63	(-0.356, 0.110)	0.290	0.992	0.44
ils	0.03	0.66	(-0.216, 0.273)	0.813	0.993	0.46
pog	-0.03	0.66	(-0.277, 0.213)	0.792	0.989	0.46
gn	0.00	1.02	(-0.381, 0.378)	0.994	0.982	0.71
men	0.27	0.98	(-0.091, 0.637)	0.136	0.971	0.71
Or	0.44	1.43	(0.167, 0.591)	<u>0.012</u>	0.911	1.21
ANS	-0.09	0.50	(-0.2823, 0.0938)	0.314	0.995	0.36
A	0.03	0.45	(-0.1361, 0.1967)	0.712	0.994	0.31
Pr	0.09	0.55	(-0.115, 0.297)	0.375	0.931	1.08
IS	0.00	0.64	(-0.239, 0.236)	0.988	0.992	0.44
II	0.15	0.68	(-0.106, 0.405)	0.241	0.991	0.49
Id	-0.12	0.58	(-0.338, 0.091)	0.250	0.992	0.41
B	0.03	0.66	(-0.215, 0.274)	0.808	0.994	0.46
Pog	0.00	0.68	(-0.257, 0.250)	0.978	0.991	0.47
Gn	-0.13	0.83	(-0.436, 0.185)	0.416	0.982	0.59
Men	-0.03	0.82	(-0.339, 0.271)	0.821	0.972	0.57
Ge	0.03	0.61	(-0.199, 0.257)	0.798	0.962	0.42
Go	0.24	0.54	(0.0418, 0.4417)	<u>0.020</u>	0.963	0.41
Ar	0.12	0.40	(-0.0260, 0.2699)	0.103	0.983	0.29
Cd	0.24	0.68	(0.010, 0.496)	<u>0.049</u>	0.968	0.50
Po	0.23	0.61	(-0.197, 0.259)	0.784	0.923	0.98
PNS	0.30	0.50	(0.1180, 0.4903)	<u>0.002</u>	0.983	0.41
UIA	0.00	0.34	(-0.1272, 0.1261)	0.993	0.984	0.24
LIA	0.09	0.61	(-0.135, 0.317)	0.417	0.973	0.43

(*) Full names of landmarks have been given in Table 3.7.

(†) Testing significant differences from zero using paired t-tests. P values below the level of significance (0.05) are underlined.

(‡) CR= coefficient of reliability calculated according to Houston[472].

(§) DEM= error of the method according to Dahlberg[473].

Table 4.12	Error of the method: soft- and hard-tissue landmark y coordinates (n=30)					
Landmark	Mean	SD	95% CI	P value†	CR‡	DEM §
gla	0.92	1.86	(0.221, 1.610)	<u>0.012</u>	0.911	1.45
na	0.40	0.82	(0.090, 0.703)	<u>0.013</u>	0.965	0.64
prn	0.09	0.60	(-0.133, 0.319)	0.405	0.984	0.43
sn	0.03	0.45	(-0.1392, 0.1961)	0.731	0.991	0.31
sls	0.09	0.56	(-0.116, 0.299)	0.374	0.971	0.39
ls	0.03	0.56	(-0.179, 0.239)	0.773	0.969	0.39
stms	0.21	0.52	(0.0175, 0.4062)	<u>0.034</u>	0.991	0.39
stmi	0.24	0.53	(0.0446, 0.4410)	<u>0.018</u>	0.987	0.41
li	0.12	0.47	(-0.0502, 0.2974)	0.157	0.981	0.34
ils	0.18	0.55	(0.0153, 0.3461)	<u>0.033</u>	0.973	0.53
pog	0.24	0.90	(-0.094, 0.575)	0.153	0.978	0.65
gn	0.09	0.44	(-0.0732, 0.2560)	0.265	0.981	0.31
men	0.33	0.56	(0.123, 0.543)	<u>0.003</u>	0.991	0.46
Or	-0.03	0.56	(-0.239, 0.179)	0.774	0.891	0.39
ANS	0.15	0.42	(-0.0046, 0.3107)	0.057	0.989	0.31
A	0.12	0.40	(-0.0273, 0.2686)	0.106	0.991	0.29
Pr	0.24	0.86	(-0.081, 0.564)	0.136	0.983	0.62
Is	0.12	0.52	(-0.0762, 0.3154)	0.222	0.991	0.37
Ii	0.00	0.48	(-0.1801, 0.1780)	0.990	0.992	0.33
Id	0.03	0.56	(-0.182, 0.238)	0.785	0.979	0.39
B	-0.04	1.05	(-0.429, 0.358)	0.854	0.978	0.73
Pog	0.00	0.64	(-0.240, 0.236)	0.989	0.981	0.44
Gn	0.03	0.45	(-0.1409, 0.1982)	0.732	0.979	0.32
Men	0.03	0.51	(-0.1607, 0.2185)	0.758	0.991	0.35
Ge	0.12	0.40	(-0.0261, 0.2693)	0.103	0.982	0.29
Go	0.02	0.34	(-0.1261, 0.1381)	0.897	0.912	0.63
Ar	-0.09	0.60	(-0.317, 0.133)	0.409	0.989	0.42
Cd	0.03	0.74	(-0.244, 0.307)	0.817	0.972	0.51
Po	-0.03	0.66	(-0.277, 0.213)	0.788	0.934	0.66
PNS	-0.03	0.38	(-0.1705, 0.1102)	0.664	0.982	0.46
UIA	0.06	0.41	(-0.0932, 0.2132)	0.429	0.986	0.29
LIA	0.09	0.50	(-0.0945, 0.2793)	0.320	0.989	0.35

(*) Full names of landmarks have been given in Table 3.7.

(†) Testing significant differences from zero using paired t-tests. P values below the level of significance (0.05) are underlined.

(‡) CR= coefficient of reliability calculated according to Houston[(472)].

(§) DEM= error of the method according to Dahlberg[(473)].

4.2.5.2 Reproducibility of mandibular closure simulation method

The reproducibility of mandibular closure simulation was assessed by looking at the x and y coordinates of the affected landmarks. In the x-axis (Table 4.13), a systematic error was observed in Stomion superius (stms; p=0.046). The random error in identifying the selected six soft-tissue and eleven hard-tissue landmarks was slightly higher than the random error in identifying the same landmarks without simulating mandibular closure (see Table 4.11). Coefficients of reliability, however, were all within the acceptable range (>90%). The DEM values were, in general, higher than the corresponding values in Table 4.11, but still below 1 mm of error ranging from 0.42 to 0.90.

In the y-axis (Table 4.14), systematic differences were seen in the inferior labial sulcus (ils), incision inferius (II), bony Pogonion (Pog) and Mention (Men) (p<0.05). Random error in identifying lower facial landmarks (based on coefficients of reliability) increased in the vertical dimension when comparing landmarks from the first set (i.e. without mandibular closure simulation; Table 4.12) with landmarks in the second set (with mandibular closure simulation). No landmark, however, showed a CR or a DEM value outwith the acceptable limits.

Table 4.13	Reproducibility of mandibular closure method Differences in soft- and hard-tissue landmark x coordinates (n=30)					
Landmark*	Mean	SD	95.0% CI	P value†	CR‡	DEM§
stmi	-0.34	0.89	(-0.668, -0.007)	0.046	0.902	0.66
li	-0.09	0.73	(-0.363, 0.183)	0.504	0.956	0.51
ils	-0.16	0.59	(-0.376, 0.066)	0.162	0.962	0.42
pog	-0.09	0.81	(-0.395, 0.207)	0.528	0.951	0.56
gn	0.03	1.09	(-0.376, 0.435)	0.882	0.952	0.75
men	-0.32	0.89	(-0.653, 0.023)	0.066	0.964	0.64
Il	0.12	0.63	(-0.113, 0.355)	0.298	0.956	0.54
Id	0.09	0.74	(-0.187, 0.362)	0.521	0.957	0.61
B	0.03	0.61	(-0.201, 0.258)	0.800	0.976	0.52
Pog	-0.06	0.59	(-0.281, 0.157)	0.565	0.976	0.50
Gn	-0.12	0.82	(-0.432, 0.183)	0.414	0.974	0.67
Men	0.34	0.94	(-0.017, 0.688)	0.061	0.975	0.79
Ge	0.09	0.77	(-0.198, 0.375)	0.533	0.968	0.63
Go	-0.37	1.09	(-0.777, 0.040)	0.075	0.976	0.90
Ar	-0.28	0.60	(-0.500, 0.438)	0.237	0.986	0.55
Cd	-0.42	0.98	(-1.121, 0.920)	0.544	0.955	0.90
LIA	0.06	0.71	(-0.206, 0.327)	0.646	0.966	0.59

(*) Full names of landmarks have been given in Table 3.7.

(†) Testing significant differences from zero using paired t-tests. A P-value below the level of significance (0.05) is underlined.

(‡) CR= coefficient of reliability calculated according to Houston[472].

(§) DEM= error of the method according to Dahlberg[473].

Table 4.14	Reproducibility of mandibular closure method Differences in soft- and hard-tissue landmark y coordinates (n=30)					
Landmark*	Mean	SD	95.0% CI	P value†	C.R‡	DEM§
stmi	0.21	0.58	(-0.003, 0.427)	0.053	0.961	0.43
li	-0.16	0.69	(-0.412, 0.100)	0.223	0.975	0.49
ils	-0.40	0.99	(-0.769, -0.032)	<u>0.034</u>	0.970	0.74
pog	-0.07	1.22	(-0.522, 0.391)	0.771	0.958	0.85
gn	0.00	0.59	(-0.218, 0.218)	0.999	0.947	0.41
men	-0.19	0.71	(-0.460, 0.082)	0.165	0.965	0.50
II	-0.46	0.67	(-0.710, -0.209)	<u>0.001</u>	0.968	0.57
Id	-0.12	0.71	(-0.388, 0.142)	0.350	0.967	0.50
B	-0.16	0.88	(-0.482, 0.171)	0.339	0.975	0.62
Pog	-0.43	0.71	(-0.695, -0.163)	<u>0.003</u>	0.969	0.58
Gn	-0.09	0.56	(-0.298, 0.119)	0.385	0.972	0.39
Men	-0.18	0.44	(-0.3462, -0.0174)	<u>0.031</u>	0.972	0.33
Ge	-0.10	0.65	(-0.338, 0.148)	0.430	0.986	0.46
Go	-0.25	0.93	(-0.593, 0.099)	0.155	0.980	0.67
Ar	0.09	0.89	(-0.239, 0.423)	0.573	0.972	0.62
Cd	-0.42	0.82	(-0.723, 0.110)	0.092	0.962	0.68
LIA	-0.03	0.66	(-0.278, 0.216)	0.801	0.961	0.46

(*) Full names of landmarks have been given in Table 3.7.

(†) Testing significant differences from zero using paired t-tests. P values below the level of significance (0.05) are underlined.

(‡) Cr= coefficient of reliability calculated according to Houston[472].

(§) DEM= error of the method according to Dahlberg[473].

4.2.6 3D versus 2D facial soft-tissue measurements

The results of the analysis of compatibility between 2D and 3D soft-tissue measurements are illustrated in Table 4.15. Applying paired t tests, there were three significant differences related to three angular measurements. The nasal tip angle was slightly greater in the 3D-based measurement compared with the cephalometric measurement (p=0.034). The facial profile angle (na-prn-pog) was also slightly greater in the 3D data (p=0.021). The greatest significant difference was observed with the nasolabial angle (p=0.008). Linear measurements were, generally, similar in both techniques.

Table 4.15	2D versus 3D assessment of facial soft tissues using seven linear and angular measurements (n=30)					
Variable	2D method	SD	3D method	SD	Difference	P values*
Tip of the nose angle	96.79	5.05	98.45	4.48	2.26	0.034
Nasolabial angle	127.02	8.89	130.26	7.12	3.24	0.008
Labiomental angle	137.12	11.55	138.87	10.69	1.75	0.320
Facial profile angle	128.57	5.85	130.26	5.84	1.69	0.021
Lower facial height	66.89	5.20	67.59	5.65	0.70	0.212
Nose height	49.90	4.36	50.54	3.71	0.64	0.248
Total upper lip height	19.65	2.74	20.42	2.05	0.76	0.062
(*) Paired t test were used to detect significant differences between the two techniques.						

4.3 3D and 2D morphometric analyses

4.3.1 Subgroup A: Class III patients treated by bimaxillary surgery

4.3.1.1 Stereophotogrammetry-based linear measurements

4.3.1.1.1 Surgical change (T1-T2; Table 4.16)

The main facial changes observed were: Increase in alar base width ($p<0.01$), increase in upper lip height ($p<0.05$), increase in upper vermilion height ($p<0.05$), decrease in mouth width ($p<0.05$) increase in lower facial height ($p<0.05$) and decrease in the mandibular length on both sides ($p<0.01$).

4.3.1.1.2 Postsurgical relapse (T2-T3 and T3-T4)

Little and insignificant changes occurred between one month and three months postsurgery (T2-T3) as well as between three months and six months postsurgery (T3-T4) with the exception of the lower vermilion height which showed a significant mean decrease of approximately 1mm between T2-T3 and T2-T4.

4.3.1.1.3 The overall change (T1-T4)

The overall facial changes were: Significant increase in the alar base width ($p<0.01$), significant increase in the upper lip height ($p<0.01$), significant increase in the upper vermilion height ($p<0.01$), significant decrease in the lower lip height ($p<0.05$), significant decrease in the mouth width ($p<0.01$) and significant reduction in lower facial depth (or mandibular length; $p<0.01$). These changes were similar to the changes observed at one month following surgery except for the lower lip height and the lower facial height. The lower lip height decreased gradually in the postsurgical period with an overall mean difference of about 1.5 mm, which was statistically significant at T4 (p=0.011). The increase in lower facial height seen at T2 relapsed in the postsurgical period with an insignificant change in the overall assessment.

Table 4.16		**Linear measurements in subgroup A (n=20)†**								
	Distance (in mm)	**Mean at T1** (SD)	T1-T4	T1-T2	**Mean at T2** (SD)	T2-T3	**Mean at T3** (SD)	T3-T4	**Mean at T4** (SD)	T2-T4
1	Alar base width	**32.60** (1.902)	**	**	**36.43** (2.175)	ns	**35.47** (1.93)	ns	**35.33** (1.92)	ns
2	Nasal projection	**17.63** (1.633)	ns	ns	**16.88** (2.142)	ns	**17.50** (1.313)	ns	**17.42** (1.576)	ns
3	Nasal bridge length	**43.84** (3.808)	ns	ns	**43.67** (4.060)	ns	**43.42** (3.67)	ns	**43.79** (4.226)	ns
4	Upper lip height	**18.62** (2.462)	**	*	**20.23** (2.886)	ns	**19.93** (2.493)	ns	**20.27** (2.969)	ns
5	Upper vermilion height	**4.90** (1.763)	**	*	**6.12** (1.587)	ns	**5.918** (1.539)	ns	**6.35** (1.663)	ns
6	Lower lip height	**18.47** (2.637)	*	ns	**17.29** (3.252)	ns	**17.13** (2.639)	ns	**16.99** (2.351)	ns
7	Lower vermilion height	**7.68** (1.851)	ns	ns	**8.40** (1.857)	*	**7.48** (1.716)	ns	**7.44** (1.661)	**
8	Mouth width	**47.96** (3.202)	**	*	**46.58** (3.69)	ns	**46.32** (2.371)	ns	**46.00** (2.341)	ns
9	Upper facial height	**49.48** (3.072)	ns	ns	**50.14** (3.680)	ns	**49.50** (2.677)	ns	**49.80** (3.228)	ns
10	Lower facial height	**65.12** 6.32	ns	*	**67.39** (5.850)	ns	**66.3** (5.82)	ns	**66.38** (5.91)	ns
11	Total facial height	**113.53** (8.030)	ns	ns	**114.52** (8.07)	ns	**113.14** (7.10)	ns	**113.61** (7.20)	ns
12	Mandibular length right	**130.05** (7.510)	**	**	**127.75** (8.170)	ns	**126.11** (7.66)	ns	**126.03** (7.13)	ns
13	Mandibular length left	**131.15** (5.63)	**	**	**126.92** (6.400)	ns	**126.55** (5.85)	ns	**126.85** (6.03)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols used: * statistically significant difference at p<0.05, ** p<0.01; ns= non-significant. Student's paired t tests are indicated in black; while Wilcoxon signed-rank tests are indicated in blue.

4.3.1.2 Stereophotogrammetry-based angular measurements

4.3.1.2.1 Surgical changes (T1-T2; Table 4.17)

Surgery in this subgroup of patients resulted in significantly less obtuse facial convexity angle and facial profile angle (p<0.01). Significant increases were also observed in the nasolabial angle and the nasal tip angle (p<0.01). The labiomental angle became less obtuse (p<0.01), although this measurement showed a high variability between subjects (SD> 9° for all assessment times).

4.3.1.2.2 Postsurgical relapse (T2-T3 and T3-T4)

The general direction of change between T2 and T3 was opposite to the direction of surgical change (between T1-T2), but the differences were not significant. Between three months and six months postoperatively (T3-T4), angular changes were small and statistically insignificant ($p>0.05$), with the exception of the facial profile angle ($p<0.05$). The overall relapse measured between T2 (one month) and T4 (six months postsurgery) was significant for three angles, i.e. facial convexity angle ($p<0.01$), nasolabial angle ($p<0.05$) and nasal tip angle ($p<0.05$).

4.3.1.2.3 Overall changes (T1-T4)

The observed postsurgical relapse did not affect the significant overall facial angular changes calculated between T1 and T4, which were similar to the initial surgical changes, but of a lesser magnitude.

Table 4.17 **Angular measurements in subgroup A (n=20)†**

	Angle	Mean at T1 (SD)	T1-T4	T1-T2	Mean at T2 (SD)	T2-T3	Mean at T3 (SD)	T3-T4	Mean at T4 (SD)	T2-T4
1	Facial convexity angle	**171.7** (4.45)	**	**	**159.85** (6.36)	ns	**161.57** (4.79)	ns	**162.32** (5.17)	**
2	Facial profile angle	**139.56** (4.86)	**	**	**131.97** (5.15)	ns	**131.27** (4.36)	*	**131.98** (4.53)	ns
3	Nasolabial angle	**124.72** (11.56)	*	**	**132.77** (6.95)	ns	**129.33** (8.89)	ns	**128.59** (8.86)	*
4	Nasal tip angle	**98.15** (6.07)	*	**	**102.43** (5.77)	ns	**100.08** (5.95)	ns	**99.84** (6.25)	*
5	Labiomental angle	**147.58** (10.49)	**	**	**137.69** (11.82)	ns	**140.26** (9.67)	ns	**138.77** (11.12)	ns
6	Chin angle	**138.77** (4.80)	ns	ns	**140.42** (7.02)	ns	**138.26** (5.24)	ns	**137.51** (6.84)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols used: * statistically significant difference at $p<0.05$, ** $p<0.01$; ns= non-significant. Student's paired t tests are indicated in black; while Wilcoxon signed rank tests are indicated in blue.

4.3.1.3 3D displacements of soft-tissue landmarks

The statistical software was programmed to calculate the x-, y- and z- displacements of landmarks after finding the best fit between each couple of 3D landmarks' configurations. In this analysis, thirteen landmarks were used with 9 landmarks in the midsagittal plane and 4 located laterally.

4.3.1.3.1 Z-displacements of landmarks (Table 4.18)

Surgical change (T1-T2). Pronasale (prn), alar crest (acL and acR), Subnasale (sn) and superior labial sulcus (sls) moved forward significantly ($p<0.01$) and there was an insignificant forward movement in Labrale superius (ls) ($p>0.05$). The points that retruded significantly were Cheilion right (chR; $p<0.001$), Cheilion left (chL; $p<0.001$), Stomion inferius (stmi; $p<0.001$), Labrale inferius (li; $p<0.001$), inferior labial sulcus (ils; $p<0.001$) and Pogonion (pog; $p<0.001$).

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, relapse was significant for three points and insignificant for another three points. Right and left alar landmarks and 'sls' relapsed significantly ($p<0.05$), while the nasal tip (prn), the subnasal point (sn) and Labrale superius showed insignificant relapse. Relapse was also seen in 'stmi', 'li' and 'ils', but this did not reach significance. The only significant change detected in the lower lip and chin areas was the forward movement of Pogonion point of about 0.75 mm ($p<0.05$). Between T3 and T4, negligible amounts of movement occurred apart from 'stmi' and 'pog', which showed a forward movement of about 0.6 and .05 mm, respectively.

Overall change (T1-T4). The overall soft-tissue changes between T1 and T4 were identical to the initial surgical changes (between T1 and T2) in terms of direction and statistical significance, but they were all less in magnitude. The overall mean movements for 'prn', 'sls', 'ils' and 'pog' were + 0.58 mm, + 1.16 mm, -6.80 mm and –6.85 mm, respectively.

Table 4.18	Z-displacements of 13 soft-tissue landmarks in subgroup A (n=20)											
L*	T1-T2†	SD	P value‡	T2-T3	SD	P value	T3-T4	SD	P value	T1-T4	SD	P value
prn	**0.57**	0.52	0.007	**0.00**	0.60	0.691	**0.01**	0.58	0.651	**0.58**	0.55	<0.001
acR	**2.59**	0.87	<0.001	**-0.55**	0.90	0.036	**0.30**	0.82	0.128	**2.34**	0.77	<0.001
acL	**2.96**	1.32	<0.001	**-0.83**	1.08	0.049	**-0.17**	0.92	0.441	**1.96**	1.34	<0.001
sn	**1.48**	1.13	0.002	**-0.40**	0.95	0.369	**0.07**	1.30	0.809	**1.15**	1.17	<0.001
sls	**1.76**	1.23	0.001	**-0.54**	0.61	0.015	**-0.06**	0.68	0.694	**1.16**	1.03	<0.001
ls	**0.81**	1.85	0.178	**-0.16**	0.84	0.397	**0.02**	0.81	0.930	**0.66**	1.54	0.077
chR	**-3.32**	1.96	<0.001	**0.00**	1.22	0.879	**0.22**	1.11	0.404	**-3.11**	1.40	<0.001
chL	**-2.92**	1.34	<0.001	**-0.37**	1.16	0.169	**0.03**	1.26	0.910	**-3.26**	1.53	<0.001
stms	**0.82**	1.77	0.125	**-0.31**	1.23	0.728	**-0.21**	1.39	0.523	**0.30**	1.50	0.235
stmi	**-5.86**	2.48	<0.001	**0.30**	2.80	0.399	**0.65**	2.16	0.210	**-4.91**	2.57	<0.001
li	**-6.36**	2.01	<0.001	**0.22**	1.47	0.301	**0.03**	1.29	0.924	**-6.11**	2.12	<0.001
ils	**-7.55**	2.44	<0.001	**0.49**	1.27	0.127	**0.26**	1.27	0.377	**-6.80**	2.61	<0.001
pog	**-8.11**	2.56	<0.001	**0.75**	1.32	0.025	**0.52**	1.51	0.154	**-6.85**	2.82	<0.001

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate forward movements and negative values indicate backward movements.

(‡) One-sample t tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.3.2 Y-displacements of landmarks (Table 4.19)

Surgical change (T1-T2). In the vertical dimension, facial changes were generally of a lesser magnitude than those observed anteroposteriorly. Mean upward movement of 'prn' was 0.65 mm ($p<0.05$). There was a mean downward movement of the alar base points of about 0.75 mm. Also significant inferior repositioning was observed for 'sls', 'ls' and mouth corner points. The most inferior movement was seen in 'li' point (mean= -2.68 mm, $p<0.01$). An upward movement was observed in 'ils' and 'pog'.

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, the most obvious change was a mean upward movement of 2 mm for Labrale inferius ($p<0.01$) cancelling out more than two thirds of the initial surgical change (T1-T2). All of the landmarks, which moved downward between T1 and T2, moved superiorly again between one month and three months postsurgery; this was especially so for Cheilion ($p<0.05$) and Stomion inferius ($p=0.129$). Additional insignificant superior movements were observed for 'ils' and 'pog'. Between T3 and T4, soft tissue landmarks were fairly stable with insignificant mean displacements ranging from –0.20 mm to +0.36 mm.

Overall change (T1-T4). Significant downward movements for 'acR' ($p<0.05$), 'acL' ($p<0.01$), 'sls' ($p<0.01$), 'ls' ($p<0.01$), 'chR' ($p<0.05$) and 'chL' ($p<0.01$) were observed. 'Ils' and 'pog', however, showed a significant mean upward movement of 1.8 mm and 2.8 mm, respectively ($p<0.01$).

Table 4.19	**Y displacements of 13 soft-tissue landmarks in subgroup A (n=20)**											
L*	**T1-T2†**	SD	P value‡	**T2-T3**	SD	P value	**T3-T4**	SD	P value	**T1-T4**	SD	P value
prn	**0.65**	0.73	0.020	**-0.07**	0.71	0.967	**-0.05**	0.93	0.833	**0.54**	1.19	0.062
acR	**-0.72**	1.27	0.108	**-0.05**	0.99	0.441	**0.13**	0.97	0.562	**-0.63**	1.17	0.030
acL	**-0.74**	0.94	0.035	**0.19**	0.95	0.679	**-0.10**	1.01	0.687	**-0.64**	0.74	0.001
sn	**-0.47**	0.97	0.155	**0.34**	1.24	0.400	**0.04**	0.88	0.854	**-0.09**	0.73	0.578
sls	**-1.09**	1.05	0.009	**0.15**	1.31	0.882	**0.23**	1.07	0.368	**-0.72**	1.04	0.008
ls	**-1.09**	0.94	0.005	**-0.20**	0.91	0.574	**0.18**	0.62	0.218	**-1.11**	0.86	<0.001
chR	**-1.24**	1.17	0.009	**0.55**	1.20	0.032	**-0.11**	0.98	0.634	**-0.79**	1.60	0.045
chL	**-1.54**	2.08	0.044	**0.49**	0.57	0.030	**-0.12**	0.64	0.419	**-1.17**	1.75	0.009
stms	**0.05**	1.42	0.914	**0.24**	1.56	0.790	**-0.20**	1.11	0.446	**0.10**	1.51	0.788
stmi	**-1.42**	2.46	0.100	**0.57**	1.24	0.129	**0.11**	0.85	0.567	**-0.74**	1.80	0.091
li	**-2.68**	2.51	0.008	**1.93**	1.54	0.003	**0.03**	1.24	0.906	**-0.71**	2.52	0.235
ils	**0.79**	2.68	0.376	**0.67**	1.08	0.052	**0.36**	1.04	0.146	**1.82**	2.41	0.004
pog	**1.76**	2.56	0.057	**0.82**	1.73	0.078	**0.23**	1.35	0.478	**2.80**	1.98	0.002

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate upward movements and negative values indicate downward movements.

(‡) One-sample t tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.3.3 X-displacements of landmarks (Table 4.20)

In the transverse direction, positive values indicated movements toward the right side of the subject's face, while negative values indicated movements toward the left side. Displacements in the x-direction were less than those observed for the anteroposterior or vertical directions.

Surgical change (T1-T2). There was a statistically significant divergence of points 'acL' and 'acR', which moved in opposite directions along the x-axis. This, of course, increased the alar base width, which was one of the findings of the analysis of linear soft-tissue changes in subgroup A. Convergence of points 'chL' and 'chR' was also detectable. The movement of 'chL' was significant ($p<0.05$). There was a mean movement of about 1 mm for 'ils' and 1.43 mm for 'pog' to the right side of the face.

Postsurgical relapse (T2-T3 and T3-T4). Small soft-tissue changes were observed between T2 and T3. Soft tissues were generally stable between T3 and T4.

Overall change (T1 and T4). There were a statistically significant divergence of alar crest points ($p<0.01$), a statistically significant change in Cheilion left point moving toward the midsagittal plane ($p<0.01$) and some significant changes with regard to 'ils' and 'pog' which moved toward the right side of the face ($p<0.05$).

Table 4.20 **X displacements of 13 soft-tissue landmarks in subgroup A (n=20)**

L*	T1-T2†	SD	P value‡	T2-T3	SD	P value	T3-T4	SD	P value	T1-T4	SD	P value
prn	**-0.28**	0.97	0.385	**0.36**	1.06	0.185	**-0.08**	0.71	0.624	**-0.01**	1.11	0.984
acR	**1.48**	1.55	0.015	**0.10**	0.81	0.818	**0.00**	0.62	0.981	**1.58**	1.08	<0.001
acL	**-2.10**	0.96	<0.001	**0.66**	0.70	0.038	**0.13**	0.56	0.346	**-1.31**	0.83	<0.001
sn	**-0.42**	1.14	0.275	**0.51**	0.94	0.080	**0.06**	0.74	0.731	**0.15**	1.14	0.570
sls	**0.05**	0.99	0.878	**0.27**	0.64	0.054	**0.15**	0.69	0.165	**0.47**	1.19	0.103
ls	**0.32**	1.07	0.375	**-0.05**	0.54	0.074	**0.32**	0.85	0.122	**0.59**	1.23	0.052
chR	**-0.39**	1.44	0.415	**0.18**	1.42	0.172	**-0.03**	1.11	0.915	**-0.24**	1.76	0.566
chL	**1.37**	1.44	0.015	**0.07**	1.13	0.500	**0.30**	1.15	0.305	**1.73**	1.64	<0.001
stms	**0.32**	1.06	0.365	**0.01**	0.64	0.094	**0.27**	0.89	0.208	**0.60**	1.23	0.048
stmi	**0.43**	1.08	0.237	**-0.11**	0.69	0.137	**0.38**	1.08	0.147	**0.70**	1.29	0.029
li	**0.61**	1.67	0.279	**-0.04**	1.15	0.143	**0.24**	1.06	0.345	**0.81**	1.79	0.065
ils	**1.01**	2.09	0.160	**-0.20**	1.20	0.191	**0.34**	1.09	0.189	**1.16**	2.30	0.041
pog	**1.43**	2.77	0.221	**-0.37**	0.97	0.168	**0.28**	1.32	0.375	**1.34**	2.78	0.050

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate movements to the right side of the patient's face and negative values indicate movements to the left side.

(‡) One sample t-tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.4 3D landmark-based facial asymmetry scores

Applying Anderson-Darling normality tests revealed that the asymmetry scores were not normally distributed. The median and its related values (the minimum value, the first quartile, the third quartile, the maximum value) were used as summary measures rather than means and standard deviations. Non-parametric tests were applied to detect significant differences in the variables assessed between assessment times.

4.3.1.4.1 General facial asymmetry scores (Tables 4.21 and 4.22)

General asymmetry scores indicated a significant improvement between T1-T2 (p=0.023) and T1-T4 (p=0.049). Eight out of twenty subjects had clinically marked facial asymmetry before surgery. There was a small increase in the facial asymmetry score between T2 and T3 but it was insignificant. The interquartile range decreased from 4.54 (at T1) to 1.21 (at T4) indicating less variability and lack of extreme values at six months following surgery.

Table 4.21	**Facial asymmetry scores in subgroup A (n=20)**				
Time	**Median**	Minimum	Maximum	1st Quartile	3rd Quartile
T1	**2.42**	0.30	13.60	1.53	6.07
T2	**1.52**	1.02	3.87	1.18	2.76
T3	**2.09**	0.79	5.20	1.35	3.75
T4	**1.88**	0.47	4.66	1.37	2.58

Table 4.22	**Differences in facial asymmetry scores in subgroup A (n=20)**				
Time comparison	**T1-T4**	**T1-T2**	**T2-T3**	**T2-T4**	**T3-T4**
Median of difference	-1.17	-1.98	0.11	-0.16	-0.32
95% CI of median	-3.02, -0.01	-4.98, -0.09	-0.40, 0.63	-0.65, 0.5	-0.80, 0.05
P value	**<u>0.049</u>**	**<u>0.023</u>**	**0.689**	**0.824**	**0.099**

4.3.1.4.2 Individual landmark asymmetry scores (Tables 4.23 and 4.24)

Moving to the individual facial asymmetry scores, the landmarks were ranked in order of ascending asymmetry. The most asymmetric landmarks at T1 were the right and left exocanthion, right and left alar landmarks and Menton. At T4, Menton moved upward in its rank. The right and left Exocanthion as well as alar points stayed at the bottom of the table with the highest scores of asymmetry.

Table 4.23	Individual landmark asymmetry scores at T1 in subgroup A				
Landmark*	Median	Minimum	Maximum	1st Quartile	3rd Quartile
na	1.5	0.1	12.1	0.8	2.4
ils	1.6	0.1	18.6	0.6	3.9
li	1.9	0.1	10.4	1.1	3.9
stmi	2.1	0.3	9.3	1.3	3.6
stms	2.5	0.3	9.0	1.1	3.9
ls	2.8	0.1	8.1	0.7	3.7
sls	3.1	0.8	10.6	1.4	4.2
prn	3.1	0.0	15.8	0.7	8.4
chL	3.9	1.7	7.8	3.0	5.6
chR	3.9	1.7	7.8	3.0	5.6
sn	4.3	0.1	10.4	0.9	7.4
pog	4.4	0.6	21.6	1.3	5.7
encL	4.6	1.8	11.6	2.9	7.5
encR	4.6	1.8	11.6	2.9	7.5
men	5.7	0.2	15.6	3.6	9.1
acL	6.5	2.9	11.1	4.9	8.1
acR	6.5	2.9	11.1	4.9	8.1
excL	7.5	0.9	18.7	4.9	11.2
excR	7.5	0.9	18.7	4.9	11.2
(*) Landmarks are ranked in order of ascending asymmetry					

Table 4.24	Individual landmark asymmetry scores at T4 in subgroup A				
Landmark	Median	Minimum	Maximum	1st Quartile	3rd Quartile
li	1.0	0.0	4.4	0.4	1.6
stms	1.1	0.2	2.9	0.7	1.9
stmi	1.1	0.0	4.0	0.5	2.3
na	1.2	0.0	10.1	0.6	4.0
ls	1.3	0.0	4.0	0.5	2.5
sls	1.7	0.1	8.0	0.7	3.0
sn	2.4	0.5	13.4	1.4	5.0
ils	2.6	0.1	6.1	1.2	3.5
men	3.3	0.2	9.7	1.0	7.2
encL	4.3	1.0	7.2	2.1	5.4
encR	4.3	1.0	7.2	2.1	5.4
prn	4.5	0.3	13.6	1.4	6.3
pog	4.6	0.0	8.3	0.8	5.6
chL	4.7	1.7	9.5	3.5	5.8
chR	4.7	1.7	9.5	3.5	5.8
acL	5.6	2.3	8.1	5.0	6.4
acR	5.6	2.3	8.1	5.0	6.4
excL	7.2	3.5	10.6	5.0	8.8
excR	7.2	3.5	10.6	5.0	8.8
(*) Landmarks are ranked in order of ascending asymmetry					

4.3.1.5 Facial volumetric changes

Volumetric changes of four facial regions in subgroup A were calculated using the Facial Analysis Tool and the results are shown in Table 4.25. These changes represent the overall volumetric differences between T1 and T4. The "+" sign indicated an overall forward movement of the whole region, while the 'minus' sign indicated an overall backward movement. One-sample t-tests showed that all of the volumetric changes calculated between T1 and T4 were statistically significant from zero. The mean volumetric difference in the nasal and the upper lip regions were + 1.513 cm^3 and +1.529 cm^3 respectively. Negative values of volumetric change were observed for the lower lip and chin regions, i.e. –3.265 cm^3 and – 7.015 cm^3. When the reproducibility of the procedure was evaluated on 10 patients, the average mean difference was 0.122 cm^3 and the average SD was 0.118 cm^3 for the four facial regions under inspection.

Table 4.25	**Volumetric changes in four facial regions in subgroup A between T4 and T1 (n=20; values stated in cubic centimetres)**			
Subject no.	**Nasal region**	**Upper lip region**	**Lower lip region**	**Chin region**
1	2.829	2.352	-5.538	-12.654
2	1.663	2.107	-0.956	-1.683
3	1.602	1.899	-4.323	-7.344
4	2.551	4.015	-0.803	-5.663
5	1.535	2.369	-1.346	-1.640
6	0.569	1.718	-3.385	-5.191
7	1.926	1.513	-3.477	-4.773
8	0.511	-1.679	-5.045	-9.888
9	2.241	1.282	-1.220	-5.960
10	0.659	0.392	-2.718	-6.608
11	1.026	1.009	-2.533	-6.437
12	0.612	0.668	-5.038	-9.733
13	2.490	3.705	-1.588	-4.601
14	4.326	1.558	-3.751	-5.269
15	0.783	1.969	-4.883	-8.397
16	0.126	-0.994	-5.237	-9.934
17	0.729	2.284	-2.065	-8.027
18	1.157	1.764	-3.257	-10.528
19	0.410	0.541	-4.545	-9.348
20	2.514	2.103	-3.590	-6.622
Mean	1.513	1.529	-3.265	-7.015
SD	1.064	1.337	1.547	2.856
95.0% CI	(1.015, 2.011)	(0.903, 2.154)	(-3.989, -2.541)	(-8.351, -5.679)
P value*	<0.001	<0.001	<0.001	<0.001

(*) One sample t-test was applied to detect if the mean volumetric change for each region was significantly different from zero.

4.3.1.6 Cephalometric analyses in subgroup A

4.3.1.6.1 Surgical change (T1-T2)

4.3.1.6.1.1 Anteroposterior displacements of landmarks (Table 4.26)

The immediate surgical changes in the x-axis were significant for most of the landmarks. The maxilla was brought forward a mean of 4.11 mm when looking at the change in point A (p <0.001), while the mandibular body, represented by point Ge, moved backward a mean of 4.88 mm (p<0.001). The mean backward movement of the bony chin point (Pogonion) was 4.39 mm (p=0.001). The maxillary-related soft-tissue landmarks moved in a forward direction and this anterior movement varied depending on their locations. Nasal tip showed the least mean displacement, which was 1.6 mm (p<0.001), whereas the Labrale superius landmark showed the most mean displacement, which was + 5.47 mm exceeding any mean value observed in the underlying bony landmarks. Moving inferiorly from Labrale inferius towards Menton, there was a gradual increase in the backward movement of 'li', 'ils', 'pog', 'gn' and 'men' with a mean backward movement of 4.57 mm at Menton (p=0.002).

4.3.1.6.1.2 Vertical displacements of landmarks (Table 4.27)

Overall, vertical change in each landmark position was less than the anteroposterior change. Upper anterior maxillary landmarks showed a downward movement, which was significant for Prosthion (Pr) and Incision superius (IS) (p=0.004 and p=0.039, respectively). Pogonion and Gnathion moved superiorly a mean of 2.08 mm and 1.88 mm (p=0.016, p=0.012), respectively. This may be due to the genioplasty performed for six subjects in this subgroup. Genion (Ge), however, showed a superior movement, which was marginally significant (p=0.047). Changes in the integumental profile varied in its magnitude and direction between T1-T2. The nasal tip moved upwards about 2 mm (p<0.001). The upper labial landmarks, apart from 'stms', moved upward and this was only significant for Subnasale (p=0.003). Lower labial landmarks moved inferiorly, which was significant for 'stmi' and 'li' (p<0.05). Upward movement for soft tissue Pogonion, Gnathion and Menton was insignificant.

Table 4.26	X displacements landmarks in subgroup A (n=20)								
Landmarks	**T1-T2***	SD	P value†	**T2-T3**	SD	P value	**T1-T3**	SD	P value
prn	**1.60**	1.20	<0.001	**-0.55**	1.29	0.099	**1.05**	1.01	0.001
sn	**3.58**	1.90	<0.001	**-2.00**	1.88	<0.001	**1.59**	1.54	0.001
sls	**4.93**	2.61	<0.001	**-2.36**	2.07	<0.001	**2.57**	2.27	<0.001
ls	**5.47**	3.57	<0.001	**-3.19**	3.15	0.001	**2.28**	2.43	0.001
stms	**3.42**	4.02	0.003	**-1.82**		0.001	0.91		0.173
stmi	**1.48**	4.38	0.182	**-2.73**		0.001	**-1.66**	3.96	0.104
li	**-0.85**	4.16	0.412	**-3.35**		0.001	**-4.12**	3.73	<0.001
ils	**-2.72**	3.74	0.009	**-2.11**	2.77	0.006	**-4.83**	3.97	<0.001
pog	**-3.49**	4.41	0.005	**-2.00**	3.46	0.030	**-5.49**	4.39	<0.001
gn	**-3.92**	3.90	0.001	**-1.42**	3.54	0.118	**-5.34**	4.53	<0.001
men	**-4.57**	5.02	0.002	**-1.81**	3.65	0.058	**-6.38**	4.13	<0.001
ANS	**3.38**	2.40	<0.001	**-0.32**	1.36	0.351	**3.06**	2.95	0.001
A	**4.11**	2.18	<0.001	**-0.78**	1.19	0.015	**3.33**	2.45	<0.001
Pr	**4.15**	2.08	<0.001	**-0.48**	1.26	0.133	**3.67**	1.94	<0.001
IS	**3.72**	2.13	<0.001	**0.00**		0.670	**3.61**	2.51	<0.001
II	**-4.32**	2.99	<0.001	**0.01**	1.34	0.985	**-4.31**	3.04	<0.001
Id	**-4.63**	3.30	<0.001	**-0.21**	1.80	0.644	**-4.84**	3.33	<0.001
B	**-4.90**	3.66	<0.001	**-0.77**	2.64	0.247	**-5.67**	3.67	<0.001
Pog	**-4.39**		0.001	**-1.26**	2.79	0.080	**-6.38**	4.76	<0.001
Gn	**-4.55**		0.002	**-1.26**	3.00	0.103	**-6.25**	4.98	<0.001
Men	**-4.01**		0.001	**-1.18**	3.04	0.129	**-6.27**	4.89	<0.001
Ge	**-4.88**	3.76	<0.001	**-0.74**	2.41	0.222	**-5.62**	3.63	<0.001
Go	**-2.09**	3.47	0.024	**2.44**	2.14	<0.001	**0.36**	3.54	0.685
Ar	**0.62**	1.16	0.042	**0.19**		0.638	**0.68**	1.14	0.025
Cd	**0.91**		0.021	**-0.36**	1.83	0.424	**0.47**	1.32	0.159
PNS	**2.62**	2.23	<0.001	**-0.29**	1.68	0.486	**2.33**	2.04	<0.001
UIA	**3.86**	2.39	<0.001	**-0.18**	1.60	0.647	**3.68**	2.87	<0.001
LIA	**-4.77**	3.30	<0.001	**-0.49**	1.94	0.310	**-5.27**	3.49	<0.001

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate forward movements, whereas negative values indicate backward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

Table 4.27	Y displacement of 28 landmarks in subgroup A (n=20)								
Landmark	T1-T2*	SD	P value†	T2-T3	SD	P value	T1-T3	SD	P value
prn	2.09	1.20	<0.001	-1.44	1.60	0.002	0.64	1.14	0.034
sn	1.43	1.68	0.003	-1.10	1.61	0.013	0.34	1.01	0.186
sls	0.48	1.35	0.160	-0.90	1.45	0.020	-0.42	1.35	0.215
ls	0.23	2.27	0.685	-0.92	1.59	0.029	-0.70	1.55	0.083
stms	-1.16	1.97	0.027	-0.04	1.04	0.876	-1.20	1.29	0.001
stmi	-2.03	3.31	0.022	0.78	2.69	0.249	-1.25	2.58	0.063
li	-2.98	4.44	0.014	1.30	3.81	0.177	-1.67	3.72	0.082
ils	-0.30	3.67	0.741	0.58	4.09	0.567	0.28	3.03	0.707
pog	0.84	2.36	0.161	0.68	3.22	0.398	1.52	2.70	0.033
gn	0.87	2.33	0.143	0.92	3.11	0.239	1.79	2.46	0.008
men	0.91		0.182	1.21	2.62	0.075	0.91		0.008
ANS	-0.58	1.62	0.161	0.73	1.40	0.049	0.15	1.62	0.707
A	-0.56	1.49	0.143	0.69	1.37	0.045	0.13	1.35	0.696
Pr	-1.65	2.01	0.004	1.26	1.95	0.017	-0.39	1.53	0.308
IS	-1.19	2.19	0.039	0.91		0.108	-0.53	1.70	0.218
II	1.01	3.08	0.196	0.43		0.147	1.67	2.29	0.009
Id	1.08	3.19	0.181	0.91	2.17	0.103	1.99	2.16	0.002
B	0.88	3.55	0.319	0.91		0.198	1.37		0.007
Pog	2.08	3.17	0.016	0.91		0.066	3.14	2.42	<0.001
Gn	1.88	2.72	0.012	1.18	1.95	0.024	1.82		0.001
Men	1.82		0.002	0.85	1.77	0.064	3.17	2.33	<0.001
Ge	1.44	2.77	0.047	0.98	1.85	0.045	2.42	2.16	<0.001
Go	-0.06	2.41	0.914	3.10	3.15	0.001	3.03	2.41	<0.001
Ar	0.81	1.27	0.018	-0.20	1.35	0.551	0.61	1.24	0.057
Cd	0.14	1.50	0.705	0.08	1.19	0.779	0.22	1.61	0.577
PNS	0.55	1.25	0.087	0.38	1.33	0.253	0.91		0.060
UIA	-0.91		0.032	0.25	1.48	0.495	-0.63	0.95	0.014
LIA	1.32	3.54	0.143	1.12	1.91	0.028	2.44	2.34	0.001

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate upward movements, whereas negative values indicate downward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

4.3.1.6.1.3 Linear measurements (Table 4.28)

As a result of the surgical intervention, there was a significant decrease in the total anterior facial height (p=0.016) and a significant decrease in the mandibular length measured between Condylion and Gnathion (p<0.001). Mandibular body length reduced significantly between T1 and T2 (p<0.001). Facial axis length decreased significantly (p<0.001). The reverse overjet (-5.66 mm) was corrected to an acceptable amount of 2.7 mm at T2 (p<0.001). The reduced overbite (-0.91 mm) was also corrected to an acceptable amount of 1.24 mm (p=0.001). The mean amount of incisor display remained stable between T1 and T2. With regard to soft tissues, a significant increase was seen in the upper labial height (p<0.001), a significant decrease in the lower labial height (p<0.001), a significant increase in the upper vermilion border (p=0.007), and a similar increase in the lower vermilion border (p=0.015). Consequently, the total vermilion height measured from Labrale superius to Labrale inferius increased significantly (p=0.005). The change in the interlabial distance was not significant. The mean columella length measured from Subnasale to Pronasale decreased from 15.02 mm to 13.09 mm, and this change was significant (p<0.001).

Table 4.28	Interlandmark distances in subgroup A (n=20)								
Distance*	T1†	SD	P value T2-T1‡	T2	SD	P value T3-T2	T3	SD	P value T3-T1
TAFH	115.42	8.71	0.016	113.65	7.11	0.105	112.89	7.61	0.001
UAFH	50.83	2.72	0.079	51.57	3.03	0.048	50.89	3.14	0.950
LAFH	65.02	6.42	0.054	63.58	4.38	0.580	63.88	5.24	0.089
PFH	74.67	5.69	0.670	74.76	5.88	0.001	71.70	5.74	<0.001
MdL	117.38	6.46	<0.001	112.39	6.57	0.031	110.85	5.33	<0.001
MdRmH	56.92	4.92	0.818	56.80	5.62	0.012	54.10	4.88	0.002
MdBL	76.18	4.69	<0.001	72.70	4.53	<0.001	70.21	3.76	<0.001
MxL1	80.06	3.30	<0.001	83.36	3.60	0.219	82.86	3.62	<0.001
MxL2	83.41	3.82	<0.001	86.32	3.95	0.532	85.92	4.44	0.012
MxL3	48.51	3.39	0.062	49.54	2.72	0.485	49.40	3.58	0.442
FAL	124.44	7.18	<0.001	120.06	6.70	0.002	118.47	6.20	<0.001
PCB	30.31	3.15	0.019	29.34	2.65	0.264	29.77	2.74	0.180
OJ	-5.66		<0.001	2.70	1.19	0.196	1.82		<0.001
OB	-0.91		0.001	1.24	1.07	0.865	1.82		<0.001
Incisor Show	3.08	1.46	0.856	3.00	1.60	0.030	2.41	1.24	0.141
ULH (S)	17.98	2.21	<0.001	20.74	1.97	0.006	19.63	2.38	<0.001
UVH (S)	5.40	1.13	0.007	6.73	1.24	0.020	5.96	1.66	0.239
LLH (S)	18.96	2.06	<0.001	17.28	1.85	0.671	17.09		<0.001
LVH (S)	7.94	1.18	0.015	8.99	1.25	0.014	8.26	1.49	0.449
LFH (S)	68.21	5.92	0.288	67.27		0.007	66.83	5.67	0.027
ILD (S)	0.91		0.239	2.00	1.69	0.241	0.91		0.897
TVH (S)	14.84	2.68	0.005	17.83	2.99	0.050	15.77	4.10	0.299
ColumL (S)	15.02	2.31	<0.001	13.09	2.07	<0.001	14.48	2.07	0.041

(*) Abbreviations of the distances used have been explained in Table 3.8 and 3.9. 'S' stands for a soft-tissue distance.

(†) Values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.6.1.4 Angular measurements (Table 4.29)

The mean 'SNA' angle was below the normal limits (norm=82 ± 3°) indicating a retrognathic maxilla[467]. 'SNB' angle was approximately 83° indicating a prognathic mandible (norm=79 ±3°). This was also confirmed by the 'SNPog' angle, which had a mean of 84° exceeding the normal limits (norm=80 ±3°). The mean 'ANB' angle confirmed the Class III skeletal relationship (norm=3±1°). The mean maxillary-mandibular planes angle was 23.65°, which was within the normal range (norm=27±5°)[467]. The dentoskeletal angles revealed that the inclinations of the upper and lower incisors were within normal limits before surgery. The interincisor angle was within normal limits (mean= 134.03°) at T1.

Between T1 and T2, there was a clear correction of the anteroposterior discrepancy, which resulted in mean values of 'SNA', 'SNB', 'ANB' and 'SNPog' within the normal limits at T2 ($p<0.001$). Maxillary-cranial base planes angle increased significantly ($p=0.033$). The nasal tip angle increased also significantly between T1 and T2 ($p=0.003$). There was a significant improvement in the labiomental angle ($p=0.004$) as well as in the facial profile angle ($p<0.001$). The mean labiomental angle reduced from 142.52° (at T1) to 129.13° (at T2), whereas the mean facial profile angle reduced from 136.86° to 130.68°.

Table 4.29	Interlandmark angles in subgroup A (n=20)								
Angle*	**T1†**	SD	P value T2-T1‡	**T2**	**SD**	P value T3-T2	**T3**	**SD**	P value T3-T1
SNA	**78.60**	3.78	<u>≤0.001</u>	**82.54**	4.42	0.053	**81.87**	4.19	<u>≤0.001</u>
SNB	**83.19**	3.45	<u>≤0.001</u>	**80.17**	3.74	0.255	**79.75**	3.70	<u>≤0.001</u>
ANB	**-4.59**	2.42	<u>≤0.001</u>	**2.39**	2.31	0.490	**2.12**	2.56	<u>≤0.001</u>
SNPog	**83.98**	3.45	<u>0.001</u>	**81.19**	3.81	0.157	**80.64**	3.65	<u>≤0.001</u>
MxSN	**9.82**	3.55	<u>0.033</u>	**11.30**	4.59	0.234	**10.66**	4.76	0.236
MdSN	**33.46**	5.58	0.642	**33.14**	5.63	<u>0.001</u>	**36.20**	6.69	<u>0.001</u>
MxMd	**23.65**	5.27	0.052	**21.84**	5.72	<u>≤0.001</u>	**25.56**	6.52	<u>0.025</u>
MPIA	**91.86**	7.28	0.109	**90.52**	8.17	0.135	**91.64**	7.46	0.786
UISN	**104.36**	7.35	0.521	**103.77**	7.43	0.604	**104.36**	7.26	0.996
IIA	**134.03**	6.97	0.677	**133.61**	7.55	0.020	**131.06**	8.50	<u>0.010</u>
Nasal tip	**95.70**	4.45	<u>0.003</u>	**98.75**	5.14	<u>0.001</u>	**95.81**	5.50	0.862
Nasolabial	**128.70**		0.452	**122.59**	7.71	0.901	**122.84**	9.32	0.306
Labiomental	**142.52**	10.95	<u>0.004</u>	**129.13**	15.45	<u>0.028</u>	**136.44**	9.69	<u>0.049</u>
Chin	**121.06**	7.32	0.893	**121.43**	10.59	0.492	**119.44**	8.14	0.315
Facial profile	**136.86**	4.92	<u>≤0.001</u>	**130.68**	5.47	0.221	**129.84**	5.31	<u>≤0.001</u>

(*) Abbreviations of the angles used have been explained in Table 3.8 and 3.9.

(†) Values are stated in degrees. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.6.1.5 Soft-tissue thicknesses (Table 4.30)

The soft-tissue thickness between anterior nasal spine (ANS) and Subnasale did not show any difference. There was an insignificant increase, however, in the upper labial thickness in this period when measured at 'sls' and 'ls' levels (p=0.183 at 'sls' level; p=0.08 at 'ls' level). Significant thickening of the lower lip as well as the chin was observed at the four different levels in these regions, with the most change observed at the Labrale inferius level (p<0.001).

Table 4.30	**Facial soft-tissue thicknesses in the midsagittal plane at 7 levels in subgroup A (n=20)**								
Thickness at	**T1***	SD	P value T2-T1†	**T2**	SD	P value T3-T2	**T3**	SD	P value T3-T1
sn	**12.10**	2.20	0.918	**12.03**	3.16	0.004	**10.51**	2.55	0.010
sls	**15.62**	1.59	0.183	**16.38**	2.80	0.006	**14.97**	2.25	0.122
ls	**14.79**	2.14	0.088	**16.33**	3.63	0.001	**13.46**	2.33	0.024
li	**13.44**	1.25	<0.001	**17.44**	2.60	<0.001	**13.64**		0.225
ils	**11.23**	1.53	<0.001	**13.41**	2.04	0.001	**12.08**	2.04	0.031
pog	**12.20**	2.12	0.018	**13.88**	3.25	0.108	**13.15**	2.61	0.056
men	**8.37**	1.87	0.016	**10.01**	2.96	0.381	**9.55**	2.54	0.026

(*) Values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(†) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.1.6.2 Postsurgical relapse (T2-T3)

4.3.1.6.2.1 Anteroposterior displacements of landmarks (Table 4.26)

Relapse was not significant for most of the skeletal landmarks, while most soft-tissue landmarks showed significant relapse between T2 and T3. Mean maxillary relapse, assessed at ‘A’ point, was 0.78 mm (p=0.015) and this was the only significant movement for a hard-tissue landmark in the anterior maxillary region. Although Pogonion showed a higher degree of displacement, which was in the same direction of the initial surgical correction (mean= -1.26 mm), this result was not significant. The interpretation of Pogonion’s displacements should be made with caution since six subjects in this subgroup had an adjunctive genioplasty procedure. Genion, a point assumed not to be affected by genioplasty or any superficial remodelling, had a mean backward displacement of about 0.74 mm and that was also insignificant (p=0.222). It seemed to be that the changes in the postsurgical period were in the opposite direction of the surgical correction in the maxilla, while it was in the same direction of the surgical correction in the mandible. The magnitude of soft-tissue landmark displacements was greater than those of hard-tissue landmarks with the nasal tip showing the least soft-tissue change (mean=-0.055 mm; p=0.099) and the Labrale inferius showing the most change (mean=-3.35 mm; p=0.001).

4.3.1.6.2.2 Vertical displacements of landmarks (Table 4.27)

A skeletal relapse was observed in the upper anterior maxillary landmarks cancelling out the initial surgical change and it was significant at 'ANS' ($p=0.049$), 'A' ($p=0.045$) and 'Pr' ($p=0.017$). Changes in the same direction of the initial surgical movement were observed in the lower anterior skeletal landmarks but many of them were insignificant. There was a significant upward displacement of Gonion between T2 and T3. The mean vertical movement of this point was 3.15 mm, which was the greatest among all of the landmarks evaluated in this period ($p=0.001$). Nasal and upper labial soft-tissue displacements did not follow the same direction as the underlying skeletal displacements. Pronasale, Subnasale, SLS and Labrale superius moved downward significantly. It should be taken into account, however, that the second assessment time, T2, occurred within one week following surgery when many subjects had considerable facial swelling. Consequently, many soft-tissue landmarks had significantly deviated positions from their planned positions.

4.3.1.6.2.3 Linear measurements (Table 4.28)

A significant decrease in posterior facial height occurred ($p<0.001$) while the anterior facial height did not change significantly. The shortened mandibular length had a further mean reduction of about 1.5 mm between T2 and T3 ($p=0.31$). Mean mandibular ramus height decreased significantly ($p=0.012$) whereas the mandibular body length had a further mean reduction of about 2.5 mm ($p<0.001$). Additional reduction in the facial axis length was observed also between T2 and T3 ($p=0.002$). The achieved overjet at T2 (2.7 mm) changed slightly at T3, but this change was insignificant ($p=0.196$). The overbite improved slightly from a mean of 1.24 mm at T2 to 1.82 mm, but this change was also insignificant ($p=0.865$). The dental display showed a significant reduction in its magnitude from 3 mm within one week postsurgery to 2.41 mm at six months postsurgery ($p=0.030$). The significant increase in upper labial height, upper vermilion height and lower vermilion height at T2 was partially counteracted by a significant decrease seen between T2 and T3 ($p=0.006$ for ULH, $p=0.020$ for UVH and $p=0.014$ for LVH). The total vermilion height showed a marginally significant decrease between T2 and T3 and the mean magnitude of this change was about 2 mm ($p=0.05$). The reduction in the columellar length seen between T1 and T2 was lost partially between T3 and T4 ($p<0.001$).

4.3.1.6.2.4 Angular measurements (Table 4.29)

Between T2 and T3, there was a significant change in the maxillary-mandibular planes angle ($p=0.001$) as well as in the cranial base-mandibular plane angle ($p<0.001$), which can be attributed mostly to the inclination of the mandibular plane. The inclination of this plane has a mean increase of about 3° between T2 and T3 in relation to the anterior cranial base. A significant relapse was seen in the nasal tip angle, which returned to its presurgical value at T3 ($p=0.001$). Another relapse was observed with regard to the labiomental angle ($p=0.028$), but the final result remained better than the original presurgical value. It is worth mentioning that the variability of this measurement was large at T2 (SD=15.45°).

4.3.1.6.2.5 Soft-tissue thicknesses (Table 4.30)

Significant thinning was observed at Subnasale, superior labial sulcus and Labrale superius ($p<0.01$ for each). The significant increase in lower labial thickness was opposed by a significant decrease in the postsurgical period ($p<0.001$). The labiomental fold had a mean reduction of about 1.33 mm in its thickness, which was also significant ($p=0.001$).

4.3.1.6.3 Overall change (T1-T3)

4.3.1.6.3.1 Anteroposterior displacements of landmarks (Table 4.26)

The mean overall skeletal changes were highly significant ($p<0.001$) for most of the landmarks. They followed the same pattern observed between T1-T2, but the magnitude of these changes was less in the maxilla and greater in the mandible. The mean overall backward displacement for Pogonion and Genion was 6.38 mm ($p<0.001$) and 5.62 mm ($p<0.001$), respectively. The mean overall forward displacement for A point was 3.33 mm and it was highly significant ($p<0.001$). The significant changes in soft tissues were: a forward movement of Pronasale (mean≈1 mm, $p=0.001$), a forward movement of upper labial landmarks (range of means: +1.59 mm to +2.28 mm), a backward movement of lower labial and mental landmarks with a gradual increase in magnitude when moving from Labrale inferius towards Menton.

4.3.1.6.3.2 Vertical displacements of landmarks (Table 4.27)

The mean overall vertical changes included: a significant upward movement of lower anterior mandibular landmarks (Id, B, Pog, Gn and Men), a significant upward displacement of Gonion, a significant raise in the nasal tip, significant inferior displacements of 'stms', 'stmi' and 'li' and significant superior movements of the soft-tissue mental landmarks.

4.3.1.6.3.3 Linear measurements (Table 4.28)

The overall changes can be summarised as follows: significant decrease in bony total facial height ($p<0.001$); significant decrease in posterior facial height ($p<0.001$); significant increase in upper labial height with a significant decrease in lower labial height ($p<0.001$ for each); significant decrease in soft-tissue lower facial height ($p=0.027$); significant shortening of the columellar length ($p=0.041$); significant decrease in mandibular, mandibular body and facial axis lengths ($p<0.001$ for each); significant shortening of the ramus height ($p=0.002$); significant increase in the maxillary length assessed between Condylion and 'ANS' ($p<0.001$) and significant correction of overbite and overjet ($p<0.001$).

4.3.1.6.3.4 Angular measurements (Table 4.29)

The overall changes were: significant correction of the anteroposterior discrepancy confirmed by the 'SNA', 'SNB', 'ANB' and 'SNPog' angles ($p<0.001$ for each); significant increase in the 'MdSN' and 'MxMd' angles; significant improvement in the facial profile ($p=0.001$) and labiomental angles ($p=0.049$).

4.3.1.6.3.5 Soft-tissue thicknesses (Table 4.30)

The net changes in soft-tissue thicknesses were: significant thinning of soft-tissues at the nasal base level ($p=0.010$), significant thinning at Labrale superius ($p=0.024$), significant increase in soft-tissue thickness at the labiomental fold ($p=0.031$) and significant increase in soft-tissue thickness at Menton ($p=0.026$).

4.3.1.6.3.6 Soft- to hard-tissue displacement ratios (Table 4.31)

Anteroposterior ratios. The nasal tip displaced in a median ratio of 0.29:1 with 'ANS' displacement ($p=0.038$). The Subnasale-ANS median displacement ratio was 0.43:1 ($p=0.008$). The median ratio increased to 0.75:1 for 'sls' to 'A' displacements ($p=0.001$). Moving slightly downward, the ratio between the upper vermilion border displacement (represented by 'ls') and Prosthion displacement was less than the previous one (median= 0.60:1; $p=0.011$). In the lower labial and mental regions, the

Stomion inferius (stmi) to Incision inferius (II) median displacement ratio was also small, i.e. 0.28:1 (p=0.033). This median ratio increased to 0.81:1 at the Labrale inferius-Infradentale level (p=0.004). At the level of the labiomental groove, the soft-tissue to hard-tissue displacement ratios had a median of 0.94:1 (ils to B; p<0.001). A one-to-one ratio was achieved at the Pogonion level and the same was noticed at the Menton level.

Vertical ratios. The median displacement ratios did not follow a specific trend and most of them were not significantly different from zero. The only significant results were located in the chin area where the soft-tissue Pogonion followed hard-tissue Pogonion in about a one-to-two displacement ratio (p=0.022).

Table 4.31	**Soft- to hard-tissue displacement ratios in subgroup A (n=20)**			
Soft-tissue/hard-tissue	**X axis***	P value	**Y axis**	P value
prn-ANS	**0.29**	<u>0.038</u>	0.09	0.290
prn-A	**0.29**	<u>0.022</u>	0.27	0.208
sn-ANS	**0.43**	<u>0.008</u>	0.37	0.476
sn-A	**0.43**	<u>0.003</u>	0.00	0.965
sls-ANS	**0.83**	<u>0.002</u>	0.00	0.424
sls-A	**0.75**	<u>0.001</u>	0.08	0.563
ls-A	**0.71**	<u>0.001</u>	0.48	0.142
ls-Pr	**0.60**	<u>0.011</u>	0.50	0.345
stms-IS	0.20	0.142	0.42	0.666
stmi-IS	0.00	0.410	1.00	0.683
stmi-II	**0.28**	<u>0.033</u>	-0.33	1.000
li_II	**1.00**	<u>0.001</u>	0.25	0.367
li_Id	**0.91**	<u>0.004</u>	0.00	0.834
li-B	**0.79**	<u>0.001</u>	0.00	0.552
ils-Id	**1.00**	<u><0.001</u>	0.41	0.366
ils-B	**0.94**	<u><0.001</u>	0.36	0.609
ils-Ge	**0.90**	<u>0.001</u>	0.23	0.737
pog-B	**0.96**	<u>0.001</u>	0.67	0.124
pog-Pog	**1.00**	<u>0.001</u>	**0.57**	<u>0.022</u>
pog-Ge	**1.00**	<u>0.001</u>	0.69	0.060
gn-Gn	**0.81**	<u>0.005</u>	**0.57**	<u>0.038</u>
men_Men	**1.00**	<u>0.001</u>	**0.50**	<u>0.009</u>

(*) Median values are stated here instead of means. One-sample Wilcoxon singed rank test was applied to detect if the calculated ratios were significantly different from zero. Significant results are printed in a red bold font and the related p vales are underlined.

4.3.2 Subgroup B: Class III patients treated by maxillary surgery alone

4.3.2.1 Stereophotogrammetry-based linear measurements

4.3.2.1.1 Surgical changes (T1-T2; Table 4.32)

Significant changes were as follows: increase in alar base width ($p<0.05$), decrease in columellar length ($p<0.05$), decrease in nasal bridge length ($p<0.05$), a small increase in upper lip height (mean= 1.3 mm) ($p<0.05$) and a small increase in lower facial height (mean= 1.7 mm).

4.3.2.1.2 Postsurgical relapse (T2-T3 and T3-T4)

Between T2 and T3, interlandmark distances were maintained, but the mean lower facial height increased slightly (0.9 mm; $p<0.05$) as well as the insignificant relapse seen in the nasal bridge length. Between T3 and T4, no significant changes were detected.

4.3.2.1.3 Overall change (T1-T4)

Significant soft-tissue changes observed in the overall assessment were similar to those significant changes seen between T1 and T2 with the exception of nasal bridge length, which had a non-significant mean reduction of about 0.8 mm at T4.

4.3.2.2 Stereophotogrammetry-based angular measurements

4.3.2.2.1 Surgical change (T1-T2; Table 4.33)

Facial convexity angle decreased a mean of 9 degrees and the facial profile angle decreased a mean of 5 degrees ($p<0.01$).

4.3.2.2.2 Postsurgical change (T2-T3 and T3-T4)

Facial convexity angle and facial profile angle exhibited relapse between T2 and T3 and this was significant for the facial convexity angle ($p<0.05$). No other significant changes were found between T3 and T4 for all angular measurements.

Table 4.32		Linear measurements in subgroup B (n=12)†								
No	Distance (in mm)	Mean at T1 (SD)	T1-T4	T1-T2	Mean at T2 (SD)	T2-T3	Mean at T3 (SD)	T3-T4	Mean at T4 (SD)	T2-T4
1	Alar base width	33.63 (2.42)	**	*	36.47 (2.66)	ns	36.68 (2.37)	ns	36.21 (2.24)	ns
2	Columellar length	18.55 (1.70)	*	*	17.12 (2.18)	ns	17.53 (1.98)	ns	17.51 (1.63)	ns
3	Nasal bridge length	44.74 (3.42)	ns	*	42.55 (4.09)	ns	44.33 (4.05)	ns	43.92 (4.19)	ns
4	Upper lip height	19.19 (3.85)	**	*	20.48 (3.07)	ns	21.87 (4.00)	ns	21.50 (3.24)	ns
5	Upper vermilion height	4.71 (1.56)	ns	ns	5.34 (1.19)	ns	5.93 (1.16)	ns	5.69 (1.26)	ns
6	Lower lip height	18.23 (2.77)	ns	ns	18.05 (2.54)	ns	17.77 (2.51)	ns	17.86 (2.96)	ns
7	Lower vermilion height	6.45 (1.00)	ns	ns	7.18 (1.60)	ns	6.40 (1.52)	ns	7.14 (2.43)	ns
8	Mouth width	47.03 (3.68)	ns	ns	46.12 (2.45)	ns	46.60 (3.09)	ns	47.00 (2.77)	ns
9	Upper facial height	50.96 (3.31)	ns	ns	49.01 (3.93)	ns	50.22 (3.75)	ns	49.96 (3.90)	ns
10	Lower facial height	64.92 (8.16)	*	*	66.66 (5.01)	*	67.54 (7.04)	ns	67.81 (6.62)	*
11	Total facial height	114.50 10.39	ns	ns	112.90 (7.42)	ns	115.43 (9.43)	ns	115.37 (9.26)	ns
12	Mandibular length left	126.51 (7.50)	ns	ns	126.63 (7.47)	ns	126.45 (7.71)	ns	127.16 (7.21)	ns
13	Mandibular length right	126.69 (7.77)	ns	ns	126.88 (5.76)	ns	126.97 (7.54)	ns	126.95 (8.11)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols used: * statistically significant difference at p<0.05, ** p<0.01; ns= non-significant. Student's paired t tests are indicated in black; while Wilcoxon signed rank tests are indicated in blue.

4.3.2.2.3 Overall change (T1-T4)

Again, the overall changes were similar to the initial changes, but relapse lessened the magnitude of these changes.

Table 4.33		Angular measurements in Subgroup B (n=12)†								
No	Angle	Mean at T1 (SD)	T1-T4	T1-T2	Mean at T2 (SD)	T2-T3	Mean at T3 (SD)	T3-T4	Mean at T4 (SD)	T2-T4
1	Facial convexity angle	170.56 (6.46)	**	**	161.13 (6.64)	*	164.3 (6.34)	ns	164.01 (7.21)	ns
2	Facial profile angle	137.11 (5.91)	**	**	132.23 (5.97)	ns	133.74 (5.49)	ns	133.57 (5.33)	ns
3	Nasolabial angle	129.04 (7.72)	ns	ns	133.64 (8.52)	ns	131.69 (7.75)	ns	131.76 (9.28)	ns
4	Nasal projection angle	98.74 (4.57)	ns	ns	101.78 (4.16)	ns	99.28 (5.29)	ns	100.03 (5.45)	ns
5	Labiomental angle	147.02 (13.04)	ns	ns	148.73 (18.97)	ns	148.11 (13.26)	ns	147.74 (14.06)	ns
6	Chin angle	135.88 (6.90)	ns	ns	135.92 (4.87)	ns	135.75 (4.98)	ns	135.87 (4.82)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols used: * statistically significant difference at p<0.05, ** p<0.01; ns= non-significant. Student's paired t tests are indicated in black; while Wilcoxon signed rank tests are indicated in blue.

4.3.2.3 3D displacements of soft-tissue landmarks

4.3.2.3.1 Z-displacements of landmarks (Table 4.34)

Surgical change (T1-T2). Ten landmarks showed significant anteroposterior displacements. The nasal tip had a mean forward movement of 0.93 mm forward ($p<0.05$); 'acL' and 'acR' had a mean forward movement of more than 3 mm ($p<0.01$) and Subnasale had a significant mean forward movement of 2.5 mm ($p<0.01$). Even the upper lip, represented by Labrale superius (ls), advanced a mean of 1.7 mm approximately, but it was insignificant. Mouth commissure points moved backward. The mean displacement for Stomion superius was almost zero but there was wide variation (SD=3.58). Lower lip and chin-related landmarks moved backward although no setback osteotomies were performed to the body or the ramus of the mandible. Five subjects, however, underwent an adjunctive genioplasty, in which a vertical reduction and a small amount of setback were performed to the genial segment. Stomion inferius (stmi) moved backward a mean of 3.25 mm ($p<0.01$) and the same vector of movement was observed for 'li', 'ils' and 'pog' ($p<0.05$).

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, clear relapse occurred in the alar base and upper labial landmarks, i.e. 'acL' ($p<0.05$), 'acR' ($p<0.05$) and 'sls' ($p<0.05$). Subnasale and Labrale superius showed an insignificant relapse.

Changes in the lower lip and chin areas were insignificant although it was clear that these changes tended to reduce the preliminary results achieved (T1-T2). The greatest relapse was with Stomion inferius, which showed forward movement more than half of the initial surgical change (p= 0.08). Pogonion also moved forward (mean≈1.20 mm; p=0.09). Between T3-T4, small and insignificant displacements were observed.

Overall change (T1-T4). Ten landmarks showed significant displacements with the nasal and upper labial landmarks demonstrating positive values (forward movements; range of means: 0.98 mm – 2.42 mm; p<0.01), whereas the lower labial and chin landmarks demonstrated negative values (backward movements; range of means: 2.36 mm – 2.89 mm; p<0.01). The magnitude of these changes in the overall assessment was less than the initial surgical changes.

Table 4.34 **Z displacements of 13 soft-tissue landmarks in subgroup B (n=12)**

L*	T1-T2†	SD	P value‡	T2-T3	SD	P value	T3-T4	SD	P value	T1-T4	SD	P value
prn	**0.93**	0.85	0.018	**-0.20**	0.50	0.368	**0.25**	0.75	0.271	**0.98**	0.64	≤0.001
acR	**3.46**	1.30	≤0.001	**-1.01**	0.94	0.017	**-0.04**	0.83	0.867	**2.42**	1.11	≤0.001
acL	**3.19**	1.15	≤0.001	**-0.65**	0.74	0.021	**-0.21**	0.90	0.441	**2.33**	1.07	≤0.001
sn	**2.49**	1.41	0.002	**-0.59**	1.06	0.137	**0.31**	1.34	0.442	**2.20**	1.25	≤0.001
sls	**2.29**	1.65	0.006	**-0.63**	0.54	0.036	**-0.14**	1.03	0.652	**1.52**	1.31	0.002
ls	**1.71**	3.24	0.180	**-0.81**	1.17	0.237	**0.22**	1.26	0.565	**1.11**	2.01	0.081
chR	**-1.54**	1.62	0.031	**0.06**	1.01	0.636	**0.02**	0.99	0.954	**-1.46**	1.83	0.018
chL	**-1.11**	2.83	0.303	**-0.07**	1.21	0.939	**0.08**	1.35	0.845	**-1.10**	2.80	0.200
stms	**-0.03**	3.58	0.985	**-1.43**	1.46	0.070	**0.25**	1.25	0.500	**-1.21**	2.24	0.088
stmi	**-3.26**	2.40	0.006	**0.92**	1.96	0.084	**-0.54**	1.47	0.229	**-2.89**	2.16	0.001
li	**-2.98**	2.54	0.014	**0.13**	1.59	0.562	**0.28**	1.09	0.393	**-2.58**	1.99	0.001
ils	**-3.30**	3.33	0.026	**0.86**	1.71	0.178	**0.08**	1.38	0.843	**-2.36**	2.33	0.005
pog	**-4.11**	3.58	0.014	**1.04**	1.92	0.120	**0.28**	1.75	0.593	**-2.79**	2.68	0.004

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate forward movements and negative values indicate backward movements.

(‡) One-sample t tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.3.2 Y-displacements of landmarks (Table 4.35)

Surgical change (T1-T2). The nasal tip had a mean upward displacement of about 0.92 mm and to a lesser extent the Subnasale point (mean= 0.24 mm). The alar base points moved downward but this was only significant for the left point (acL). The other landmarks moved in the same direction, but with different amounts. The most obvious change was located in the Labrale inferius point, which moved inferiorly about 2 mm at T2.

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, no significant changes were detected. The inferior movement of 'ils' observed at T2, however, was reduced by an opposite movement at T3. The same is applicable to 'li', which moved superiorly a mean of 0.83 mm between T2 and T3. Mean soft-tissue displacements between T3 and T4 were all below 0.5 mm and were considered of minimal importance, with the exception of Stomion superius that moved upward cancelling partially the initial surgical change observed between T1 and T2.

Overall change (T1-T4). The main vertical changes were: Significant superior movement of the tip of the nose (mean=0.81 mm; $p<0.05$), significant inferior movement of alar base landmarks (mean≈0.9 mm; $p<0.05$ for acR and $p<0.01$ for acL), significant inferior movements of mouth commissure landmarks (mean=0.96 mm for chR; mean=1.62 mm for chL; $p<0.01$ for each), significant inferior movement of Labrale superius (mean=1.41 mm; $p<0.05$) and significant inferior movement of Labrale inferius (mean=1.51 mm; $p<0.05$).

Table 4.35	Y displacements of 13 soft-tissue landmarks in subgroup B (n=12)											
L*	**T1-T2†**	SD	P value‡	**T2-T3**	SD	P value	**T3-T4**	SD	P value	**T1-T4**	SD	P value
prn	**0.92**	1.23	0.071	**-0.46**	1.38	0.652	**0.34**	0.78	0.160	**0.81**	1.03	0.020
acR	**-0.75**	1.26	0.137	**0.08**	0.95	0.572	**-0.21**	0.98	0.466	**-0.89**	1.20	0.027
acL	**-1.24**	0.67	0.001	**0.53**	0.86	0.053	**-0.15**	0.81	0.522	**-0.86**	0.67	0.001
sn	**0.24**	0.94	0.493	**-0.04**	0.63	0.756	**0.21**	0.56	0.232	**0.41**	0.72	0.076
sls	**-1.46**	1.62	0.039	**0.49**	0.91	0.369	**0.10**	1.01	0.290	**-0.87**	1.47	0.066
ls	**-1.61**	1.87	0.045	**-0.01**	0.44	0.869	**0.21**	0.89	0.443	**-1.41**	1.62	0.011
chR	**-1.26**	1.44	0.043	**0.03**	1.17	0.726	**0.27**	1.27	0.969	**-0.96**	1.02	0.008
chL	**-1.79**	0.87	0.001	**0.25**	1.12	0.842	**-0.07**	0.80	0.756	**-1.62**	0.98	<0.001
stms	**-0.80**	1.25	0.112	**-0.16**	0.74	0.373	**0.60**	1.06	0.092	**-0.37**	1.41	0.385
stmi	**-1.21**	1.38	0.043	**0.00**	0.95	0.765	**0.12**	0.71	0.562	**-1.09**	1.74	0.054
li	**-2.00**	2.16	0.021	**0.83**	1.37	0.132	**-0.34**	1.47	0.445	**-1.51**	2.59	0.069
ils	**-0.99**	1.78	0.158	**0.43**	2.16	0.243	**-0.16**	1.38	0.690	**-0.72**	3.15	0.784
pog	**-0.12**	2.04	0.870	**-0.92**	1.73	0.529	**0.07**	1.57	0.886	**-0.97**	4.02	0.420

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate upward movements and negative values indicate downward movements.

(‡) One-sample t tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.3.3 X-displacements of landmarks (Table 4.36)

Transversely, soft tissue displacements were minimal in comparison with displacements in the z- or y-axes. Significant divergence of alar base points was observed ($p<0.01$) between T1 and T2. Labrale superius moved laterally to the right about 0.74 mm ($p<0.05$). The same vector and amount of movement was observed with 'stms', 'stmi' and 'li'. Changes from T2-T3 and T3-T4 were insignificant and for many landmarks, these were negligible. The main overall soft-tissue responses encountered transversely in this subgroup were: divergence in 'acL' and 'acR' ($p<0.01$) and a mean deviation of Labrale inferius to the right side of about 0.6 mm ($p<0.05$).

Table 4.36	X displacements of 13 soft-tissue landmarks in subgroup B (n=12)*											
L*	T1-T2†	SD	P value‡	T2-T3	SD	P value	T3-T4	SD	P value	T1-T4	SD	P value
prn	**0.25**	0.40	0.117	**-0.06**	0.73	0.838	**-0.17**	0.46	0.410	**0.02**	0.82	0.928
acR	**1.89**	0.71	<0.001	**-0.24**	0.78	0.936	**-0.28**	0.55	0.100	**1.36**	0.88	<0.001
acL	**-1.20**	0.78	0.003	**-0.22**	0.57	0.726	**0.18**	0.48	0.237	**-1.24**	1.05	0.002
sn	**0.21**	0.36	0.080	**-0.25**	0.58	0.518	**0.14**	0.39	0.231	**0.10**	0.79	0.673
sls	**0.38**	0.70	0.165	**-0.38**	0.79	0.352	**0.03**	0.54	0.843	**0.04**	0.86	0.888
ls	**0.74**	0.81	0.037	**-0.75**	0.94	0.147	**0.21**	0.49	0.169	**0.20**	0.83	0.422
chR	**0.84**	1.44	0.142	**-0.55**	1.09	0.487	**0.20**	0.71	0.351	**0.49**	1.61	0.314
chL	**0.46**	1.82	0.494	**0.24**	0.38	0.060	**-0.20**	1.01	0.497	**0.50**	1.43	0.252
stms	**0.75**	0.72	0.022	**-0.32**	0.90	0.978	**0.05**	0.74	0.290	**0.47**	1.12	0.169
stmi	**0.70**	0.75	0.034	**-0.33**	0.76	0.726	**0.11**	0.90	0.675	**0.48**	1.17	0.184
li	**0.76**	0.83	0.035	**-0.47**	0.61	0.177	**0.30**	0.56	0.089	**0.59**	0.83	0.038
ils	**0.46**	0.82	0.158	**0.06**	1.43	0.954	**-0.10**	0.47	0.461	**0.41**	1.50	0.366
pog	**0.36**	1.28	0.447	**0.18**	1.35	0.728	**0.01**	0.74	0.978	**0.55**	2.23	0.411

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate movements to the right side of the patient's face and negative values indicate movements to the left side.

(‡) One-sample t tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.4 3D landmark-based facial asymmetry analysis

4.3.2.4.1 General facial asymmetry scores (Tables 4.37 and 4.38)

There was a small improvement as a result of surgery (between T2-T1; median= 1.19), but it was statistically insignificant. The best scores were achieved at T2 (Table 4.35). Insignificant deterioration occurred in the postsurgical period (between T2-T4). The reduction in the inter-quartile range from T1 to T4 indicated less variation in facial asymmetry scores and lack of extreme values at six months following surgery.

Table 4.37	Facial asymmetry scores in subgroup B (n=12)				
Time	**Median**	Minimum	Maximum	1st Quartile	3rd Quartile
T1	**2.29**	0.77	7.23	1.33	4.84
T2	**1.66**	0.96	4.15	1.32	2.82
T3	**1.68**	0.42	4.34	1.03	3.44
T4	**2.09**	0.42	4.10	1.72	2.92

Table 4.38	Differences in facial asymmetry scores in subgroup B (n=12)				
Time comparison	T1-T4	T1-T2	T2-T3	T2-T4	T3-T4
Median of difference	-0.57	-1.19	-0.09	0.29	0.02
95% CI of median	-1.93, 0.28	-2.82, 0.11	-1.11, 1.17	-0.82, 1.13	-0.58, 0.65
P value	**0.152**	**0.183**	**0.726**	**0.624**	**0.912**

4.3.2.4.2 Individual landmark asymmetry scores (Tables 4.39 and 4.40)

At the presurgical assessment (Table 4.31), the most symmetric points were 'stmi', 'li', 'sn', 'ils' and 'sls'. The most asymmetric points were 'chL', 'chR', 'acL', 'acR', 'excL' and 'excR'. The ranks changed at T4 (Table 4.32) with 'stms', 'stmi', 'li', 'ls' and 'ils' being the most symmetric landmarks, whereas 'prn', 'chL', 'chR', 'excL' and 'excR' were the most asymmetric ones. The rank of the nasal tip landmark at T4 was lower than at T1 indicating deterioration in symmetry status.

Table 4.39	Individual landmark asymmetry score at T1 in subgroup B				
Landmark	Median	Minimum	Maximum	1st Quartile	3rd Quartile
stmi	1.20	0.10	5.60	0.40	2.93
li	1.35	0.40	8.60	0.83	4.75
sn	1.50	0.40	7.70	1.03	5.98
ils	2.05	0.50	6.70	1.73	4.43
sls	2.20	0.30	9.80	1.08	4.90
stms	2.20	0.10	6.60	0.33	3.13
na	2.70	0.10	10.10	0.73	3.53
ls	3.10	0.10	6.70	1.23	4.90
prn	3.15	0.00	13.90	1.15	7.78
men	3.50	0.90	13.80	2.90	10.83
encL	3.80	1.90	10.10	2.58	7.13
encR	3.80	1.90	10.10	2.58	7.13
pog	4.00	2.40	15.00	3.63	8.90
chL	5.30	0.90	10.40	2.68	7.38
chR	5.30	0.90	10.40	2.68	7.38
acL	5.60	1.90	13.20	3.45	6.38
acR	5.60	1.90	13.20	3.45	6.38
excL	7.40	1.70	14.40	4.00	9.83
excR	7.40	1.70	14.40	4.00	9.83

(*) Landmarks are ranked in order of ascending asymmetry.

Table 4.40	Individual landmark asymmetry score at T4 in subgroup B				
Landmark	Median	Minimum	Maximum	1st Quartile	3rd Quartile
stms	0.65	0.10	4.40	0.43	2.83
stmi	1.20	0.50	5.60	0.63	3.18
li	1.40	0.00	4.10	0.38	2.78
ls	1.45	0.10	3.80	0.68	3.23
ils	1.55	0.30	5.40	1.13	2.38
pog	1.70	0.10	6.40	0.40	4.98
na	2.05	0.60	4.20	1.40	2.58
men	2.15	0.20	11.20	0.50	5.60
sls	2.75	0.20	6.40	1.38	5.25
sn	2.75	0.60	5.50	2.23	4.20
encL	4.80	1.10	9.70	2.18	8.28
encR	4.80	1.10	9.70	2.18	8.28
acL	4.90	2.30	9.90	3.63	6.48
acR	4.90	2.30	9.90	3.63	6.48
prn	5.00	1.20	11.10	2.15	6.40
chL	5.15	1.70	8.10	3.23	6.55
chR	5.15	1.70	8.10	3.23	6.55
excL	7.10	2.20	10.20	6.00	9.18
excR	7.10	2.20	10.20	6.00	9.18

(*) Landmarks are ranked in order of ascending asymmetry.

4.3.2.5 Cephalometric analyses in subgroup B

4.3.2.5.1 Surgical change (T1-T2)

4.3.2.5.1.1 Anteroposterior displacements (Table 4.41)

Surgical changes included a mean advancement of the maxilla of about 3 mm when assessed at 'A' point ($p<0.001$). 'B' point had a significant median backward movement of about 1.8 mm ($p=0.014$) indicating a backward shift of the mandibular apical base. The landmarks representing the chin segment, i.e. 'Pog', 'Gn' and 'Men', moved backward significantly (mean= -2.61; $p=0.021$ for Pog). With regard to soft tissues, significant advancement of 'prn', 'sn', 'sls', 'ls' and 'stms' occurred with Labrale superius showing maximum variance among the nasal and upper labial landmarks (SD=2.87). Labrale inferius protruded significantly although the underlying bony segments showed a backward movement. The backward displacements of soft-tissue Pogonion and Gnathion were small and insignificant, whereas this movement was significant for soft-tissue Menton (mean= -2.66 mm, $p=0.010$).

Table 4.41	X displacements of 30 landmarks in subgroup B (n=12)								
Landmark	**T2-T1***	**SD**	**P value†**	**T3-T2**	**SD**	**P value**	**T3-T1**	**SD**	**P**
prn	**1.36**	0.78	<0.001	**-0.40**	1.40	0.349	**0.96**	1.42	0.038
sn	**3.50**	1.82	<0.001	**-1.73**	1.62	0.003	**1.90**		0.037
sls	**4.55**		0.003	**-2.20**	2.28	0.007	**2.75**	2.14	0.001
ls	**4.86**		0.003	**-3.41**	3.19	0.003	**2.22**	2.70	0.016
stms	**3.71**	2.35	<0.001	**-2.81**	1.81	<0.001	**0.90**	2.46	0.232
stmi	**2.72**	2.37	0.002	**-2.13**	1.85	0.002	**0.59**	2.75	0.471
li	**1.37**	1.73	0.019	**-2.04**	2.00	0.005	**0.00**		0.294
ils	**0.19**	3.26	0.843	**-0.36**	1.87	0.519	**-0.17**	2.64	0.828
pog	**-0.40**	3.28	0.683	**-0.06**	2.82	0.947	**-0.45**	3.71	0.680
gn	**-0.96**	3.48	0.358	**0.24**	2.09	0.694	**-0.72**	3.47	0.486
men	**-2.66**	2.60	0.010	**0.00**		0.142	**-1.46**	3.72	0.221
ANS	**3.07**	1.52	<0.001	**-0.54**	2.05	0.382	**2.54**	2.37	0.003
A	**3.18**	1.28	<0.001	**-0.47**	1.81	0.389	**2.71**	2.33	0.002
Pr	**2.91**	1.97	0.001	**0.46**	1.57	0.377	**3.23**		0.011
IS	**3.64**		0.009	**0.59**	1.43	0.206	**3.64**		0.007
II	**-1.80**		0.015	**0.31**	1.48	0.487	**-1.37**	2.13	0.048
Id	**-1.84**	2.26	0.017	**0.85**	1.58	0.091	**-0.99**	2.56	0.207
B	**-1.82**		0.014	**0.86**		0.209	**-1.24**	2.72	0.142
Pog	**-2.61**	3.35	0.021	**1.23**	2.47	0.112	**-1.38**	3.81	0.236
Gn	**-2.46**	2.66	0.008	**0.46**		0.197	**-1.39**	3.64	0.212
Men	**-2.03**	2.72	0.026	**0.83**	2.42	0.259	**-1.19**	3.85	0.306
Ge	**-2.57**	2.23	0.002	**1.29**	2.27	0.075	**-1.28**	3.25	0.199
Go	**-0.91**		0.099	**0.42**	2.04	0.492	**-0.94**		0.625
Ar	**0.00**		0.753	**-0.06**	0.84	0.803	**0.01**	1.06	0.966
Cd	**-0.09**	0.89	0.735	**0.00**		0.205	**0.39**	1.05	0.226
PNS	**3.36**	1.02	<0.001	**-0.39**	1.61	0.420	**2.27**		0.003
UIA	**2.98**	1.99	0.001	**-0.11**	1.56	0.834	**2.87**	2.43	0.005
LIA	**-2.17**	2.19	0.006	**0.76**	2.11	0.237	**-1.41**	3.36	0.174

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate forward movements, whereas negative values indicate backward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

4.3.2.5.1.2 Vertical displacements (Table 4.42)

Vertical displacements of landmarks were generally lower than those observed anteroposteriorly at all assessment times. Upper anterior maxillary landmarks showed a downward movement of the maxilla, which was significant at 'A' point (p=0.035). Five subjects had an inferior repositioning of the maxilla, and the amount of downward displacement could have increased if all of the twelve subjects included in this subgroup had the same vertical vector of movement. Changes in the mandibular landmarks were insignificant between T1 and T2. The nasal tip displaced significantly in a superior direction (p<0.001) and the median value was approximately 2.2 mm. The Subnasale landmark moved in the same direction 1.64 mm (p=0.003). The remaining soft-tissue landmarks moved different amounts in either direction, but these did not reach statistical significance.

Table 4.42 **Y displacement of landmarks in subgroup B (n=12)**

Landmark	T2-T1*	SD	P value†	T3-T2	SD	P value	T3-T1	SD	P value
prn	2.23	1.34	<0.001	-0.68	1.31	0.098	1.82		0.010
sn	1.64	1.48	0.003	-0.79	1.90	0.180	0.85	1.15	0.026
sls	0.92		0.050	-1.41	2.22	0.051	-0.28	2.28	0.682
ls	0.26	2.26	0.702	-0.96	2.61	0.231	-0.70	2.35	0.324
stms	-0.91	1.73	0.095	0.34	2.26	0.615	-1.39		0.328
stmi	-0.61	3.24	0.527	-0.14	3.54	0.890	-0.76	2.40	0.299
li	-1.26	4.47	0.351	0.84	4.32	0.516	-0.42	3.58	0.692
ils	0.05	5.40	0.976	-0.17	3.60	0.872	-0.12	3.88	0.915
pog	-0.20	6.68	0.920	-0.57	3.83	0.617	-0.77	4.67	0.581
gn	-0.55	5.20	0.719	0.49	1.88	0.389	-0.07	4.29	0.958
men	-1.84	3.74	0.154	1.94	2.53	0.029	0.75	3.21	0.458
ANS	-0.69		0.093	0.99	1.83	0.088	0.00		0.674
A	-1.73	2.50	0.035	0.52	1.55	0.269	-1.21	1.91	0.051
Pr	-2.04	3.10	0.067	0.23	1.33	0.605	-1.82	2.79	0.069
IS	-1.83	2.91	0.063	1.12	1.81	0.068	-0.72	3.21	0.476
II	0.39		0.683	1.40	1.84	0.023	1.70		0.328
Id	-0.42	2.46	0.565	1.23	2.22	0.082	0.81	2.36	0.258
B	-0.32	2.56	0.674	1.00	1.73	0.072	0.68	2.69	0.401
Pog	0.28	4.48	0.832	1.12	1.78	0.052	3.18		0.351
Gn	0.57	4.57	0.672	0.87	1.51	0.070	2.73		0.230
Men	0.49	4.46	0.710	1.18	1.49	0.019	1.67	4.38	0.213
Ge	-0.43	2.88	0.618	1.37	1.97	0.035	0.94	2.79	0.265
Go	0.04	1.51	0.921	0.39	1.51	0.387	0.44	1.18	0.228
Ar	0.00		0.726	0.86	1.54	0.079	0.67	1.00	0.041
Cd	0.47	1.22	0.212	-0.28	1.20	0.432	0.18	1.23	0.620
PNS	-1.01	2.63	0.212	0.91		0.168	-0.40	2.76	0.623
UIA	-1.53	2.47	0.081	0.16	1.81	0.787	-1.38	2.75	0.148
LIA	-0.32	1.97	0.588	0.60	1.78	0.266	0.29	1.89	0.610

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate upward movements, whereas negative values indicate downward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

4.3.2.5.1.3 Linear measurements (Table 4.43)

The main significant changes were: an increase in the maxillary length measured from Condylion to 'ANS' ($p<0.001$); significant overjet correction from a negative value indicating a presurgical anterior crossbite to a value within the normal limits (at T2) ($p<0.001$); significant increase in the upper labial height ($p=0.001$) as well as in the upper vermilion height ($p=0.035$); significant increase in soft-tissue lower facial height ($p=0.025$) and a significant reduction in the columellar length ($p=0.004$).

Table 4.43 — **Interlandmark distances in subgroup B (n=12)**

Distance*	T1†	SD	P value T2 - T1‡	T2	SD	P value T3 - T2	T3	SD	P value T3- T1
TAFH	**114.89**	11.16	0.610	**114.24**	8.81	0.079	**113.37**	8.64	0.256
UAFH	**50.91**	3.45	0.093	**52.37**	4.93	0.174	**51.61**	4.03	0.332
LAFH	**64.44**	8.94	0.307	**63.40**	6.61	0.359	**62.98**	6.72	0.215
PFH	**78.66**	8.13	0.884	**78.73**	7.42	0.480	**78.32**	7.75	0.309
MdL	**116.65**	7.57	0.080	**114.77**	5.81	0.560	**114.59**	6.11	0.081
MdRmH	**58.30**	4.75	0.750	**58.49**	4.38	0.447	**57.97**	4.58	0.399
MdBL	**72.73**		0.058	**73.21**	4.21	0.212	**73.73**	4.48	0.113
MxL1	**80.94**	5.90	<0.001	**84.62**	5.91	0.099	**83.60**	5.62	0.009
MxL2	**85.05**	6.07	<0.001	**88.53**	6.35	0.167	**87.51**	6.07	0.009
MxL3	**48.70**	5.17	0.294	**48.34**	5.12	0.678	**48.50**	5.12	0.628
FAL	**124.49**	8.71	0.130	**122.82**	6.72	0.721	**122.73**	7.29	0.135
PCB	**33.39**	4.19	0.122	**33.94**	4.05	0.007	**33.00**	4.05	0.131
OJ	**-2.82**	3.16	<0.001	**1.88**		0.715	**2.17**	1.45	<0.001
OB	**0.09**	2.46	0.272	**0.91**		0.899	**1.82**		0.185
Incisor show	**1.83**	2.61	0.267	**2.75**	2.11	0.120	**2.00**	1.90	0.809
ULH (S)	**17.73**		0.001	**20.99**	2.97	0.109	**19.94**	2.96	0.051
UVH (S)	**4.73**	1.04	0.035	**5.81**	1.47	0.160	**4.99**	1.02	0.505
LLH (S)	**18.44**	3.42	0.524	**17.93**	2.84	0.805	**17.80**	2.76	0.437
LVH (S)	**7.47**	1.66	0.266	**8.42**	2.02	0.019	**7.21**	1.05	0.627
LFH (S)	**67.05**	8.51	0.025	**69.72**	5.79	0.035	**67.97**	6.84	0.996
ILD (S)	**0.92**		0.388	**0.00**		0.701	**0.91**		0.554
TVH (S)	**13.94**	2.83	0.218	**15.31**	3.54	0.170	**12.73**		0.771
ColumL (S)	**15.70**	1.87	0.004	**13.71**	1.72	0.008	**14.90**	2.37	0.076

(*) Abbreviations of the distances used have been explained in Table 3.8 and 3.9. 'S' stands for a soft-tissue distance.

(†) Values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.5.1.4 Angular measurements (Table 4.44)

The skeletal characteristics of this subgroup included a retrognathic maxilla (SNA=78.13°), a prognathic mandible (SNB=82.45°, SNPog=83.65°), a Class III skeletal relationship (ANB=-4.31°) and normal inclinations of maxillary and mandibular planes to SN plane. The dentoskeletal features included normal inclinations of upper and lower incisor to their bases as well as an interincisor angle within normal limits.

Between T1 and T2, there was a significant improvement in 'SNA' angle ($p<0.001$). Although a maxillary correction was performed in this subgroup, 'SNB' angle reduced approximately 1° ($p=0.039$). Despite the reduction in the 'SNB' angle, the mandible remained prognathic at T2 and T3. The 'ANB' improved significantly but it did not lie between 2° and 4° (the normal range). The nasal tip angle increased significantly ($p=0.025$) while an insignificant decrease was observed in the labiomental angle ($p=0.100$). A significant improvement was observed in the facial profile angle ($p=0.004$).

Table 4.44	**Interlandmark angles in subgroup B (n=12)**								
Angle*	**T1†**	SD	P value T2-T1‡	**T2**	SD	P value T3-T2	**T3**	SD	P value T3-T1
SNA	**78.13**	5	<u><0.001</u>	**81.31**	5.32	0.408	**80.92**	4.92	<u>0.001</u>
SNB	**82.45**	3.83	<u>0.039</u>	**81.47**	3.71	0.136	**82.06**	4.17	0.485
ANB	**-4.31**	3.92	<u><0.001</u>	**-0.15**	3.63	<u>0.033</u>	**-1.182**	3.151	<u><0.001</u>
SNPog	**83.65**	4.07	0.063	**82.53**	3.99	0.190	**83.08**	4.11	0.386
MxSN	**8.9**	2.303	0.862	**8.67**	3.74	0.578	**9.02**	4.31	0.929
MdSN	**31.53**	7.93	0.682	**31.12**	6.66	0.400	**30.54**	6.13	0.358
MxMd	**22.62**	9.29	0.907	**22.44**	8.46	0.142	**21.53**	8.3	0.474
MPIA	**95.72**	11.17	0.073	**93.83**	10.59	0.251	**95.34**	10.78	0.833
UISN	**106.62**	7.18	0.919	**106.44**	5.93	0.124	**109.12**	7.74	0.346
IIA	**135.7**	12	0.513	**134.28**	8.22	0.782	**133.71**	9.87	0.585
Nasal tip	**94.92**	5.57	<u>0.025</u>	**97.22**	6.72	<u>0.004</u>	**94.71**	6.56	0.790
Nasolabial	**122.5**	9.76	0.444	**119.78**	8.43	0.123	**124.14**	9.86	0.570
Labiomental	**139.79**	16.28	0.100	**135.69**	15.57	<u>0.010</u>	**145.82**	13.13	0.142
Chin	**117.35**	8.05	0.329	**120.05**	8.87	<u>0.025</u>	**115.85**	8.03	0.543
Facial profile	**135.94**	5.61	<u>0.004</u>	**133.6**		0.979	**132.2**		<u>0.004</u>

(*) Abbreviations of the angles used have been explained in Table 3.8 and 3.9.

(†) Values are stated in degrees. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.5.1.5 Soft-tissue thicknesses (Table 4.45)

Results related to this subgroup are shown in Table 4.55. Apart from the Subnasale and Menton levels, significant thickening of the soft-tissue drape was observed at the remaining levels.

Table 4.45	**Facial soft-tissue thicknesses in the midsagittal plane at seven levels in subgroup B (n=12)**								
Thickness at	**T1***	SD	P value T2-T1†	**T2**	SD	P value T3-T2	**T3**	SD	P value T3-T1
sn	11.74		0.521	**13.08**	3.04	0.037	**11.73**	2.64	0.167
sls	**16.84**	2.61	0.009	**18.60**	2.32	0.007	**16.72**	2.13	0.756
ls	14.82		0.012	**17.79**	2.68	0.001	**13.73**	2.75	0.019
li	**13.64**	2.68	0.003	**16.93**	2.29	0.003	**14.27**	2.51	0.031
ils	**11.35**	1.92	0.007	**13.40**	2.00	0.032	**12.27**	1.98	0.058
pog	**12.42**	2.35	0.027	**14.71**	2.91	0.033	**13.27**	2.32	0.178
men	**8.38**	1.46	0.119	**9.51**	2.45	0.451	**9.13**	2.39	0.303

(*) Values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(†) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.2.5.2 Postsurgical relapse (T2-T3)

4.3.2.5.2.1 Anteroposterior displacements (Table 4.41)

The follow-up period revealed non-significant changes in the bony landmarks and several significant changes in the soft-tissue landmarks. The mean maxillary relapse assessed at 'A' point was of the order of 0.5 mm (p=0.389). The median mandibular body relapse assessed at 'B' point was about 0.9 mm (p=0.209). Surgical correction of the chin relapsed by 1.23 mm, which was also insignificant (p=0.112) due to the relatively large standard deviation (SD=2.47). Most soft-tissue displacements in this period were principally in a backward direction. The entire nasal, upper and lower labial landmarks, which showed a forward movement between T1 and T2, moved backward. This change was significant for the related landmarks with the exception of 'prn' (p=0.349) and 'ils' (p=0.519).

4.3.2.5.2.2 Vertical displacements (Table 4.42)

Non-significant vertical relapse was observed in the maxilla at the following landmarks: 'A', 'ANS' or 'Pr'. Mean superior movement of anterior mandibular landmarks was 1 mm at 'B' point (p=0.072) and 1.37 mm at 'Ge' (p=0.035). The nasal tip had a mean downward movement of about 0.7 mm (p=0.098). The subnasal point showed a similar relapse (p=0.180). The lower soft-tissue landmarks did not show any significant change apart from soft-tissue Menton, which displaced superiorly 1.94 mm (p=0.029) in the postsurgical period.

4.3.2.5.2.3 Linear measurements (Table 4.43)

Non-significant changes occurred with regard to hard-tissue linear measurements. There was a significant reduction in mean lower vermilion height (p=0.019). The increase in soft-tissue lower facial height seen between T1 and T2 was cancelled out between T2 and T3 (p=0.035) and the columellar length showed significant relapse (p=0.008).

4.3.2.5.2.4 Angular measurements (Table 4.44)

'ANB' relapsed significantly (p=0.033) increasing the Class III skeletal relationship. Relapse was seen in the nasal tip angle cancelling out the initial surgical change (p=0.004). One of the interesting findings in the postsurgical period was the significant increase in labiomental angle, which became more obtuse at T3 (p=0.010).

4.3.2.5.2.5 Soft-tissue thicknesses (Table 4.45)

The increase in soft-tissue thickness observed between T1 and T2, was counteracted by a significant decrease between T2 and T3 at all soft-tissue levels with the exception of the Menton level.

4.3.2.5.3 Overall change (T1-T3)

4.3.2.5.3.1 Anteroposterior displacements (Table 4.41)

The overall changes anteroposteriorly were: significant forward displacement of the maxilla assessed at 'A' point (p=0.003); non-significant backward positioning of the mandible assessed at 'B' point (p=0.142); non-significant backward movement of Pogonion (p=0.236); significant forward movement of the nasal tip (p=0.038); significant forward displacements of the upper labial landmarks apart from 'stms' ($p<0.05$) and negligible amounts of lower labial and mental landmark displacements.

4.3.2.5.3.2 Vertical displacements (Table 4.42)

The overall changes in the vertical direction were insignificant downward movement of point 'A' (p=0.051), insignificant vertical displacements in lower anterior mandibular landmarks which were generally in a superior direction, significant raise in the nasal tip (median= 1.82 mm; p=0.010) as well as in the subnasal point (mean= 0.85 mm; p=0.026) and insignificant downward displacements of upper and lower labial landmarks with Stomion superius showing the most prominent change (median= -1.39 mm; p=328).

4.3.2.5.3.3 Linear measurements (Table 4.43)

The overall hard- and soft-tissue changes can be summarised as follows: insignificant reduction in total anterior facial height (p=0.256), insignificant reduction in lower anterior facial height (p=0.215), insignificant reduction in mandibular length (p=0.081), significant increase in maxillary length (p=0.009), significant correction of the anteroposterior incisor relationship (p<0.001), insignificant improvement in the vertical incisor relationship (p=0.185), insignificant increase in upper labial height (p=0.051), insignificant decrease in columellar length (p=0.076).

4.3.2.5.3.4 Angular measurements (Table 4.44)

The overall angular changes can be summarised as follows: significant improvement in the 'SNA' angle (p=0.001) as well as in the 'ANB' angle (p<0.001), significant decrease in facial profile angle, which became more acute (p=0.004).

4.3.2.5.3.5 Soft-tissue thicknesses (Table 4.45)

The main net changes between T1 and T3 were the significant thinning of the upper lip assessed at Labrale superius (p=0.019) and the significant thickening of the lower lip assessed at Labrale inferius (p=0.031). Thickening at 'ils', 'Pog' and Menton was observed but it did not reach significance.

4.3.2.5.3.6 Soft- to hard-tissue displacements ratios (Table 4.46)

Anteroposterior ratios. At the Subnasale level, the median displacement ratio was 0.88:1 with 'ANS' (p=0.045), whereas it was almost a one-to-one ratio at the superior labial sulcus level when linked with 'A' point (p=0.037). Similar to what was observed in subgroup A, the ratio dropped down slightly when looking at Labrale superius movement as response to the movement of Prosthion (median= 0.67:1; p=0.018). Although the patients included in this subgroup did not undergo a mandibular ramus or body osteotomy, in several subjects a genioplasty was performed, which affected the soft tissues in the mental region and probably contributed to some changes in the lower labial regions. The analysis revealed some significant ratios, such as the median displacement ratio of 0.8:1 observed between

Labrale inferius and Infradentale (p=0.022). A one-to-one median displacement ratio was noticed between the soft-tissue chin landmarks and the corresponding bony landmarks. Soft-tissue Pogonion, however, moved in a ratio of 1.37:1 with the movement of 'B' point (p=0.013).

Vertical ratios. Three ratios were significant. Labrale superius moved in a median ratio of 1.05:1 with the vertical movement of 'A' point (p=0.008). Soft-tissue Gnathion moved in a ratio of 0.93:1 with the vertical movement of the bony Gnathion (p=0.013), whereas Menton gave a median displacement ratio of 0.8:1 (p=0.006).

Table 4.46	**Soft- to hard-tissue displacement ratios in subgroup B (n=12)**			
Soft-tissue/hard-tissue	**X axis***	P value	**Y axis**	P value
prn-ANS	0.25	0.141	0.64	0.529
prn-A	0.27	0.141	-1.00	0.100
sn-ANS	**0.88**	0.045	0.19	0.345
sn-A	**0.92**	0.045	0.00	0.294
sls-ANS	1.01	0.056	0.83	0.107
sls-A	**1.01**	0.037	0.80	0.154
ls-A	0.83	0.056	**1.05**	0.008
ls-Pr	**0.67**	0.018	0.00	0.834
stms-IS	0.33	0.333	0.49	0.076
stmi-IS	0.00	0.476	0.27	0.059
stmi-II	0.33	1.000	0.00	0.906
li_II	0.00	0.590	0.80	0.541
li_Id	**0.80**	0.022	0.80	0.343
li-B	0.71	0.059	0.64	0.834
ils-Id	1.00	0.062	0.75	0.236
ils-B	1.00	0.126	1.00	0.374
ils-Ge	0.82	0.074	0.75	0.214
pog-B	**1.37**	0.013	0.61	0.813
pog-Pog	**1.00**	0.006	0.67	0.168
pog-Ge	**1.02**	0.019	1.00	0.343
gn-Gn	**1.00**	0.004	**0.93**	0.013
men_Men	**1.07**	0.008	**0.80**	0.006

(*) Median values are stated here instead of means. One-sample Wilcoxon singed rank test was applied to detect if the calculated ratios were significantly different from zero. Significant results are printed in a red bold font and the related p-values are underlined.

4.3.3 Subgroup C: Class II patients treated by bimaxillary surgery

4.3.3.1 Stereophotogrammetry-based linear measurements

4.3.3.1.1 Surgical change (T1-T2; Table 4.47)

Alar base width increased significantly ($p<0.01$) as well as the mandibular length on both sides of the face ($p<0.01$). The total and the lower facial heights decreased significantly as a result of the maxillary impaction ($p<0.05$). The upper lip height did not alter significantly in this period of observation. An insignificant increase in mouth width was observed (mean≈1.2 mm).

4.3.3.1.2 Postsurgical change (T2-T3 and T3-T4)

The increase seen at T2 in alar base width did not relapse at T3, but relapsed slightly at T4 ($p<0.05$). No significant relapse could be detected for the other linear measurements between T2-T3 and T3-T4.

4.3.3.1.3 Overall change (T1-T4)

The main net changes were: increase in alar base width ($p<0.01$), decrease in total and lower facial heights ($p<0.01$), increase in mandibular right and left lengths ($p<0.01$), and small amount of decrease in upper facial height as well as nasal bridge length ($p<0.05$).

Table 4.47		Linear measurements in subgroup C (n=12)†								
No	**Distance** (in mm)	**Mean at T1** (SD)	**T1-T4**	**T1-T2**	**Mean at T2** (SD)	**T2-T3**	**Mean at T3** (SD)	**T3-T4**	**Mean at T4** (SD)	**T2-T4**
1	Alar base width	**32.43** (1.91)	**	**	**35.69** (2.43)	ns	**36.00** (2.25)	*	**35.33** (2.12)	ns
2	Nasal tip projection	**18.61** (2.35)	ns	ns	**18.07** (1.69)	ns	**18.42** (2.66)	ns	**18.56** (2.46)	ns
3	Nasal bridge length	**45.89** (3.50)	*	ns	**45.82** (3.02)	ns	**44.25** (3.75)	ns	**44.44** (3.26)	*
4	Upper lip height	**20.14** (2.25)	ns	ns	**19.83** (3.72)	ns	**20.49** (3.06)	ns	**19.81** (2.40)	ns
5	Upper vermilion height	**5.58** (0.71)	ns	ns	**5.92** (0.58)	ns	**5.63** (0.75)	ns	**5.83** (1.16)	ns
6	Lower lip height	**16.39** (1.24)	ns	ns	**16.60** (1.72)	ns	**16.46** (1.55)	ns	**16.54** (1.60)	ns
7	Lower vermilion height	**8.11** (1.30)	ns	ns	**8.31** (1.19)	ns	**8.28** (1.56)	ns	**8.17** (1.83)	ns
8	Mouth width	**45.89** 2.42	ns	ns	**47.07** (2.17)	ns	**46.65** (2.76)	ns	**46.85** (2.68)	ns
9	Upper facial height	**52.27** (3.95)	*	ns	**51.96** (2.59)	ns	**50.93** (4.32)	ns	**51.05** (3.51)	ns
10	Lower facial height	**73.94** (3.37)	**	*	**70.32** (3.66)	ns	**69.96** (2.49)	ns	**69.45** (2.93)	ns
11	Total facial height	**120.53** (4.48)	**	*	**118.09** 4.99	ns	**117.19** (4.31)	ns	**116.82** 3.59	ns
12	Mandibular length left	**117.09** (5.30)	**	**	**124.73** (5.86)	ns	**124.76** (4.54)	ns	**124.99** (5.08)	ns
13	Mandibular length right	**118.03** (5.84)	**	**	**125.75** (5.71)	ns	**124.07** (4.85)	ns	**124.46** (4.74)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols used: * statistically significant difference at p<0.05, ** p<0.01; ns= non-significant. Student's paired t tests are indicated in black, while Wilcoxon signed rank tests are indicated in blue.

4.3.3.2 Stereophotogrammetry-based angular measurements

4.3.3.2.1 Surgical change (T1-T2; Table 4.48)

Obvious improvement in facial profile was achieved. There was a significant increase in the facial convexity angle and the facial profile angle ($p<0.01$) The mean decrease in the nasolabial angle was almost 2 degrees, but this was not significant ($p>0.05$). Labiomental angle, however, showed a significant improvement ($p<0.01$).

4.3.3.2.2 Postsurgical relapse (T2-T3 and T3-T4)

No significant change was seen between T2 and T3 or T3 and T4, but a some small amount of relapse was found in the facial convexity angle, the facial profile angle, the nasal tip angle and the labiomental angle throughout the postsurgical period.

4.3.3.2.3 Overall change (T1-T4)

Three important net changes were observed: a significant increase in the facial convexity and the facial profile angles (p<0.01) as well as a significant increase in the labiomental fold angle (p<0.01).

Table 4.48		Angular measurements in subgroup C (n=12)†									
No	Angle	Mean at T1 (SD)	T1-T4	T1-T2	Mean at T2 (SD)	T2-T3	Mean at T3 (SD)	T3-T4	Mean at T4 (SD)	T2-T4
1	Facial convexity angle	**149.88** (4.26)	**	**	**155.72** (4.72)	ns	**157.89** (4.75)	ns	**157.71** (5.18)	ns
2	Facial profile angle	**122.16** (4.45)	**	**	**127.03** (5.89)	ns	**128.22** (5.83)	ns	**127.67** (5.93)	ns
3	Nasolabial angle	**132.14** (8.06)	ns	ns	**130.16** (12.39)	ns	**130.94** (10.22)	ns	**130.31** (10.64)	ns
4	Nasal tip angle	**99.60** (6.05)	ns	ns	**99.92** (7.13)	ns	**100.56** (6.54)	ns	**100.17** (6.62)	ns
5	Labiomental angle	**126.88** (12.41)	**	**	**139.04** (15.32)	ns	**135.16** (9.31)	ns	**135.23** (13.54)	ns
6	Chin angle	**142.97** (7.65)	ns	ns	**145.58** (9.62)	ns	**139.63** (7.14)	ns	**140.16** (6.02)	ns

(†) Testing for significant differences was performed for each comparison and the results are displayed in separate columns shaded in grey.

Symbols: * statistically significant difference at p<0.05, ** p<0.01; ns= non-significant. Paired t tests are indicated in black, while Wilcoxon signed rank tests are indicated in blue.

4.3.3.3 3D displacements of soft-tissue landmarks

4.3.3.3.1 Z-displacements of landmarks (Table 4.49)

Surgical change (T1-T2). The nasal tip moved slightly forward (mean=0.33 mm), while the subnasal point showed a greater extent of movement of about 1 mm (p<0.05). There was a gradual increase of anterior soft-tissue displacements from 'prn' to 'Pogonion'. 'Sls' and 'ls' displaced a mean of 1.50 mm (p<0.05) and 1.53 mm (p= 0.19) anteriorly and the magnitude was greater in 'stmi' (mean=5.77 mm; p<0.01), 'li' (mean=7.29 mm, p<0.01), 'ils' (mean=8.29 mm, p<0.01) and 'pog' (mean=8.63 mm, p<0.01). Lateral landmarks related to the alar base showed a mean advancement of 1.92 mm for 'acR' (p<0.01) and 2.58 mm for 'acL' (p<0.01). Mouth corners had a mean forward movement of more than 4 mm (p<0.01).

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, no significant landmark displacements were detected. The trend of movements for several landmarks, however, was in a backward direction, for example 'chR' and 'stms'.

Between T3 and T4, mean displacements were below 0.5 mm and did not reach significance.

Overall change (T1-T4). The overall changes observed between T1 and T4 were significant for twelve out of the thirteen landmarks. Landmarks related to the upper lip area ('sn', 'sls', 'ls' and 'stms') moved significantly forward and the mean movement ranged from 0.96 mm (p<0.01) for 'sn' to 1.91 mm (p<0.01) for 'ls'. Changes in the alar base points were in a forward direction (mean≈2 mm; p<0.01), while mouth corners showed a higher degree of advancement in the overall assessment (mean>3.5 mm; p<0.01). The maximum changes were seen at 'ils' (mean=9.23 mm; p<0.01) and 'pog' (mean=10.26 mm; p<0.01). The mean net changes (T1-T4) for 'stms', 'stmi', 'li', 'ils' and 'pog' were greater than the corresponding mean initial changes calculated between T1 and T2.

Table 4.49	**Z displacements of 13 soft-tissue landmarks in subgroup C (n=12)**											
L*	**T1-T2†**	SD	P value‡	**T2-T3**	SD	P value	**T3-T4**	SD	P value	**T1-T4**	SD	P value
prn	**0.33**	0.74	<u>≤0.001</u>	**0.35**	0.94	0.369	**0.05**	0.84	0.683	**0.73**	1.17	<u>≤0.001</u>
acR	**1.92**	1.46	<u>0.008</u>	**0.21**	1.52	0.519	**-0.10**	1.10	0.790	**2.03**	1.27	<u>≤0.001</u>
acL	**2.58**	0.83	<u>0.014</u>	**-0.67**	1.07	0.621	**0.18**	1.11	0.886	**2.09**	1.19	<u>≤0.001</u>
sn	**1.01**	0.86	<u>0.004</u>	**0.11**	0.76	0.567	**-0.16**	1.15	0.589	**0.96**	0.91	<u>0.021</u>
sls	**1.50**	1.71	<u>≤0.001</u>	**-0.06**	0.92	0.564	**0.29**	1.15	0.800	**1.73**	1.27	<u>≤0.001</u>
ls	**1.53**	2.81	<u>0.001</u>	**-0.02**	1.42	0.593	**0.40**	1.59	0.541	**1.91**	1.92	<u>≤0.001</u>
chR	**4.23**	2.82	0.167	**-0.22**	2.50	0.537	**-0.29**	1.66	0.447	**3.72**	2.80	<u>0.005</u>
chL	**4.47**	3.23	<u>0.001</u>	**0.03**	1.95	0.989	**0.05**	1.04	0.711	**4.55**	2.85	<u>≤0.001</u>
stms	**1.44**	3.44	0.250	**-0.19**	1.88	0.247	**0.44**	1.77	0.854	**1.69**	2.37	0.054
stmi	**5.77**	3.08	<u>0.042</u>	**0.49**	1.73	0.295	**0.00**	1.70	0.451	**6.26**	3.58	<u>0.001</u>
li	**7.29**	3.83	<u>0.013</u>	**0.90**	1.71	0.794	**-0.45**	1.27	0.677	**7.74**	3.76	<u>0.004</u>
ils	**8.29**	3.56	<u>0.001</u>	**1.08**	1.45	0.540	**-0.14**	1.70	0.998	**9.23**	3.81	<u>≤0.001</u>
pog	**8.63**	4.11	0.275	**1.38**	2.03	0.425	**0.25**	2.10	0.457	**10.26**	4.49	<u>0.031</u>

(*) L= landmark

(†) Mean displacements are stated (in millimetres). Positive values indicate forward movements and negative values indicate backward movements.

(‡) One-sample t-tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.3.2 Y-displacements of landmarks (Table 4.50)

Surgical change (T1-T2). Non-significant inferior displacements were observed for 10 landmarks, whereas 'prn', 'stmi' and 'li' had insignificant upward movements. It is noteworthy that the variation of vertical displacements was relatively wide for several landmarks.

Postsurgical relapse (T2-T3 and T3-T4). Between T2 and T3, there was significant inferior movement of Labrale superius (p<0.05) and Stomion superius (p<0.05). These changes, however, were counteracted by an opposite movement of these two landmarks between T3 and T4. One of the interesting findings between T2 and T3 was the superior movement of Stomion inferius (mean≈0.75 mm) and Labrale inferius (mean≈1.00).

Overall change (T1-T4). The main net changes were: a significant elevation of Stomion inferius (mean=1.72 mm; p<0.05), a significant elevation of Labrale inferius (mean=1.42 mm; p<0.05) and a significant inferior movement of 'acL' (mean=1.12 mm; p<0.05).

Table 4.50			**Y displacements of 13 soft-tissue landmark in subgroup C (n=12)**									
L*	**T1-T2†**	SD	P value‡	**T2-T3**	SD	P value	**T3-T4**	SD	P value	**T1-T4**	SD	P value
prn	**0.42**	0.86	0.212	**0.02**	1.04	0.964	**0.14**	1.21	0.719	**0.58**	1.18	0.115
acR	**-0.61**	2.17	0.453	**0.20**	1.34	0.401	**-0.30**	0.80	0.271	**-0.71**	1.32	0.088
acL	**-1.22**	1.61	0.070	**0.10**	1.47	0.473	**0.00**	1.27	0.997	**-1.12**	1.16	<u>0.007</u>
sn	**-0.28**	0.39	0.085	**0.05**	0.59	0.958	**0.06**	0.67	0.776	**-0.17**	0.81	0.493
sls	**-1.39**	1.68	0.052	**0.33**	0.88	0.163	**0.65**	1.09	0.089	**-0.40**	1.20	0.268
ls	**-0.07**	1.31	0.529	**-0.69**	0.66	<u>0.044</u>	**0.83**	0.90	<u>0.017</u>	**0.07**	1.17	0.839
chR	**-0.22**	2.43	0.807	**0.81**	1.13	0.073	**-0.33**	1.06	0.355	**0.26**	1.78	0.623
chL	**-0.16**	1.83	0.807	**0.19**	1.57	0.436	**0.07**	1.38	0.869	**0.10**	1.94	0.864
stms	**-0.34**	1.82	0.613	**-0.34**	0.93	0.099	**0.51**	1.05	0.163	**-0.17**	1.64	0.725
stmi	**0.86**	1.55	0.158	**0.74**	1.93	0.249	**0.12**	1.31	0.784	**1.72**	2.43	<u>0.032</u>
li	**0.33**	2.33	0.705	**0.96**	1.57	0.092	**0.14**	1.45	0.766	**1.42**	2.02	<u>0.033</u>
ils	**-2.30**	3.33	0.091	**0.18**	1.14	0.161	**0.42**	0.87	0.164	**-1.70**	2.73	0.054
pog	**-2.97**	3.61	0.053	**-0.50**	1.64	0.596	**0.46**	1.10	0.221	**-3.01**	3.57	<u>0.014</u>

(*) L= landmark. (†) Mean displacements are stated (in millimetres). Positive values indicate upward movements and negative values indicate downward movements. (‡) One-sample t-tests were applied on the calculated displacements. For non-normally distributed displacements, Wilcoxon matched-pairs signed-rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.3.3 X-displacements of landmarks (Table 4.51)

Surgical change (T1-T2). The main landmark displacements were located at the alar base, the mouth commissure and the chin area. Alar base points moved a significant distance apart ($p<0.01$). The same change was observed with 'chL' and 'chR', but to a lesser extent. 'Sn', 'sls' and 'ls' moved, on average, slightly and insignificantly to the left side of patient's face, while 'stmi', 'li', 'ils' and 'pog' moved , on average, insignificantly to the right side.

Postsurgical relapse (T2-T3 and T3-T4). Changes between T2 and T3 were insignificant. Pogonion continued to move laterally between T2-T3 and T3-T4, which ended up with a significant overall displacement between T1 and T4.

Overall change (T1-T4). The main net changes observed were: significant displacements of alar base landmarks in a divergent pattern (mean for 'acR'= +1.69 mm; mean for 'acL' = -1.18 mm), a significant displacement of right Cheilion (mean= 1.63 mm; $p<0.05$), and a significant lateral displacement of 'pog' (mean= +1.68 mm; $p<0.05$).

Table 4.51	**X displacements of 13 soft-tissue landmarks in subgroup C (n=12)**											
L*	**T1-T2†**	SD	P value‡	**T2-T3**	SD	P value	**T3-T4**	SD	P value	**T1-T4**	SD	P value
prn	**0.35**	0.64	0.166	**-0.05**	1.27	0.332	**-0.33**	0.92	0.294	**-0.03**	0.69	0.880
acR	**1.80**	1.25	0.005	**0.22**	0.86	0.732	**-0.33**	0.29	0.006	**1.69**	0.70	<0.001
acL	**-1.49**	0.69	<0.001	**-0.04**	0.68	0.831	**0.35**	0.83	0.220	**-1.18**	0.55	0.003
sn	**-0.08**	0.75	0.767	**0.37**	0.97	0.834	**-0.05**	0.44	0.725	**0.23**	0.75	0.302
sls	**-0.12**	0.87	0.712	**0.44**	0.88	0.978	**-0.08**	0.59	0.692	**0.25**	0.87	0.346
ls	**-0.35**	1.21	0.444	**0.76**	1.16	0.214	**-0.03**	0.68	0.911	**0.39**	1.09	0.238
chR	**1.33**	3.06	0.258	**0.09**	1.69	0.498	**0.21**	1.36	0.637	**1.63**	2.32	0.033
chL	**-0.29**	1.48	0.601	**0.90**	1.47	0.152	**0.06**	1.26	0.888	**0.67**	1.43	0.132
stms	**0.03**	1.54	0.965	**0.45**	1.22	0.328	**0.07**	0.84	0.800	**0.54**	1.38	0.203
stmi	**0.30**	1.87	0.667	**0.37**	1.38	0.444	**0.32**	0.97	0.329	**0.99**	1.72	0.073
li	**0.38**	2.11	0.624	**0.47**	1.72	0.536	**0.37**	1.19	0.354	**1.22**	1.99	0.057
ils	**0.48**	2.54	0.612	**0.12**	1.69	0.645	**0.68**	1.38	0.083	**1.28**	2.41	0.093
pog	**0.90**	2.90	0.410	**0.31**	2.09	0.455	**0.47**	1.45	0.126	**1.68**	2.63	0.049

(*) L= landmark.

(†) Mean displacements are stated (in millimetres). Positive values indicate movements to the right side of patient's face and negative values indicate movements to the left side.

(‡) Paired t-tests were applied. For non-normally distributed variables, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.4 3D landmark-based facial asymmetry analysis

4.3.3.4.1 General facial asymmetry score (Tables 4.52 and 4.53)

Table 4.50 summarises the facial asymmetry score calculated at the four assessment times. In Table 4.51, for each of the five comparisons made no significant differences were found, but the median value at T4 was surprising. It indicated that some deterioration in the symmetry, at least for some landmarks, occurred.

Table 4.52	**Facial asymmetry scores in subgroup C (n=12)**				
Time	**Median**	Minimum	Maximum	1st quartile	3rd quartile
T1	**1.55**	0.62	9.77	0.97	3.40
T2	**2.14**	0.68	4.40	1.11	2.90
T3	**2.41**	1.11	3.61	1.45	3.14
T4	**3.03**	0.85	5.39	1.46	4.13

Table 4.53	Differences in facial asymmetry scores in subgroup C (n=12)				
Time comparison	T1-T4	T1-T2	T2-T3	T2-T4	T3-T4
Median of difference	0.76	0.20	0.01	0.30	0.67
95% CI of median	-1.19, 1.83	-2.39, 1.03	-0.82, 0.59	-0.63, 1.35	-0.05, 1.67
P value	0.224	0.834	1.000	0.726	0.067

4.3.3.4.2 Individual landmark asymmetry score (Tables 4.54 and 4.55)

The landmarks with the lowest facial asymmetry scores (i.e. the most symmetric) at the presurgical assessment were 'na', 'stmi', 'stms', 'ls' and 'pog' while those landmarks in the tail of the table were 'chL', 'chR', 'excL', 'excR', 'encL' and 'encR'. The order changed at T4 with three midsagittal landmarks moving downward in the hierarchy of symmetry. These landmarks were 'pog', 'men' and 'prn'.

Table 4.54	Individual landmark asymmetry scores at T1 in subgroup C				
Landmark	Median	Minimum	Maximum	1st Quartile	3rd Quartile
na	1.20	0.20	3.40	0.80	2.50
stmi	1.20	0.00	4.70	0.43	2.40
stms	1.55	0.40	5.70	0.63	3.48
ls	1.70	0.60	5.30	1.00	3.03
pog	2.15	0.30	23.20	0.65	2.93
ils	2.30	0.10	6.20	1.13	4.50
sn	2.30	0.50	6.50	1.75	5.78
sls	2.50	0.40	9.00	1.20	4.73
men	3.10	0.70	14.50	2.15	5.83
prn	3.15	0.20	7.50	0.93	6.40
li	3.50	0.60	5.90	1.90	4.68
acL	4.45	2.40	7.70	3.33	6.48
acR	4.45	2.40	7.70	3.33	6.48
chL	5.05	2.00	10.60	2.40	7.18
chR	5.05	2.00	10.60	2.40	7.18
excL	5.20	2.50	19.00	3.73	7.88
excR	5.20	2.50	19.00	3.73	7.88
encL	5.25	1.40	7.00	2.68	6.08
encR	5.25	1.40	7.00	2.68	6.08
(*) Landmarks are ranked in order of ascending asymmetry					

Table 4.55	Individual landmark asymmetry scores at T4 in subgroup C				
Landmark	Median	Minimum	Maximum	1st Quartile	3rd Quartile
stms	1.05	0.20	3.90	0.73	2.43
li	1.50	0.20	4.00	1.00	3.38
stmi	1.55	0.20	3.00	0.65	2.58
ls	1.60	0.30	6.70	0.95	3.00
sn	2.00	0.30	6.90	0.85	5.88
na	2.65	0.30	6.90	0.43	3.78
ils	2.75	1.30	6.90	1.98	5.85
sls	3.10	0.00	7.60	1.03	6.40
encL	4.05	2.20	6.80	2.73	4.40
encR	4.05	2.20	6.80	2.73	4.40
pog	4.05	0.20	9.40	1.43	7.40
prn	4.75	0.20	8.70	1.68	7.48
chL	4.85	1.90	12.90	3.88	9.23
chR	4.85	1.90	12.90	3.88	9.23
men	4.85	0.90	10.70	3.73	7.90
acL	5.80	3.20	8.90	4.65	7.05
acR	5.80	3.20	8.90	4.65	7.05
excL	7.50	2.60	13.10	5.05	11.25
excR	7.50	2.60	13.10	5.05	11.25

(*) Landmarks are ranked in order of ascending asymmetry

4.3.3.5 Cephalometric analyses in subgroup C

4.3.3.5.1 Surgical change (T1-T2)

4.3.3.5.1.1 Anteroposterior displacements (Table 4.56)

All soft- and hard-tissue landmarks exhibited highly significant changes. The mean maxillary advancement was 3.22 mm (p<0.001), whereas the mean mandibular advancement was 10.87 mm measured at 'B' point (p<0.001). The maximum mean change was observed in the chin region with a mean advancement of 15.41 mm at 'Pog' (p<0.001).

The nasal tip had a significant anterior movement (mean= 2.41; p<0.001). The trend was a gradual increase in the significant forward displacement when looking at these landmarks starting from 'prn' and going downward towards soft-tissue Menton. The large values of anterior movement observed in the chin area for soft- and hard-tissue landmarks can be attributed to the additional surgical intervention performed (advancement genioplasty) in nine out of the twelve subjects included in this subgroup.

Table 4.56	X displacements of landmarks in subgroup C (n=12)								
Landmark	**T2-T1***	SD	P value†	**T3-T2**	SD	P value	**T3-T1**	SD	P value
prn	**2.41**	1.06	<0.001	**-1.35**	1.07	0.001	**1.06**	1.50	0.033
sn	**4.54**	1.89	<0.001	**-2.60**	1.99	0.001	**1.94**	1.59	0.001
sls	**6.93**		0.003	**-3.74**	1.44	<0.001	**2.56**	1.30	<0.001
ls	**7.77**	2.35	<0.001	**-4.93**	1.41	<0.001	**2.85**	2.39	0.002
stms	**6.84**	2.42	<0.001	**-4.62**		0.003	**2.60**	2.69	0.007
stmi	**7.82**	2.55	<0.001	**-3.64**		0.003	**3.68**	2.51	<0.001
li	**10.58**	2.53	<0.001	**-4.58**		0.003	**5.79**	2.63	<0.001
ils	**12.27**	3.26	<0.001	**-3.87**	2.28	<0.001	**8.41**	3.35	<0.001
pog	**15.50**	5.27	<0.001	**-4.80**	3.14	<0.001	**10.70**	5.02	<0.001
gn	**16.96**	5.69	<0.001	**-4.90**	3.55	0.001	**12.06**	5.75	<0.001
men	**17.47**	5.26	<0.001	**-4.25**	2.40	<0.001	**13.23**	4.84	<0.001
ANS	**2.84**	1.44	<0.001	**-0.36**	2.00	0.550	**2.49**	1.86	0.001
A	**3.22**	1.46	<0.001	**-0.61**	2.15	0.346	**2.85**		0.006
Pr	**3.91**	1.97	<0.001	**-1.18**	2.04	0.072	**2.74**	2.10	0.001
IS	**4.06**	1.94	<0.001	**-1.48**	2.41	0.056	**2.58**	2.28	0.002
II	**9.20**	2.88	<0.001	**-1.77**	1.68	0.004	**7.43**	3.28	<0.001
Id	**10.28**	3.56	<0.001	**-1.02**		0.009	**7.92**	4.09	<0.001
B	**10.87**	2.97	<0.001	**-2.83**	2.34	0.002	**8.04**	3.68	<0.001
Pog	**15.41**	4.94	<0.001	**-3.54**	2.36	<0.001	**11.87**	5.38	<0.001
Gn	**16.02**	5.17	<0.001	**-3.75**	2.41	<0.001	**12.27**	5.40	<0.001
Men	**15.93**	4.79	<0.001	**-3.40**	2.36	<0.001	**12.53**	5.10	<0.001
Ge	**10.79**	3.19	<0.001	**-2.35**	2.20	0.003	**8.43**	3.98	<0.001
Go	**4.82**	2.18	<0.001	**-1.30**	1.98	0.044	**3.52**	2.12	<0.001
Ar	**0.23**	1.55	0.622	**0.00**		1.000	**0.41**	1.22	0.274
Cd	**-0.70**		0.155	**0.13**		0.756	**-0.13**	1.16	0.699
PNS	**2.09**	1.46	<0.001	**-0.08**	1.98	0.892	**2.01**	1.78	0.002
UIA	**3.60**	1.45	<0.001	**-0.42**	1.70	0.405	**3.17**	1.90	<0.001
LIA	**11.48**	3.34	<0.001	**-3.17**	3.21	0.006	**8.31**	3.74	<0.001

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate forward movements, whereas negative values indicate backward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

4.3.3.5.1.2 Vertical displacements (Table 4.57)

Impaction of the maxilla was evident by the significant superior displacements of 'ANS', 'A' and 'Pr'. The mean upward movement of 'A' point, for example, was 3.9 mm superiorly (p<0.001). The autorotated mandible (which followed the new maxillary position) caused an upward movement of Infradentale and 'B' point. The magnitude of this superior movement, however, was not parallel to the amount of maxillary impaction, e.g. 'Id' had a mean vertical displacement of 2.27 mm (p=0.015) and 'B' had a mean vertical displacement of 1.56 mm (p=0.108). No significant changes were observed in the chin area.

With regard to soft tissue, the mean upward movement of the nasal tip was 2.92 mm (p<0.001). The subnasal point had a mean superior displacement of 2.24 mm (p<0.001). Upper and lower labial landmarks showed a superior movement.

Table 4.57	**Y displacements of landmarks in subgroup C (n=12)**								
Landmark	**T2-T1***	SD	P value†	**T3-T2**	SD	P value	**T3-T1**	SD	P value
prn	**2.92**	1.70	≤0.001	**-1.56**	1.64	0.007	**1.36**	2.29	0.051
sn	**2.24**	1.92	≤0.001	**-0.85**	1.94	0.051	**1.39**	2.03	0.054
sls	**2.55**	2.69	0.007	-1.76		0.182	**1.55**	2.54	0.058
ls	**2.85**	2.73	0.004	**-1.00**	3.06	0.280	**1.84**	3.08	0.063
stms	**2.06**	2.02	0.005	**-0.17**	2.63	0.832	**1.90**	2.99	0.050
stmi	**3.26**	3.00	0.003	**0.96**	3.37	0.347	**2.81**		0.003
li	**2.78**	3.24	0.013	**1.97**	3.98	0.114	**4.76**	4.38	0.003
ils	**0.26**	4.64	0.850	**0.67**	2.61	0.393	**0.93**	5.46	0.567
pog	**-0.15**	6.19	0.933	**0.60**	2.94	0.498	**0.44**	5.04	0.767
gn	**-0.85**	5.56	0.606	**0.69**	2.34	0.328	**-0.16**	4.01	0.894
men	0.27		0.689	**1.87**	1.99	0.008	**0.80**	3.34	0.424
ANS	**4.38**	2.71	≤0.001	**-0.86**		0.359	**3.94**	3.38	0.002
A	**3.91**	2.17	≤0.001	**-0.50**		0.894	**4.17**	2.77	≤0.001
Pr	**3.20**	2.42	0.001	**-0.38**	2.29	0.581	**2.82**	2.34	0.002
IS	**4.12**	2.23	≤0.001	**-0.73**	1.33	0.085	**3.39**	2.37	≤0.001
II	**2.20**	2.93	0.025	**0.10**	1.80	0.854	**2.30**	3.22	0.031
Id	**2.27**	2.74	0.015	**-0.12**	1.26	0.739	**2.15**	2.71	0.019
B	**1.56**	3.10	0.108	**-0.34**	1.25	0.369	**0.25**		0.154
Pog	**1.48**	3.92	0.219	**-0.34**	1.52	0.461	**1.14**	3.56	0.291
Gn	**0.63**	4.27	0.619	**-0.13**	1.06	0.671	**0.50**	3.82	0.662
Men	**-0.15**	4.07	0.903	**-0.19**	1.01	0.534	**-0.33**	3.64	0.757
Ge	**0.88**	2.77	0.295	**0.23**	1.28	0.548	**1.11**	2.92	0.216
Go	**-0.46**		0.724	**3.45**	1.69	≤0.001	**3.20**	2.10	≤0.001
Ar	**-0.19**	0.97	0.511	**1.13**	1.03	0.003	**0.94**	1.20	0.021
Cd	**-0.87**	1.29	0.040	**1.13**	1.69	0.042	**0.86**		0.308
PNS	**2.01**	1.02	≤0.001	**0.42**		1.000	**2.11**	1.70	0.001
UIA	**3.53**	2.12	≤0.001	**0.00**		0.575	**3.26**	2.66	0.001
LIA	**1.79**	3.40	0.095	**-0.34**	0.96	0.247	**1.45**	3.22	0.146

(*) All the values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are presented rather than means. Positive values indicate upward movements, whereas negative values indicate downward movements.

(†) Student paired t tests were applied. Variables showing non-normal distributions (confirmed by normality tests) were analysed using Wilcoxon matched pairs signed rank tests. Figures related to these variables are shown in blue. P values below the level of significance are underlined.

4.3.3.5.1.3 Linear measurements (Table 4.58)

The main surgical changes observed were: significant reduction in skeletal total anterior facial height ($p=0.014$); significant decrease in skeletal upper anterior facial height ($p<0.001$); significant increase in mandibular length ($p<0.001$), mandibular body length ($p<0.001$) and facial axis length ($p=0.001$); significant increase in maxillary length measured between 'Cd' and 'ANS' or 'A' ($p=0.001$ for the first method); significant correction of the overjet (mean at T1=7.28 mm, median at T2=1.42 mm; $p<0.001$); significant change in the overbite from a mean of 2.62 mm to 0.85mm ($p=0.018$) and significant reduction in the amount of incisor display, which was reduced from a mean of 5.13 mm at T1 to 3.30 mm at T2 ($p=0.014$).

With regard to soft tissue, significant increase in upper vermilion height ($p=0.036$) and a significant increase in soft-tissue lower facial height measured from Subnasale to Menton ($p=0.011$) were observed. In addition, the columellar length had a significant decrease ($p<0.001$).

Table 4.58	Interlandmark distances in subgroup C (n=12)								
Distance*	**T1†**	SD	P value T2-T1‡	**T2**	SD	P value T3-T2	**T3**	SD	P value T3-T1
TAFH	**120.39**	4.52	0.014	**117.24**	3.59	0.327	**117.50**	3.08	0.016
UAFH	**52.12**	2.27	<0.001	**47.89**	3.43	0.570	**48.18**	3.81	0.003
LAFH	**72.32**	3.95	0.467	**71.65**	2.51	0.497	**71.98**	2.70	0.575
PFH	**69.27**	5.30	0.710	**70.91**		<0.001	**68.18**		0.001
MdL	**103.31**	5.89	<0.001	**111.28**	3.18	0.018	**109.90**	4.37	<0.001
MdRmH	**51.34**	4.61	0.664	**50.95**	4.77	0.009	**48.63**	4.39	0.004
MdBL	**66.59**	4.82	<0.001	**74.66**	5.40	0.657	**74.41**	4.60	0.003
MxL1	**81.73**	3.10	0.001	**83.68**	3.52	0.070	**83.06**	3.40	0.028
MxL2	**84.87**	3.38	0.003	**86.82**	3.37	0.415	**86.56**	3.35	0.015
MxL3	**50.88**	2.74	0.092	**51.56**	2.05	0.458	**51.28**	2.14	0.356
FAL	**113.96**	4.77	0.001	**119.79**	2.94	<0.001	**118.40**	3.28	0.002
PCB	**31.17**	4.15	0.943	**31.20**	3.54	0.031	**30.35**	3.64	0.060
OJ	**7.28**	1.72	<0.001	**1.42**		0.334	**1.82**		<0.001
OB	**2.62**	2.71	0.018	**0.85**	1.27	0.059	**1.45**	1.43	0.074
Incisor Display	**5.13**	2.37	0.014	**3.30**	1.35	0.729	**3.56**	2.06	0.034
ULH (S)	**19.99**	2.03	0.875	**20.00**	1.63	0.439	**19.41**	2.70	0.323
UVH (S)	**5.89**	1.26	0.036	**6.68**	1.90	0.037	**5.84**	1.36	0.554
LLH (S)	**14.16**	2.18	0.023	**17.08**	2.29	0.643	**17.36**	1.79	0.002
LVH (S)	**10.48**	1.68	0.289	**10.80**	1.88	0.121	**9.94**	1.71	0.322
LFHS (S)	**65.76**	4.05	0.011	**69.14**	3.29	0.001	**66.35**	2.73	0.458
ILD (S)	**5.65**	4.12	0.362	**4.53**	2.15	0.356	**1.82**		0.048
TVH (S)	**22.02**	4.66	0.962	**22.09**	3.71	0.039	**19.11**	4.27	0.064
ColumL (S)	**16.52**	2.90	<0.001	**14.31**	2.44	0.014	**16.82**		0.083

(*) Abbreviations of the distances used have been explained in Table 3.8 and 3.9. 'S' stands for a soft-tissue distance.

(†) Values are stated in millimetres. For non-normally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.5.1.4 Angular measurements (Table 4.59)

Looking at the 'SNA' angle, the presurgical maxillary position was slightly retrognathic (mean SNA=78.67°). The mandible assessed by the 'SNB' angle showed a clear retrognathic position (mean SNB=70.66°). The 'ANB' angle confirmed the skeletal class II relationship, which had a median value of 7.60°. The mean cranial base-mandibular plane angle at T1 (MdSN) was 44.69° indicating a posterior mandibular rotation in this subgroup. This was also confirmed by the increased value of the maxillary-mandibular planes angle, which was approximately 35° before any surgical correction. The presurgical inclinations of the incisors showed slightly lingually inclined lower and upper incisors, which meant that the orthodontic decompensation was achieved in the lower arch, but not in the upper arch. All of the patients in this subgroup had presurgical orthodontics.

When examining angular changes between T1 and T2 for hard-tissue landmarks, significant improvement was observed with regard to the 'SNA', 'SNB', 'ANB' and 'SNPog' angles ($p<0.001$ for each). Both 'SNA' and 'SNB' lay within the normal range according to Houston and Tulley[467], but the 'ANB' angle indicated a skeletal Class II relationship. The 'SNPog' angle approximated more to the Caucasian norm (mean SNPog=78.33), and this could be attributed to the additional horizontal advancement genioplasty performed for several cases. The interincisor angle showed a significant improvement ($p=0.018$), which was more related to positional changes in the apical bases than changes in the incisors' inclination to their apical bases. This can be seen in the stable 'MPIA' angle at T1 and T2. The cranial base-mandibular plane angle became less steep at T2 ($p<0.001$) and a significant correction was noticed with the regard to the maxillary-cranial base angle ($p=0.012$).

With regard to soft-tissue angles, a significant decrease was noticed in the nasolabial angle ($p=0.001$), but this change was lost partially at T3 ($p=0.026$). The overall change in the nasolabial angle was insignificant ($p=0.200$). The change in the labiomental angle was not obvious between T1-T2, but it was very clear in the T1-T3 comparison ($p=0.034$) as well as in the T2-T3 comparison ($p=0.013$). The labiomental angle became more obtuse reflecting a more balanced relationship between the lower lip and the chin. It was clear that the advancement of the chin made the chin angle more acute ($p=0.004$) and this effect was not temporary as it remained statistically significant between T1 and T3 ($p=0.006$) with no evident relapse between T2 and T3 ($p=0.670$). There was an improvement in the facial profile angle between T1 and T2 ($p<0.001$) that did not relapse significantly, with an overall change of about 6° between T1 and T3 ($p=0.002$).

Table 4.59	Interlandmark angles in subgroup C (n=12)								
Angle*	T1†	SD	P value T2-T1‡	T2	SD	P value T3-T2	T3	SD	P value T3-T1
SNA	**78.67**	3.71	<0.001	**81.73**	4.45	0.347	**81.22**	3.32	<0.001
SNB	**70.66**	4.37	<0.001	**76.88**	4.11	0.001	**75.39**	3.51	<0.001
ANB	7.60		<0.001	**4.84**	1.76	0.073	**5.82**	2.03	0.001
SNPog	**70.62**	4.63	<0.001	**78.33**	3.97	<0.001	**76.65**	3.46	<0.001
MxSN	**9.75**	2.50	0.012	**7.17**	3.95	0.348	**7.78**	3.29	0.051
MdSN	**44.69**	5.60	<0.001	**39.29**	3.82	<0.001	**42.33**	4.15	0.024
MxMd	**34.97**	5.37	0.131	**32.13**	2.62	0.002	**34.55**	2.84	0.709
MPIA	**85.84**	6.48	0.957	**85.88**	6.04	0.682	**86.53**	4.82	0.586
UISN	**96.81**	4.35	0.181	**98.08**	5.11	0.057	**95.17**	5.98	0.241
IIA	**124.37**	9.80	0.018	**128.53**	8.34	0.780	**129.05**	9.44	0.021
Nasal tip	**97.14**	4.61	0.103	**99.03**	5.02	0.119	**97.00**	4.91	0.903
Nasolabial	**126.80**		0.001	**120.53**	9.71	0.026	**125.72**	11.49	0.200
Labiomental	**121.06**	12.94	0.930	**121.63**	16.59	0.013	**132.57**	10.72	0.034
Chin	**131.63**	8.60	0.004	**122.88**	7.25	0.670	**123.48**	7.88	0.006
Facial profile	**120.87**	4.56	<0.001	**127.50**	5.53	0.076	**125.95**	5.89	0.002

(*) Abbreviations of the angles used have been explained in Table 3.8 and 3.9.

(†) Values are stated in degrees. For non-noramally distributed variables, medians (shown in blue) are used instead of means.

(‡) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.5.1.5 Soft-tissue thicknesses (Table 4.60)

The most prominent changes were observed at the 'sls' and Labrale superius levels (p<0.001 for each).

Table 4.60	Facial soft-tissue thicknesses in the midsagittal plane at seven levels in subgroup C (n=12)								
Thickness at	T1*	SD	P value T2-T1†	T2	SD	P value T3-T2	T3	SD	P value T3-T1
sn	9.09		0.006	**10.97**	2.51	0.009	**8.57**	2.27	0.172
sls	**13.17**	1.07	<0.001	**16.18**	1.59	0.005	12.48		0.742
ls	**13.39**	1.62	<0.001	**16.95**	2.90	0.004	**13.58**	2.11	0.717
li	**14.87**	2.61	0.344	**15.41**	2.45	<0.001	**13.05**	1.92	0.027
ils	**11.56**	2.49	0.004	**13.19**	1.52	0.009	**11.62**	2.11	0.914
pog	**12.33**	3.08	0.880	**12.43**	2.48	0.038	**11.23**	3.04	0.101
men	**7.58**	1.73	0.044	**8.20**	1.79	<0.001	**6.53**	1.39	0.004

(*) Values are stated in millimetres. For non-noramally distributed variables, medians (shown in blue) are used instead of means.

(†) Paired t tests were applied to detect statistically significant differences. In case of asymmetric distributions of the differences, Wilcoxon matched pairs signed rank tests were applied and the related p values are shown in blue. P values below the level of significance are underlined.

4.3.3.5.2 Postsurgical relapse (T2-T3)

4.3.3.5.2.1 Anteroposterior displacements (Table 4.56)

Evidence of a backward relapse of the advanced maxilla was not very clear at 'ANS', 'A' point or 'Pr' with Prosthion showing a mean backward displacement of 1.18 mm ($p=0.072$). The mandibular body relapse was significant at 'B' and 'Ge' ($p=0.002$ and $p=0.003$, respectively). The bony mental points also showed a significant relapse ($p<0.001$).

With regard to soft tissues, the nasal tip, which moved initially a mean of 2.41 mm, relapsed in a backward direction (mean= 1.35 mm; $p<0.001$). The Labrale superius, which moved initially a mean of 7.77 mm in an anterior direction, relapsed a mean of 4.93 mm posteriorly ($p<0.001$), whereas soft-tissue Pogonion, which had a mean forward movement of 15.50 mm, relapsed a mean of 4.8 mm posteriorly ($p<0.001$).

4.3.3.5.2.2 Vertical displacements (Table 4.57)

Between T2 and T3, the impaction of the maxilla appeared stable. No significant change could be detected for the mandible. Mental bony landmarks did not show any specific vertical relapse. The soft-tissue behaviour in the postsurgical period varied. A highly significant relapse was observed in the nasal tip position ($p=0.007$), and an insignificant relapse was observed at Subnasale ($p=0.051$). Both moved downward minimising the initial surgical change. The same downward movement was observed for the upper labial landmarks but without reaching statistical significance. Lower labial landmarks moved upward, i.e. 'li' and 'stmi', and to a lesser extent 'ils', Pogonion and Gnathion.

4.3.3.5.2.3 Linear measurements (Table 4.58)

The linear hard-tissue changes were: a significant decrease in posterior facial height and this could be explained, as in subgroup A, by a significant superior shift in Gonion at T3; significant relapse in mandibular length which lost a mean of 1.4 mm from the initial amount of the surgical advancement ($p=0.018$); a significant reduction in the ramus height, similar to what was observed with the posterior facial height ($p=0.009$); a significant relapse in the facial axis length ($p<0.001$) and an insignificant change in the vertical incisor relationship with a better overbite value at T3 compared with T2 (p=0.059).

With regard to soft tissues, the significant increase in the upper vermilion border height and the lower facial height seen between T1 and T2 was cancelled out between T2 and T3 (p=0.037 for 'UVH' and p=0.001 for 'LFH'). One of the interesting findings was the significant reduction in the mean total vermilion height from approximately 22 mm at T2 to approximately 19 mm (p=0.039). The interlabial distance reduced also between T2 and T3, but not to a statistically significant extent. The significant increase in the columellar length found as a result of surgery (T1-T2) was counteracted between T2 and T3 (p=0.014).

4.3.3.5.2.4 Angular measurements (Table 4.59)

Between T2 and T3, there was a significant relapse in the SNB angle (p=0.001) indicating a backward shift of the mandibular apical base, which has affected adversely the 'ANB' angle at T3. Significant relapse was also noted with regard to the 'SNPog' angle (p<0.001). The significant changes seen with the cranial base-mandibular plane angle could be attributed to the significant upward movement of point Gonion between T2 and T3, which affected the construction of the mandibular plane and, consequently, its inclination with the cranial base and the maxillary plane at six months following surgery.

4.3.3.5.2.5 Soft-tissue thicknesses (Table 4.60)

At six months postsurgery, the seven measurements showed significant decrease cancelling out the initial increase (observed at one week postsurgery) and ending up with soft-tissue thicknesses lower than the original value obtained before orthognathic surgery for most of them.

4.3.3.5.3 Overall change (T1-T3)

4.3.3.5.3.1 Anteroposterior displacements (Table 4.56)

The overall changes were similar in their direction to the initial surgical changes despite the significant relapse between T2 and T3. The median maxillary advancement was 2.85 mm at 'A' point (p=0.006), whereas the mean mandibular advancement was

8.04 mm at 'B' point ($p<0.001$). For Pog, the mean overall advancement was 11.87 mm ($p<0.001$).

4.3.3.5.3.2 Vertical displacements (Table 4.57)

The overall vertical changes observed in this subgroup were: significant maxillary impaction at 'A' point ($p<0.001$); less significant mandibular superior movement at Infradentale ($p=0.019$); significant elevation of Subnasale ($p=0.017$); significant elevation of lower labial landmarks, i.e. Stomion inferius and Labrale inferius ($p=0.003$ for both).

4.3.3.5.3.3 Linear measurements (Table 4.58)

The overall skeletal linear changes were: a significant reduction in the total anterior facial height ($p=0.026$); significant reduction in the upper anterior facial height ($p=0.003$); significant reduction in the posterior facial height ($p=0.001$) as well as in the ramus height ($p=0.004$); significant increase in the mandibular length ($p<0.001$), the mandibular body length ($p=0.003$) and the facial axis length ($p=0.002$); significant reduction in the overjet ($p<0.001$) and insignificant reduction in the overbite ($p=0.074$) and significant improvement in the vertical relationship between the upper incisor teeth and the upper lip ($p=0.034$).

The overall linear changes in soft tissues were: significant increase in the lower lip height ($p=0.002$), significant reduction in the interlabial distance ($p=0.048$) and insignificant decrease in the total vermilion height ($p=0.064$).

4.3.3.5.3.4 Angular measurements (Table 4.59)

The overall changes were: a significant improvement in 'SNA' and 'SNB' angles ($p<0.001$); significant improvement in 'ANB' angle although it remained in the skeletal Class II range ($p=0.001$); significant improvement in the 'SNPog' angle ($p<0.001$); significant reduction of the posterior rotation pattern ($p=0.024$); significant correction in the interincisor angle ($p=0.021$).

With regard to soft tissues: the labiomental and facial profile angles became significantly more obtuse ($p=0.034$ and $p=0.002$, respectively) and the chin angle became significantly more acute ($p=0.006$).

4.3.3.5.3.5 Soft-tissue thicknesses (Table 4.60)

The overall changes were: a significant soft-tissue thinning at the Labrale inferius level (p=0.027), insignificant soft-tissue thinning at the Pogonion level (p=0.101) and significant soft-tissue thinning at the Menton level (p=0.004).

4.3.3.5.3.6 Soft- to hard-tissue displacements ratios (Table 4.61)

Anteroposterior ratios. The tip of the nose moved anteriorly in a median ratio of 0.15:1 when linked with the movement of 'A ' point (p=0.042). The median displacement ratio increased to 0.65:1 at the level of the nasal base (p=0.008) and further increased to 0.85:1 at the superior labial sulcus level (p=0.015). A 1:1-displacement ratio was observed between Labrale superius and Prosthion (p=0.004) and this reduced to 0.76:1 at the Stomion superius level (p=0.009).

In the lower labial and mental regions, the anteroposterior displacement ratios had different degrees. The median displacement ratio was one-to-two between 'stmi' and 'II' (p=0.004), which increased to 0.79:1 between 'li' and 'Id' (p=0.003) and reached almost the one-to-one level between 'ils' and 'B' point (0.003). The ratio was less than that between soft- and hard-tissue Pogonion points (median=0.87:1; p=0.003). The high displacement ratios observed when the soft-tissue Pogonion was linked to points 'B' or 'Ge' can be explained, as before in subgroup B, by the effect of the genioplasty performed in several subjects which advanced the soft-tissue mental landmarks additional amounts compared with the mandibular apical base landmarks, i.e. 'B' and 'Ge'.

Vertical ratios. The nasal tip showed a median vertical displacement ratio of 0.34:1 with 'ANS' (p=0.045). A similar ratio of 0.37:1 was observed between Subnasale and point 'A' (p=0.0.37). In the mandible, soft-tissue points seemed to move more vertically than the underlying bony movements. For example, the median displacement ratio between Labrale inferius and 'B' point was 1.83:1 (p=0.019). A similar ratio was obtained between 'ils' and 'Ge' (p=0.009), whereas soft-tissue Pogonion to hard-tissue Pogonion had a displacement ratio of 1.38:1 (p=0.005).

Table 4.61	Soft- to hard-tissue displacement ratios in subgroup C (n=12)			
Soft-tissue/hard-tissue	**X axis***	**P value**	**Y axis**	**P value**
prn-ANS	0.21	0.141	**0.34**	0.045
prn-A	**0.15**	0.042	**0.38**	0.045
sn-ANS	**0.65**	0.008	0.38	0.050
sn-A	0.53	0.100	**0.37**	0.037
sls-ANS	**0.85**	0.015	0.29	0.155
sls-A	0.80	0.126	0.31	0.155
ls-A	**1.00**	0.005	0.45	0.556
ls-Pr	**1.00**	0.004	0.67	0.824
stms-IS	**0.76**	0.009	0.25	0.221
stmi-IS	0.98	0.083	0.77	0.068
stmi-II	**0.50**	0.004	1.00	0.182
li-II	**0.80**	0.004	1.20	0.142
li-Id	**0.79**	0.003	1.14	0.050
li-B	**0.74**	0.003	**1.83**	0.019
ils-Id	**1.04**	0.003	0.89	0.239
ils-B	**0.97**	0.003	1.56	0.838
ils-Ge	**1.09**	0.003	**1.86**	0.009
pog-B	**1.29**	0.003	1.28	1.000
pog-Pog	**0.87**	0.003	**1.38**	0.005
pog-Ge	**1.30**	0.003	1.33	0.450
gn-Gn	**0.99**	0.003	0.93	0.083
men-Men	**1.10**	0.003	0.71	0.193

(*) Median values are stated here instead of means. One-sample Wilcoxon singed rank test was applied to detect if the calculated ratios were significantly different from zero. Significant results are printed in a red bold font and the related p-values are underlined,

4.3.4 Facial asymmetry analysis in the whole study group (n=70)

The analysis was applied on the whole study group, which contained Class II and Class III patients (n=70). From Table 4.62, no significant differences were detected between Class II and Class III patients.

Class III patients exhibited improved symmetry between T1 and T2 (Table 4.63). The median asymmetry score improved from 2.55 at T1 to 1.86 at T2 with a median difference of 1.2 (p=0.006). Changes in median asymmetry score between T2-T3 and T3-T4 were small and insignificant. The median net change in asymmetry score between T1 and T4 was about 1 unit (p<0.001). The overall deterioration in the achieved result (between T2 and T4) was very small with a median value of 0.10 (p=0.762).

Asymmetry scores of Class II subgroup are presented in Table 4.64. All the comparisons made between assessment times failed to show any significant improvement or deterioration in asymmetry scores. Only four out of the 24 subjects in this subgroup had clinically-detected presurgical facial asymmetry. It can be seen, however, that there was a small improvement in median asymmetry score between T1 and T2, which was lost between T2 and T4.

Table 4.62	**Facial Asymmetry Scores: Class III (n=46) versus Class II patients (n=24)***							
Time	**T1**		**T2**		**T3**		**T4**	
Class	III	II	III	II	III	II	III	II
Median	2.55	2.05	1.86	1.94	2.06	2.33	1.95	2.96
Minimum	0.30	0.62	0.59	0.68	0.42	0.54	0.42	0.79
Maximum	13.97	10.43	5.4	4.40	6.20	6.05	5.52	5.39
Q1	1.70	1.34	1.31	1.18	1.29	1.61	1.31	1.39
Q3	5.2	3.40	2.87	2.83	3.55	3.23	2.81	3.84
II vs. III 95% CI of the difference	(-0.276 - 1.450)		(-0.657 - 0.700)		(-0.897 - 0.471)		(-1.292 - 0.176)	
II vs. III P value	**0.1876**		**0.9094**		**0.4898**		**0.1426**	
(*) Asymmetry scored were multiplied by 10^4 for better readability. Q1= First quartile, Q3= Third quartile.								

Table 4.63	**Differences in facial asymmetry scores in Class III patients (n=46)**				
Time comparison	**T1-T4**	**T1-T2**	**T2-T3**	**T2-T4**	**T3-T4**
Median of difference	-0.98	-1.20	0.05	0.10	-0.21
95% CI of median	-1.93, -0.40	-2.39, -0.33	-0.32, 0.41	-0.43, 0.28	-0.46, 0.03
P value	**<0.001**	**0.006**	**0.863**	**0.762**	**0.084**

Table 4.64	**Differences in facial asymmetry scores in Class II patients (n=24)**				
Time Comparison	**T1-T4**	**T1-T2**	**T2-T3**	**T2-T4**	**T3-T4**
Median of difference	0.23	-0.29	0.31	0.42	0.36
95% CI of median	-0.81, 1.00	-1.72, 0.49	-0.27, 0.78	-0.12, 1.05	-0.16, 0.89
P value	**0.558**	**0.636**	**0.328**	**0.142**	**0.162**

4.4 *Psychosocial analysis*

4.4.1 The whole sample of Class II and Class III patients

4.4.1.1 Motivation for surgery

4.4.1.1.1 General overview

Looking at the whole sample of Class II and Class III patients (n=70), the motivation for orthognathic surgery is illustrated in Figure 4.4 where only the end poles of the scale are displayed, i.e. the percentage of patients who scored '1' or '4' on the scale for each motive.

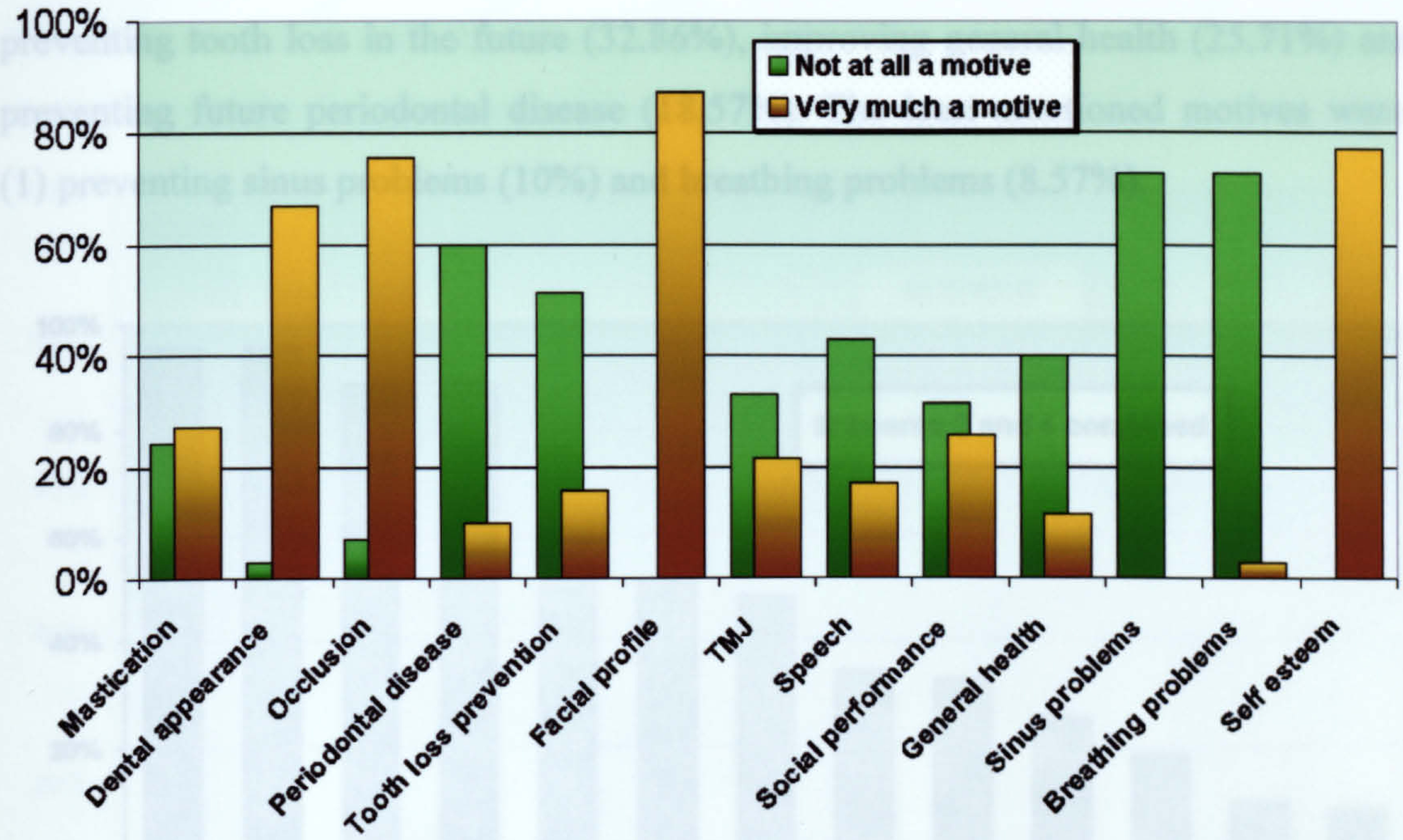


Figure 4.4 Motivation for surgery for the whole study group.

From the above figure, it can be seen that improving facial profile was a very important motive for 87% of the patients. This was followed by improving self-esteem (77%), occlusion (76%) and dental appearance (67%). Improving mastication and enhancing social performance were mentioned as important motives by 27% and 26%, respectively. It is also important to notice that 21% of patients mentioned the TMJ as an important motive. The other reasons for undergoing surgery were less important for many patients. Improving speech, for example, was 'not at all a motive' for 43% of the study group. Sixty percent regarded periodontal disease and 73% considered breathing problems or sinus problems 'not at all a motive'.

The four-point scale was converted into a dichotomous scale (or a binary variable) by combining scores (1) and (2) together and scores (3) and (4) together. Figure 4.5 illustrates the motives ranked in a descending order from the most mentioned motive (as moderate to strong) to the least one. 'Improving facial profile' and 'feeling better about myself' were mentioned most (95.71% for each). These were followed by improving dental appearance and occlusion (88% for each). 'Improving chewing ability' was mentioned as a motive by 60% of the subjects, while improving social importance was mentioned by approximately half of the study group. The following reasons for undergoing orthognathic surgery were reported less frequently: preventing temporomandibular joint (TMJ) problems (48.57%), improving speech (34.29%), preventing tooth loss in the future (32.86%), improving general health (25.71%) and preventing future periodontal disease (18.57%). The least mentioned motives were: (1) preventing sinus problems (10%) and breathing problems (8.57%).

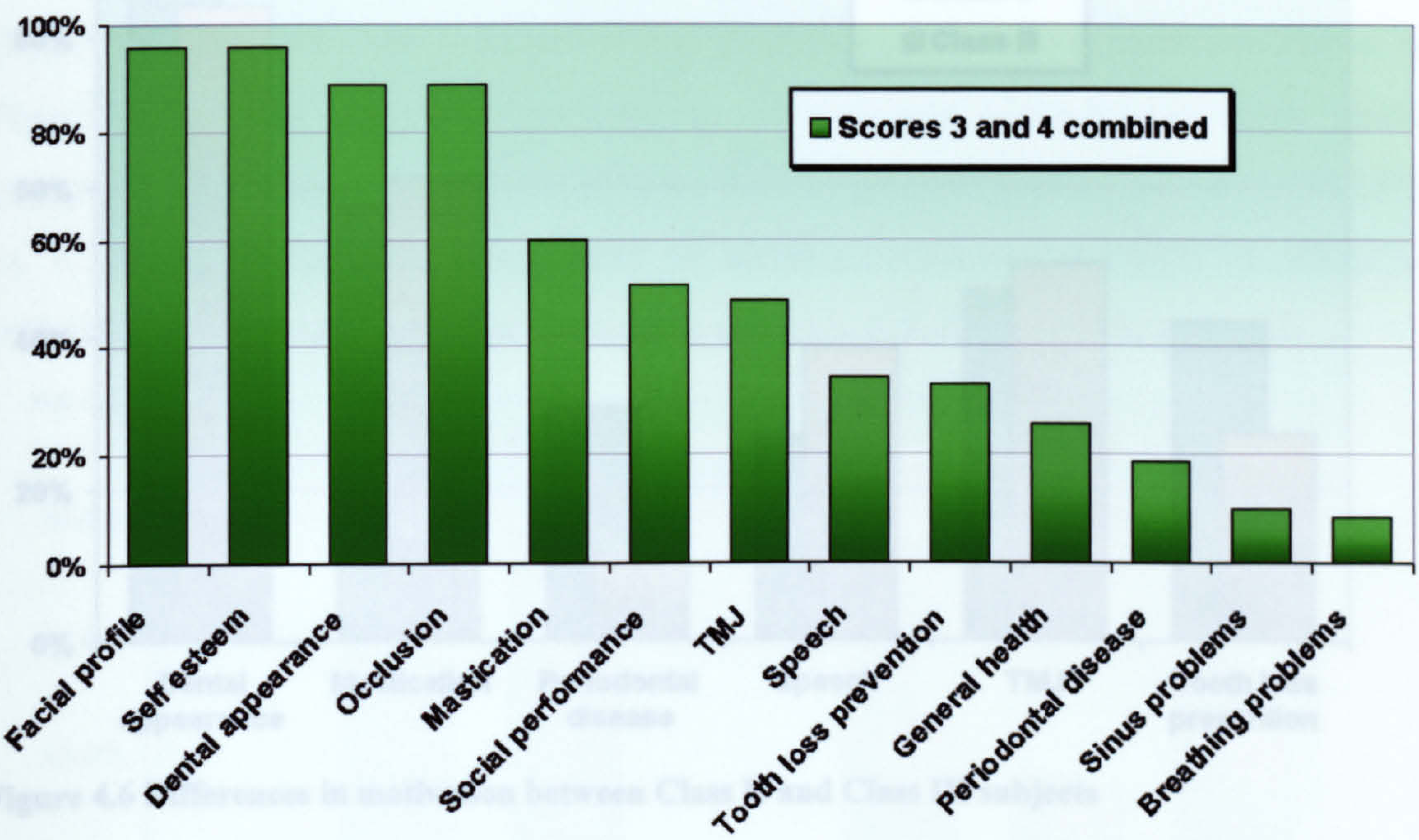


Figure 4.5 Motives ranked in a descending order for the whole study group (when scores 3 and 4 were combined).

4.4.1.1.2 Comparisons based on type of deformity, sex and age group

When the sample was divided into two groups, i.e. Class II and Class III subgroups, chi-squared tests were generally applied to detect significant differences between the two groups.

Figure 4.6 shows the main differences in percentages between Class II and Class III patients with regard to six motives. The improvement of dental appearance was mentioned as a moderate to strong reason by 96.15% in the Class II group, while the percentage was 84% in the Class III group (p=0.168). The only difference that reached statistical significance was related to the prevention of periodontal disease, where it was mentioned by 30.77% in the Class II group compared with 11.36% in the Class III group (p=0.022). About 42% of the Class II subjects reported the prevention of tooth loss, whereas the percentage was lower in the Class III group (27.27%; p=0.095). On the other had, it was noticed that a higher proportion of subjects considered 'improving speaking ability' as a motive for surgery in the class III group (38.64%) compared with the Class II group (26.92%; p=0.176). Small differences were observed for the remaining motives in the questionnaire.

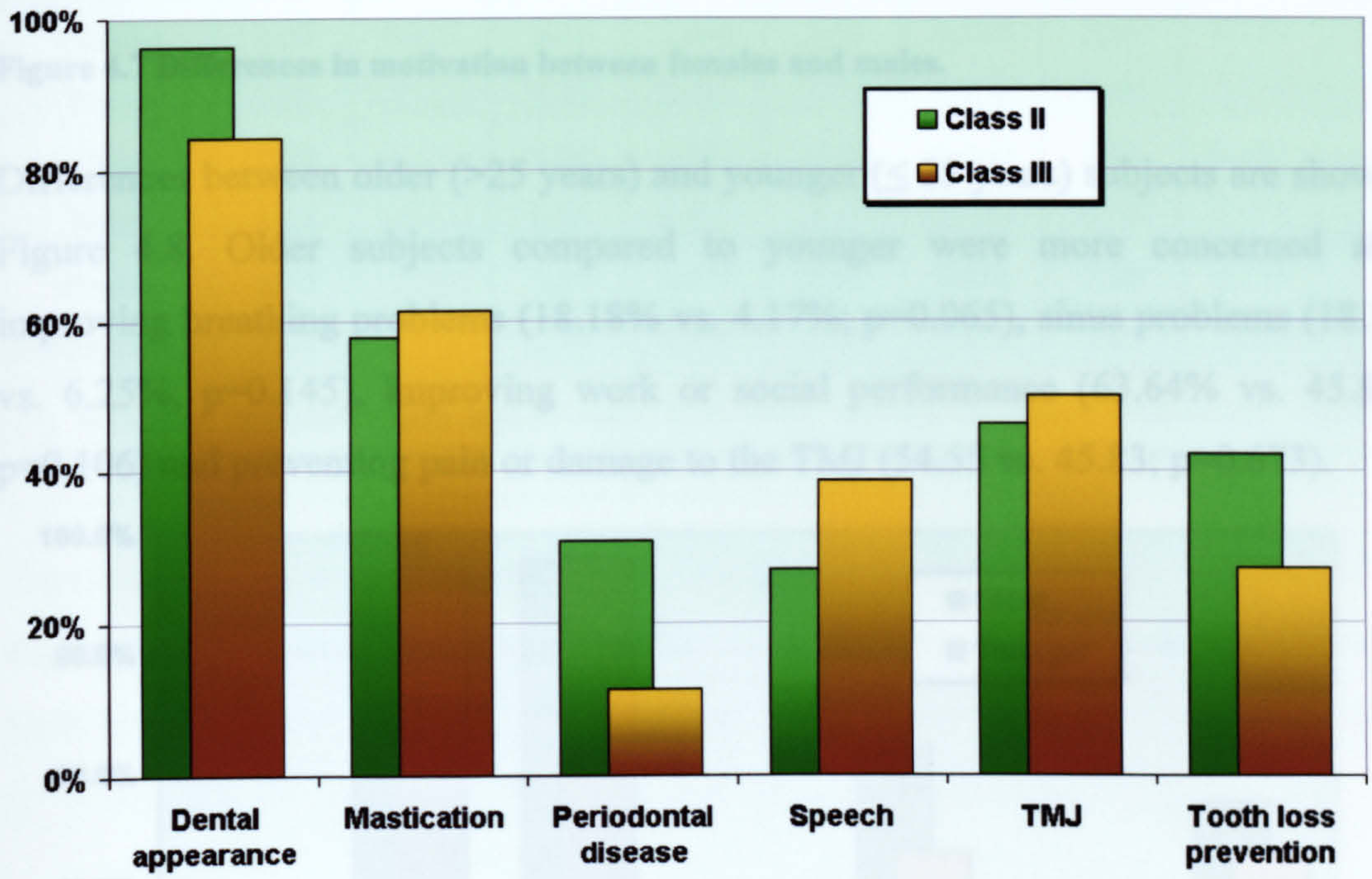


Figure 4.6 Differences in motivation between Class II and Class III subjects

Differences between males and females are shown in Figure 4.7. Females compared to males were more concerned about improving self-esteem (100% vs. 82.35%; p=0.0142 by Fisher's exact test), preventing pain or damage to the TMJ (54.72% vs. 29.41%; p=0.069) and preventing any future tooth loss (35.85% vs. 23.53%; p=0.347). On the other hand, males were more concerned about improving speaking ability (52.94% vs. 28.3%; p=0.063) and sinus problems (17.65% vs. 7.55%, p=0.227).

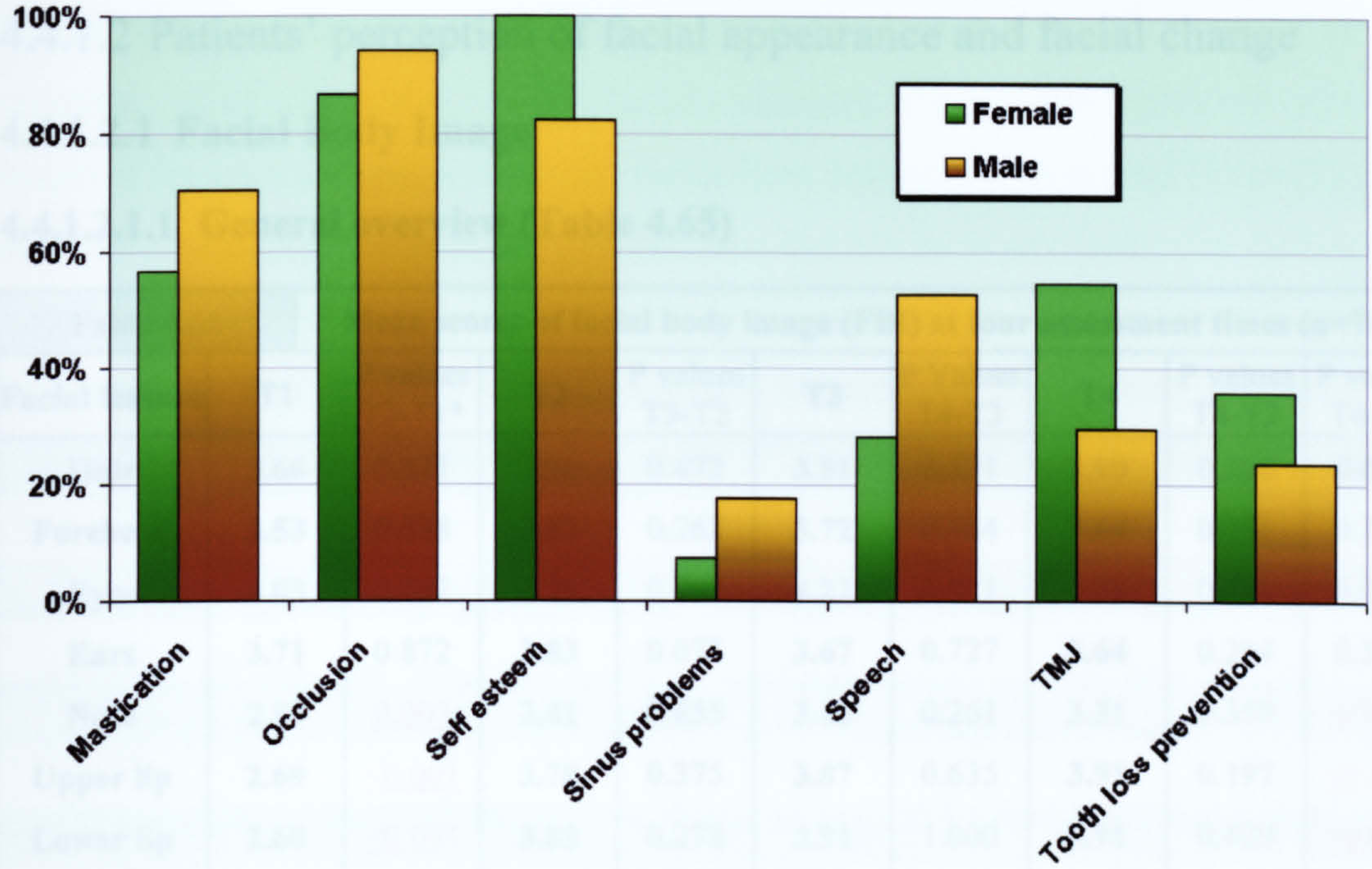


Figure 4.7 Differences in motivation between females and males.

Differences between older (>25 years) and younger ($\leq$ 25 years) subjects are shown in Figure 4.8. Older subjects compared to younger were more concerned about improving breathing problems (18.18% vs. 4.17%; p=0.065), sinus problems (18.18% vs. 6.25%; p=0.145), improving work or social performance (63.64% vs. 45.83%; p=0.106) and preventing pain or damage to the TMJ (54.55 vs. 45.83; p=0.673).

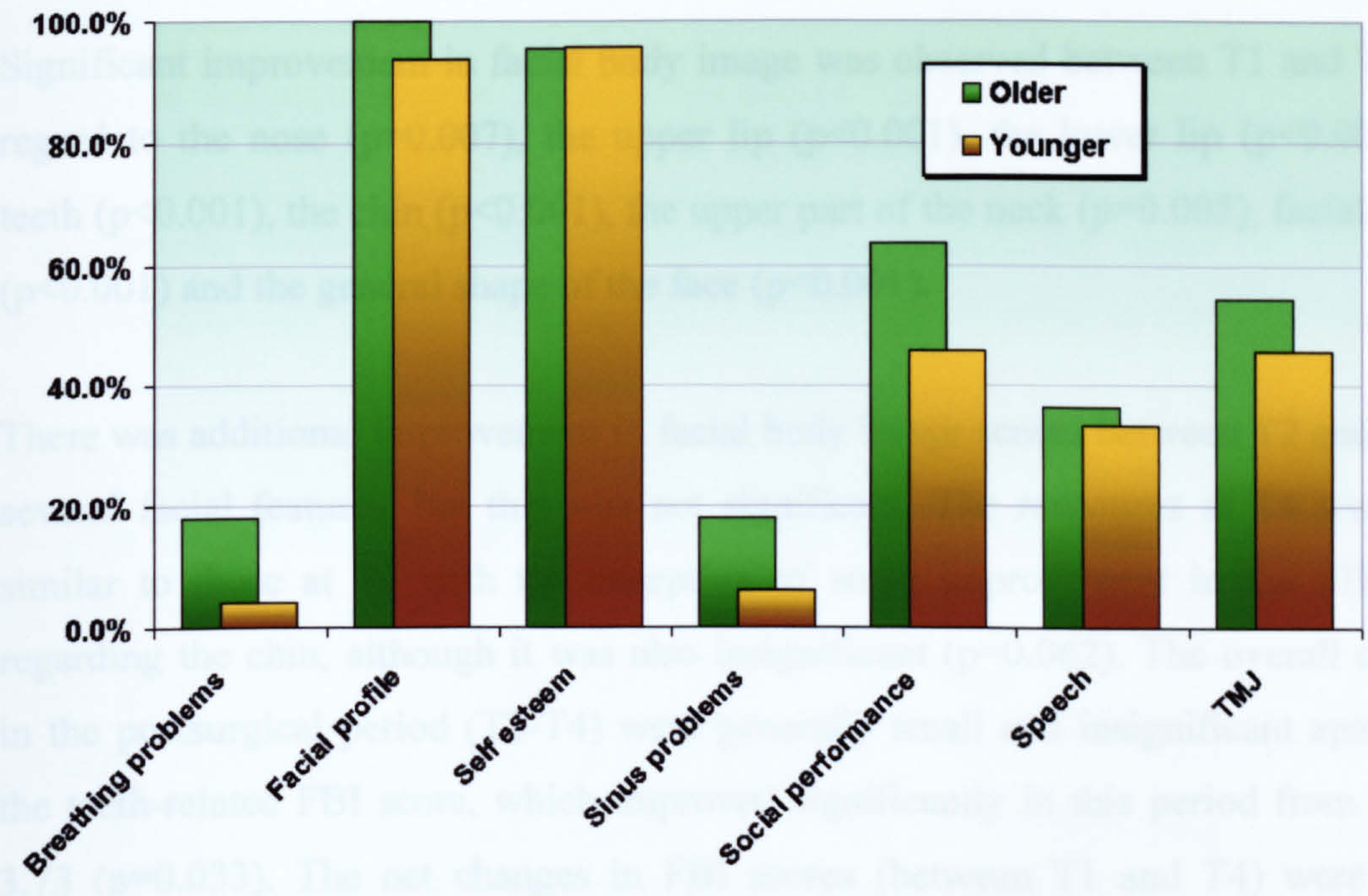


Figure 4.8 Difference in motivation between younger and older subjects.

4.4.1.2 Patients' perception of facial appearance and facial change

4.4.1.2.1 Facial Body Image

4.4.1.2.1.1 General overview (Table 4.65)

Table 4.65	Mean scores of facial body image (FBI) at four assessment times (n=70)									
Facial feature	**T1**	P values T2-T1*	**T2**	P values T3-T2	**T3**	P Values T4-T3	**T4**	P values T4-T2	P values T4-T1
Hair	**3.66**	0.241	**3.96**	0.472	**3.81**	0.331	**3.90**	0.868	0.098
Forehead	**3.53**	0.538	**3.57**	0.262	**3.72**	0.484	**3.64**	0.351	0.251
Eyes	**4.03**	0.152	**4.20**	0.767	**4.22**	0.871	**4.23**	0.511	0.070
Ears	**3.71**	0.872	**3.83**	0.073	**3.67**	0.727	**3.64**	0.204	0.526
Nose	**2.99**	0.007	**3.41**	0.855	**3.43**	0.261	**3.31**	0.359	0.006
Upper lip	**2.69**	<0.001	**3.78**	0.375	**3.87**	0.635	**3.91**	0.197	<0.001
Lower lip	**2.60**	<0.001	**3.83**	0.278	**3.91**	1.000	**3.91**	0.429	<0.001
Cheeks	**3.34**	0.117	**3.61**	1.000	**3.70**	0.328	**3.81**	0.124	0.003
Teeth	**2.00**	<0.001	**3.44**	0.361	**3.51**	0.124	**3.73**	0.033	<0.001
Chin	**1.69**	<0.001	**3.54**	0.241	**3.78**	0.062	**3.91**	0.192	<0.001
Neck	**3.14**	0.005	**3.65**	0.812	**3.63**	0.358	**3.70**	0.728	<0.001
Profile	**1.73**	<0.001	**3.57**	0.070	**3.90**	0.880	**3.86**	0.176	<0.001
Shape of face	**2.26**	<0.001	**3.76**	0.538	**3.85**	0.859	**3.87**	1.000	<0.001

(*) Wilcoxon matched pairs signed rank tests were applied to detect statistically significant differences. P values under level of significance (0.05) are underlined and highlighted in red.

Significant improvement in facial body image was observed between T1 and T2 with regard to the nose (p=0.007), the upper lip (p<0.001), the lower lip (p<0.001), the teeth (p<0.001), the chin (p<0.001), the upper part of the neck (p=0.005), facial profile (p<0.001) and the general shape of the face (p<0.001).

There was additional improvement in facial body image scores between T2 and T3 for several facial features, but this was not significant. The responses at T4 were very similar to those at T3 with the exception of some improvement in the FBI score regarding the chin, although it was also insignificant (p=0.062). The overall changes in the postsurgical period (T2-T4) were generally small and insignificant apart from the teeth-related FBI score, which improved significantly in this period from 3.44 to 3.73 (p=0.033). The net changes in FBI scores (between T1 and T4) were highly significant for eight facial features.

Patient responses on this questionnaire can be reviewed in another way. For each subscale, three categories were created: category (I) included patients who had negative feelings towards a particular facial item (subjects who scored (1) or (2) in the subscale); category (II) included patients who did not have any particular feelings one way or another (subjects who scored (3) in the subscale) and category (III) included subjects who had positive feelings towards a particular facial item (subjects who scored (4) and (5) in the subscale).

Regions not affected by surgery. The presurgical scores (at T1) showed a high percentage of subjects who had positive feelings towards their hair (61.43%), the forehead (57.14%), the eyes (81.43%) and the ears (68.57%). The percentage of positive feelings increased slightly in the postsurgical period, although the surgical correction did not involve any of them, e.g. the percentage with positive feelings towards their hair increased to 70% at T4.

Nasal region. Subjects who were moderately or very satisfied with the nasal appearance comprised 40% of the study group and this figure increased to 56.52% at one month following surgery, with a small drop observed at T4 (52.86%). The percentage of patients who did not like the nasal appearance decreased from 32.86% (at T1) to 17.39% (at T2) as a result of the surgical correction, but there was a gradual increase in this percentage at T3 (22.39%) and T4 (25.71%).

Lips, cheeks, teeth and chin. Subjects' feelings towards the upper lip appearance improved between T1 and T2. In contrast to what was observed in the nasal image, the negative feelings towards the upper lip were minimal at T4 (1.43%). A similar improvement was observed in the scores related to the lower lip. Subjects had positive feelings towards the cheek at T1 (52.86%), and the percentage of subjects with these feelings improved further to 70% at six months following surgery. About 74 % of the study group believed that the appearance of the teeth was not satisfactory and pleasing. Eighty percent did not like the appearance of the chin. A dramatic reduction in these percentages, however, occurred at T2 with an accompanying increase in the proportion of subjects who possessed positive feelings towards the teeth and the chin. This response did not change considerably at three months and six months postsurgery.

Facial periphery, profile and shape. The question about patient's feelings towards the upper part of the neck did not yield any definite answer in about 50% of the subjects at T1. The perception of the facial profile was negatively rated at T1 by more than 75% of the subjects. The percentage respondents with negative opinion about their facial profile reached its minimal value at T4 (8.57%). Similar changes were observed with regard to self-perception of facial shape.

Overall facial image. The average percentage for the thirteen facial items at each assessment time was calculated. Before surgery, 40% of the subjects indicated their unhappiness with their overall facial features, whereas another 40% of the subjects were satisfied or even happy with the overall facial features. The remaining 20% did not have any particular feelings at that time. At six months following surgery, over 70% of the subjects perceived their overall facial features positively.

4.4.1.2.1.2 Class II versus Class III patients (Figures 4.9 - 4.12)

Fisher's exact tests were applied to detect differences in facial body image between the two groups since the validity of chi-squared approximations was in doubt for most of the variables assessed.

Before surgery (Figure 4.9). Class II subjects compared with Class III subjects had more negative feelings regarding the teeth (87.5% vs. 67.3; p=0.186), the chin (83.33% vs. 78.2%; p=0.703), the upper part of the neck (25% vs. 13%; p=0.335) and the hair (33.33% vs. 15.2%; p=0.125). On the other hand, Class III subjects had more negative feelings regarding the forehead (15.2% vs. 4.17%; p=0.250), the nose (36.9% vs. 25%; p=0.435), the upper lip (47.8% vs. 41.67%; p=0.275) and the facial profile (78.2% vs. 70.83%; p=0.754). All of the observed differences between both groups were insignificant.

At one month following surgery (Figure 4.10). There was a fall in the percentages of subjects having negative feelings towards their facial components. At this assessment time, Class II subjects compared with Class III subjects had more negative feelings regarding the hair (29.4% vs. 6.9%; p=0.004), the upper lip (11.7% vs. 3.45%; p=0.565), the facial profile (35.2% vs. 17.24%; p=0.325) and the shape of the face (17.6% vs. 3.45%; p=0.313). Class III subjects had more negative feelings regarding the forehead (17.24% vs. 5.8%; p=0.406), the nose (20.69% vs. 11.7%; p=0.504) and the upper part of the neck (10.34% vs. 0%; p=0.337). The only significant difference was in the hair-related FBI score.

At three months following surgery (Figure 4.11). Class II subjects compared with Class III subjects were more negative regarding the upper lip (14.29% vs. 4.3%; p=0.083) and the shape of the face (19.05% vs. 8%; p=0.313). However, these differences were insignificant.

At the final assessment (Figure 4.12), Class II subjects had more negative feelings regarding their hair (20.8% vs. 6.52%; p=0.106) whereas Class III subjects had more negative feelings regarding their nose (30.43% vs. 16.6%; p=0.314), their cheeks (13.04% vs. 0%; p=0.124) and their upper part of the neck (10.87% vs. 0%; p=0.205). All of the observed differences, however, were insignificant.

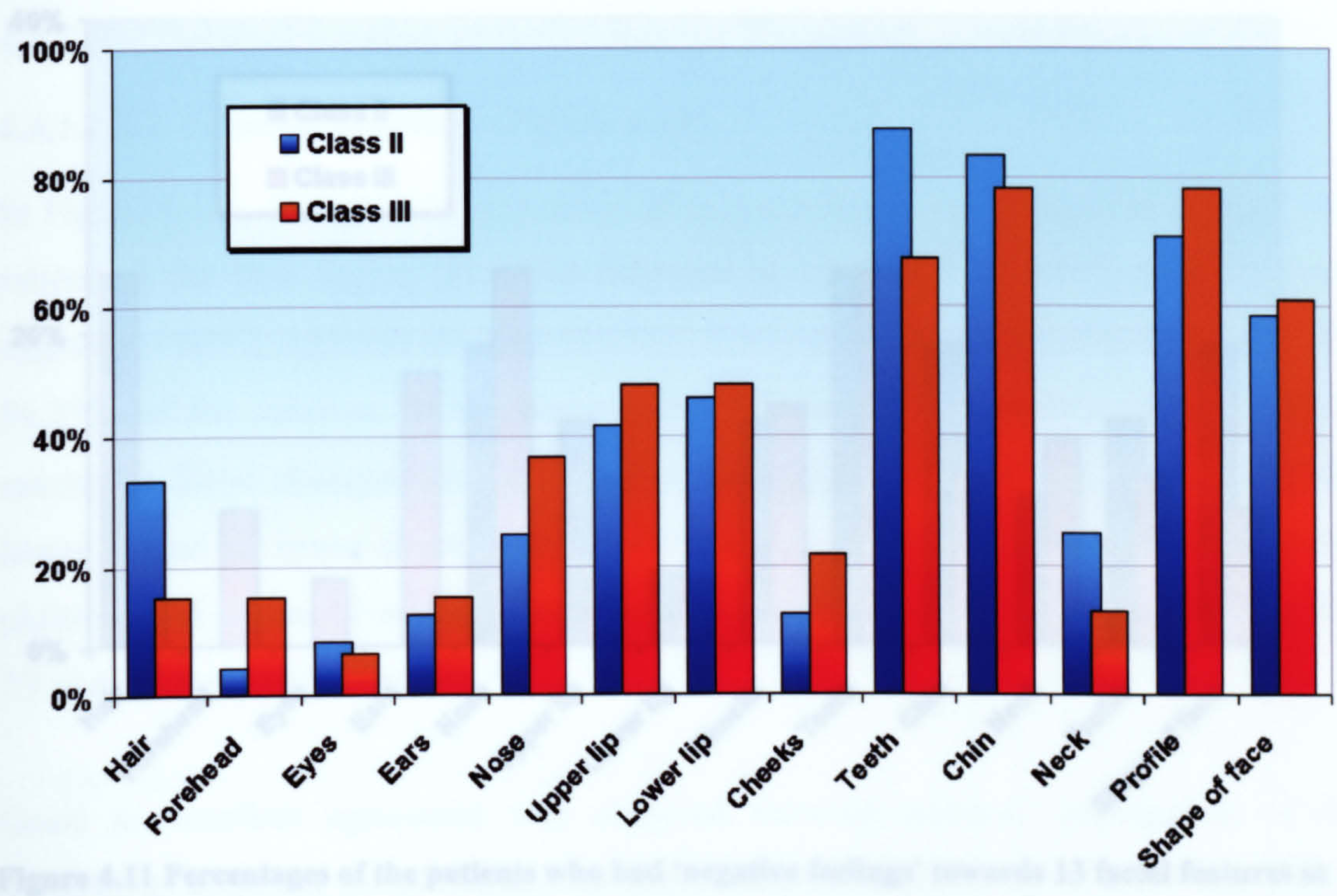


Figure 4.9 Percentages of patients who had 'negative feelings' towards 13 facial features in Class II and Class III groups at T1 (within one week before surgery).

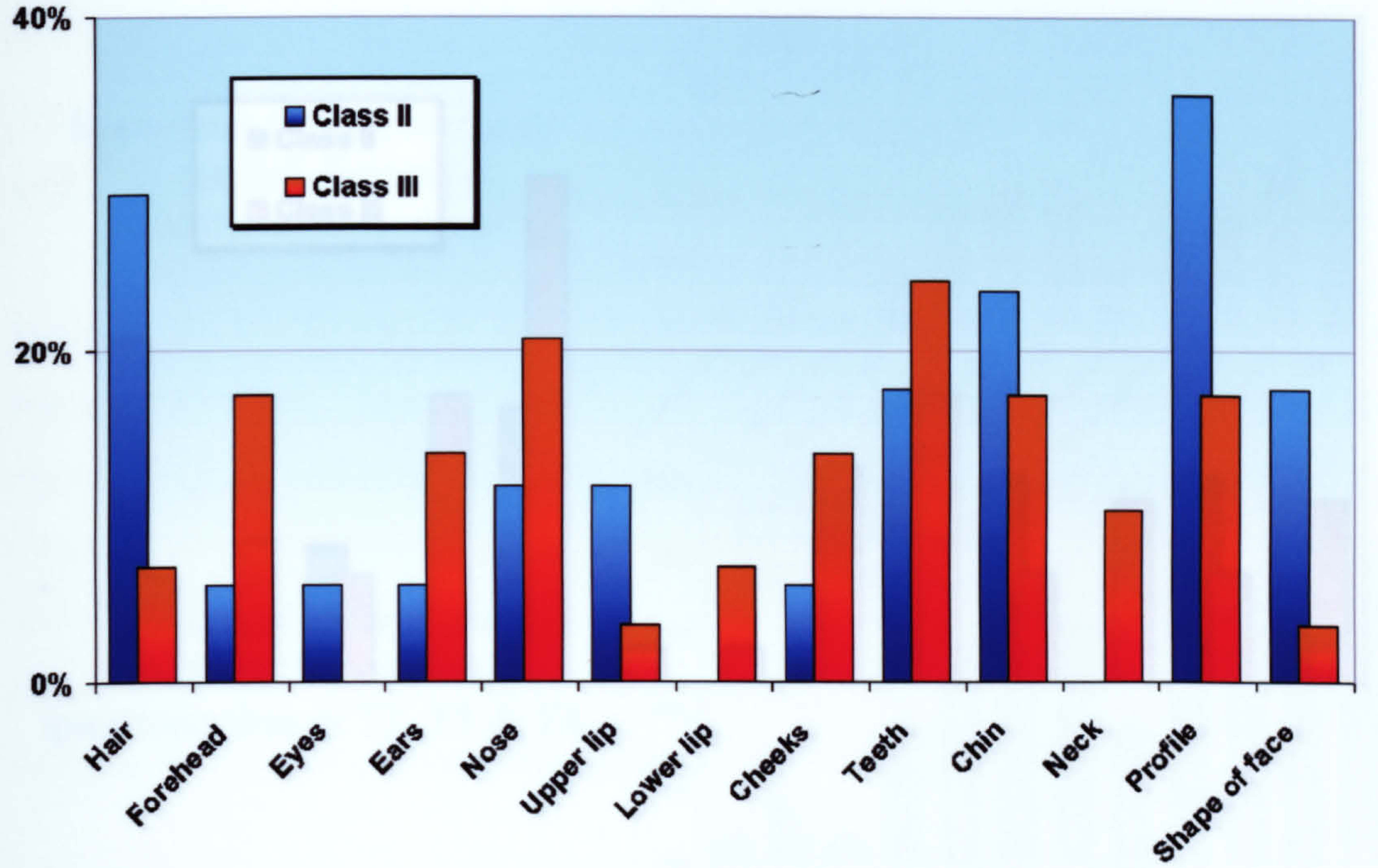


Figure 4.10 Percentages of patients who had 'negative feelings' towards 13 facial features at one month postsurgery.

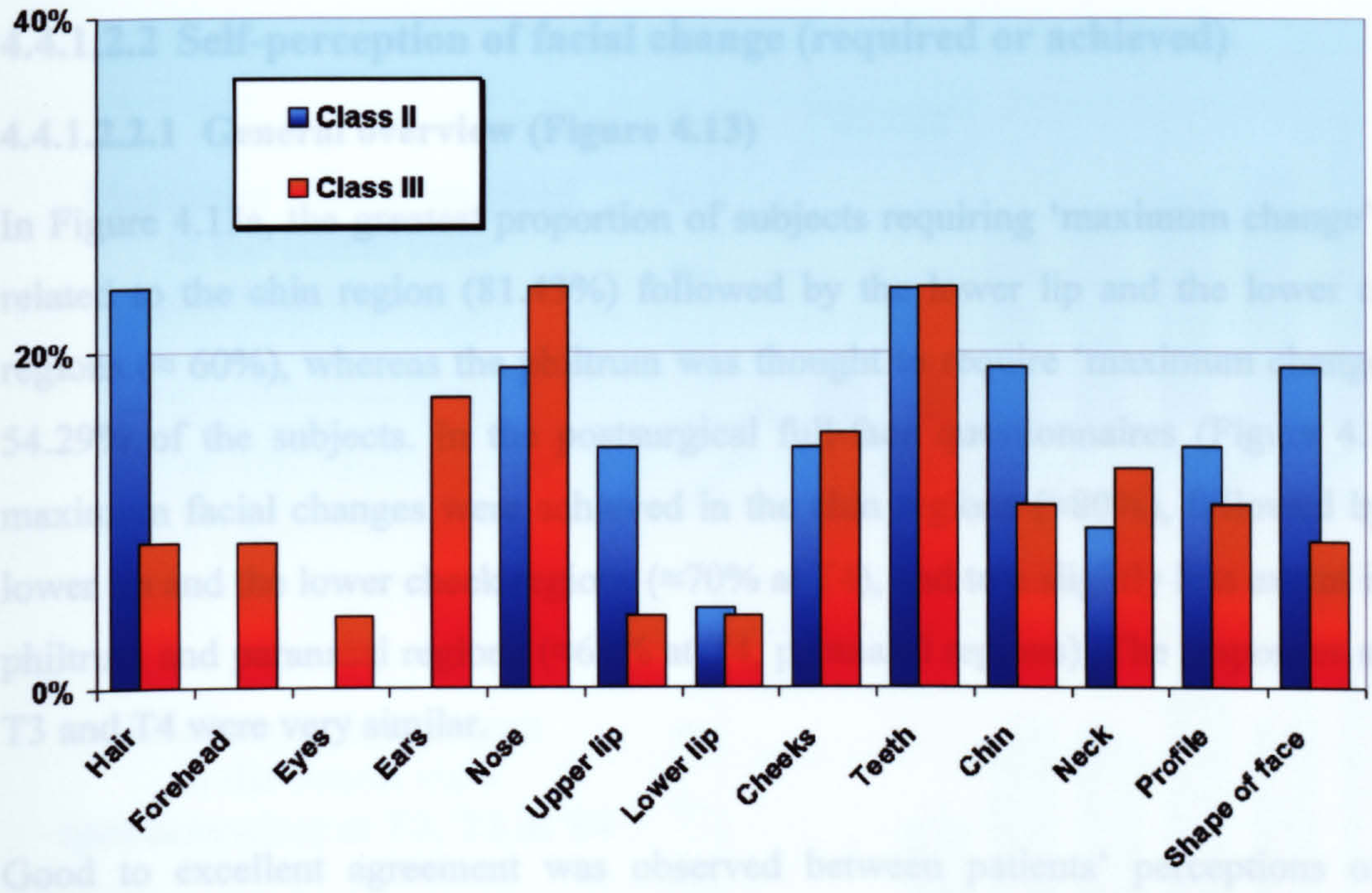


Figure 4.11 Percentages of the patients who had 'negative feelings' towards 13 facial features at three months postsurgery.

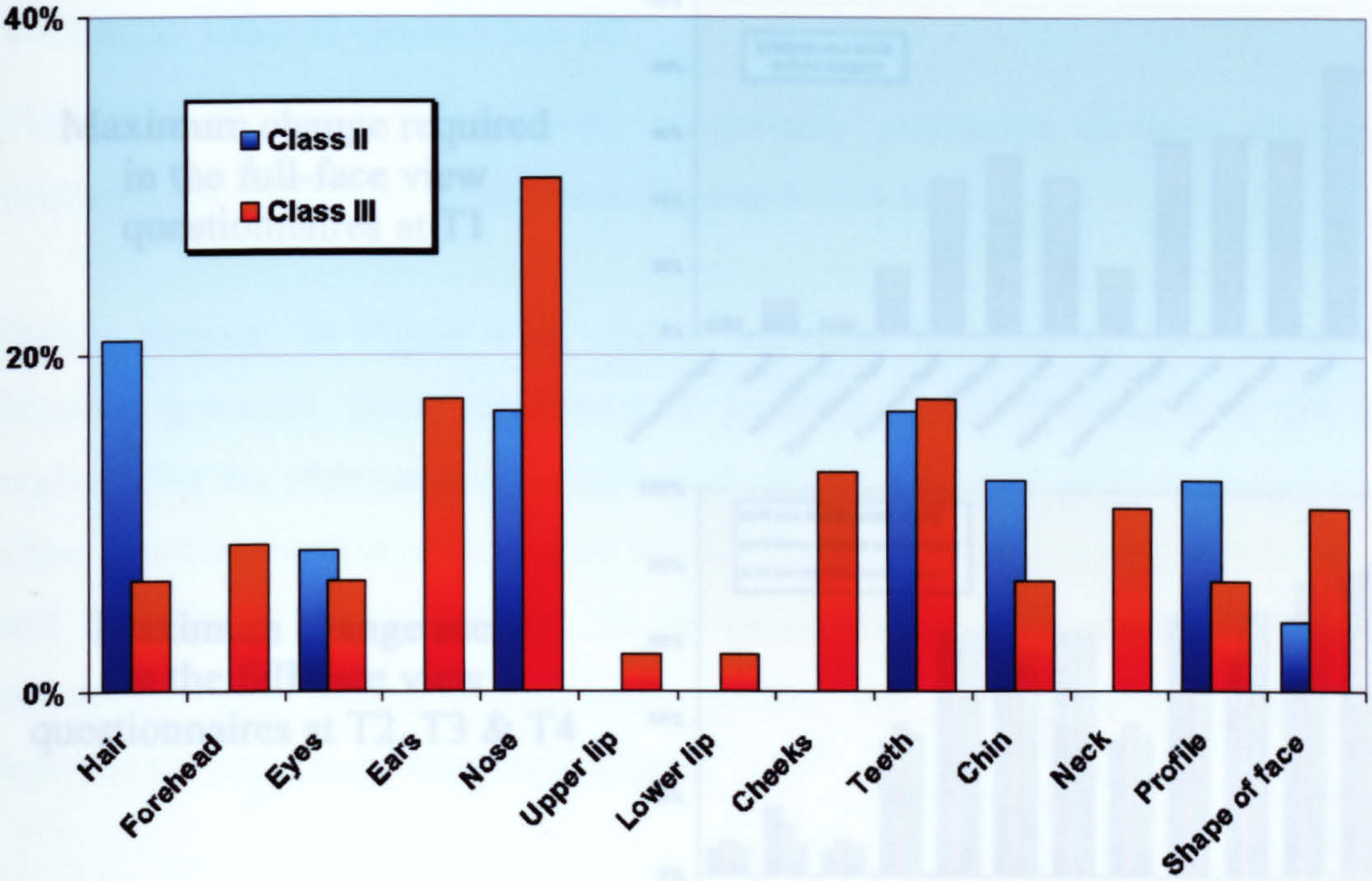


Figure 4.12 Percentages of patients who had 'negative feelings' towards 13 facial features at six months postsurgery.

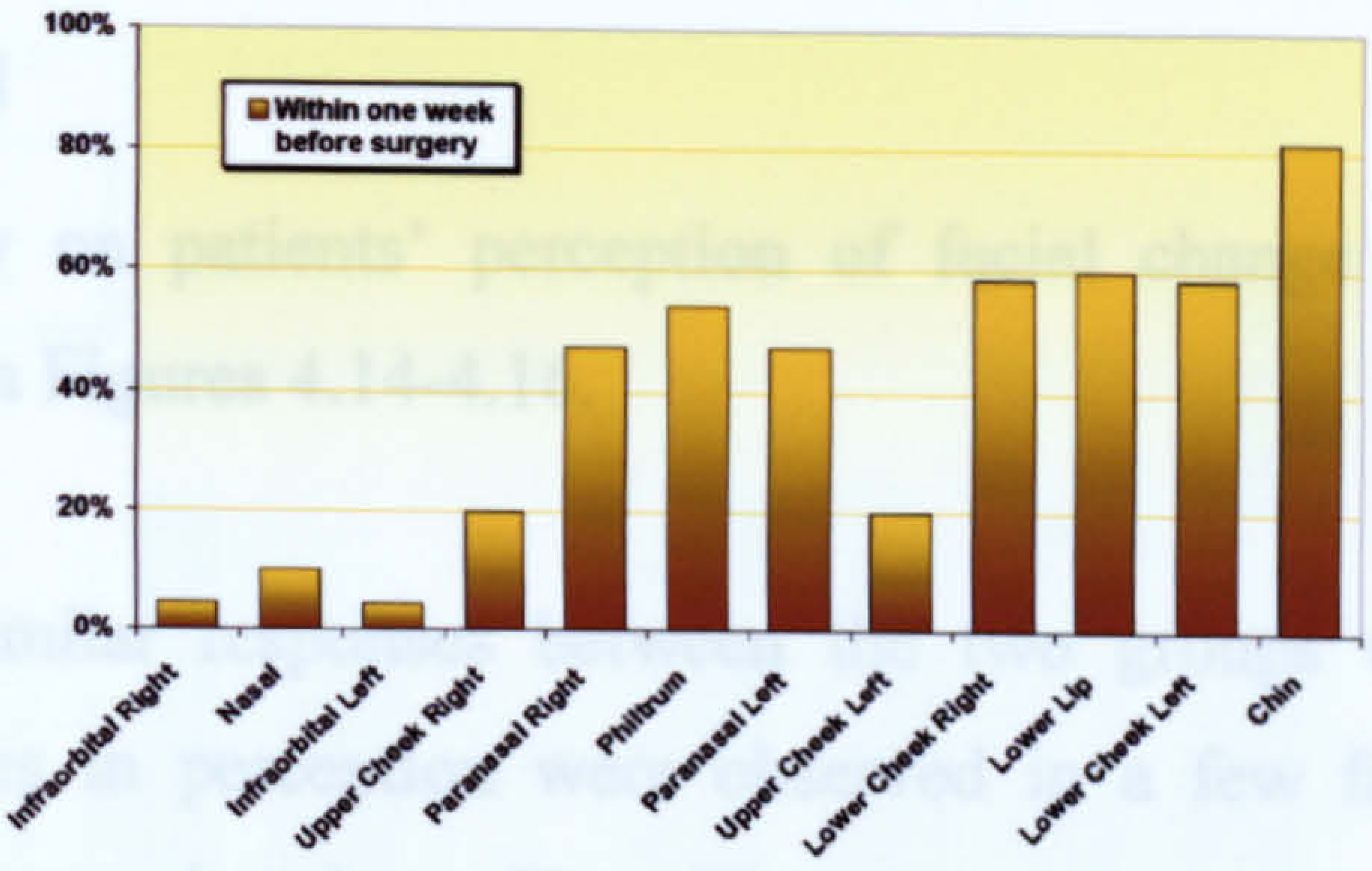
4.4.1.2.2 Self-perception of facial change (required or achieved)

4.4.1.2.2.1 General overview (Figure 4.13)

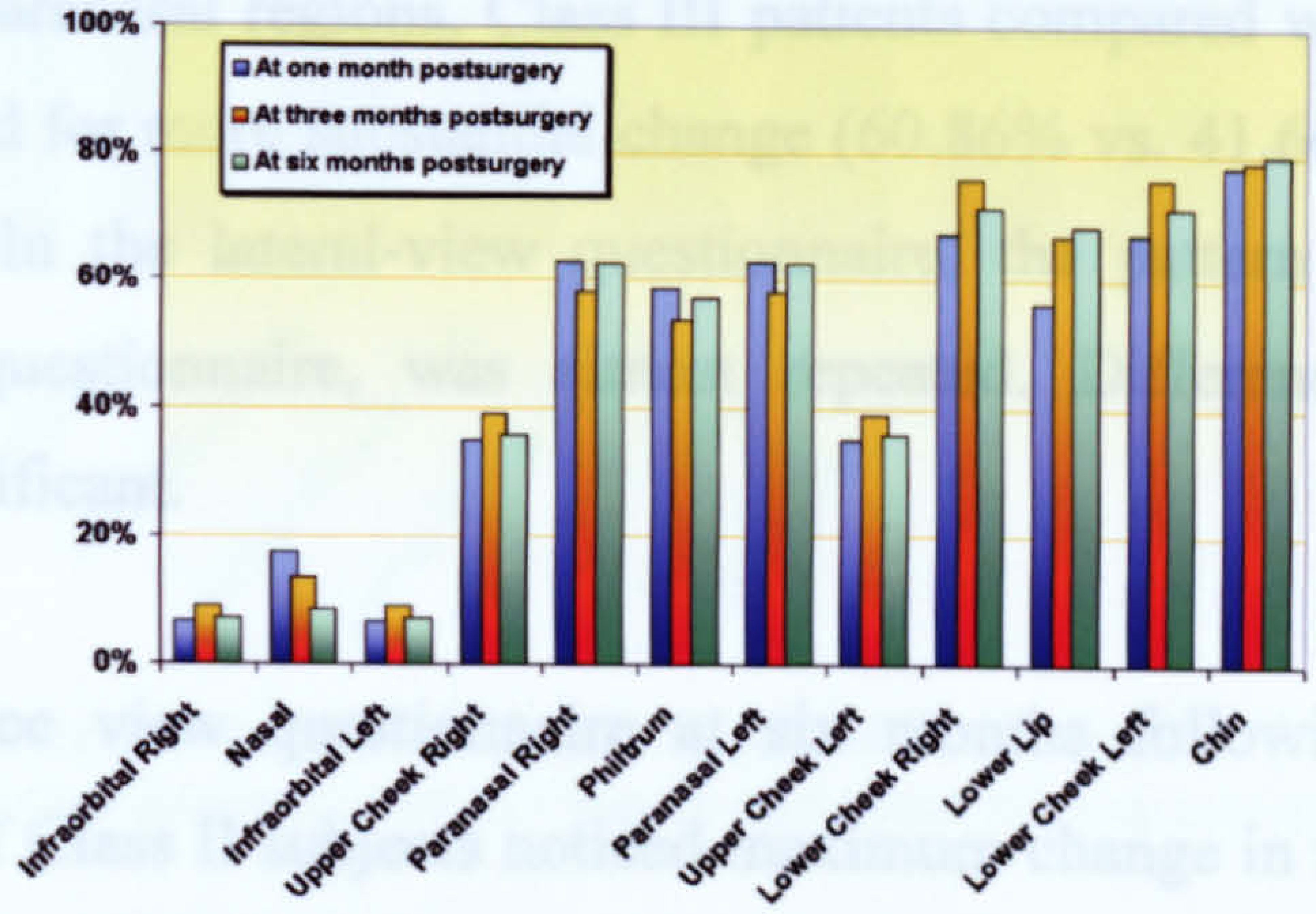
In Figure 4.13a, the greatest proportion of subjects requiring 'maximum change' was related to the chin region (81.43%) followed by the lower lip and the lower cheek regions (≈ 60%), whereas the philtrum was thought to require 'maximum change' by 54.29% of the subjects. In the postsurgical full-face questionnaires (Figure 4.13b), maximum facial changes were achieved in the chin regions (≈80%), followed by the lower lip and the lower cheek regions (≈70% at T4), and to a slightly less extent in the philtrum and paranasal regions (≈63% at T4, paranasal regions). The responses at T2, T3 and T4 were very similar.

Good to excellent agreement was observed between patients' perceptions of the required or achieved facial changes on lateral view drawings (Figure 4.13c and 4.13d) and those perceptions indicated on the full-face view drawings (Kappa statistic values ranged from 0.72 to 0.96).

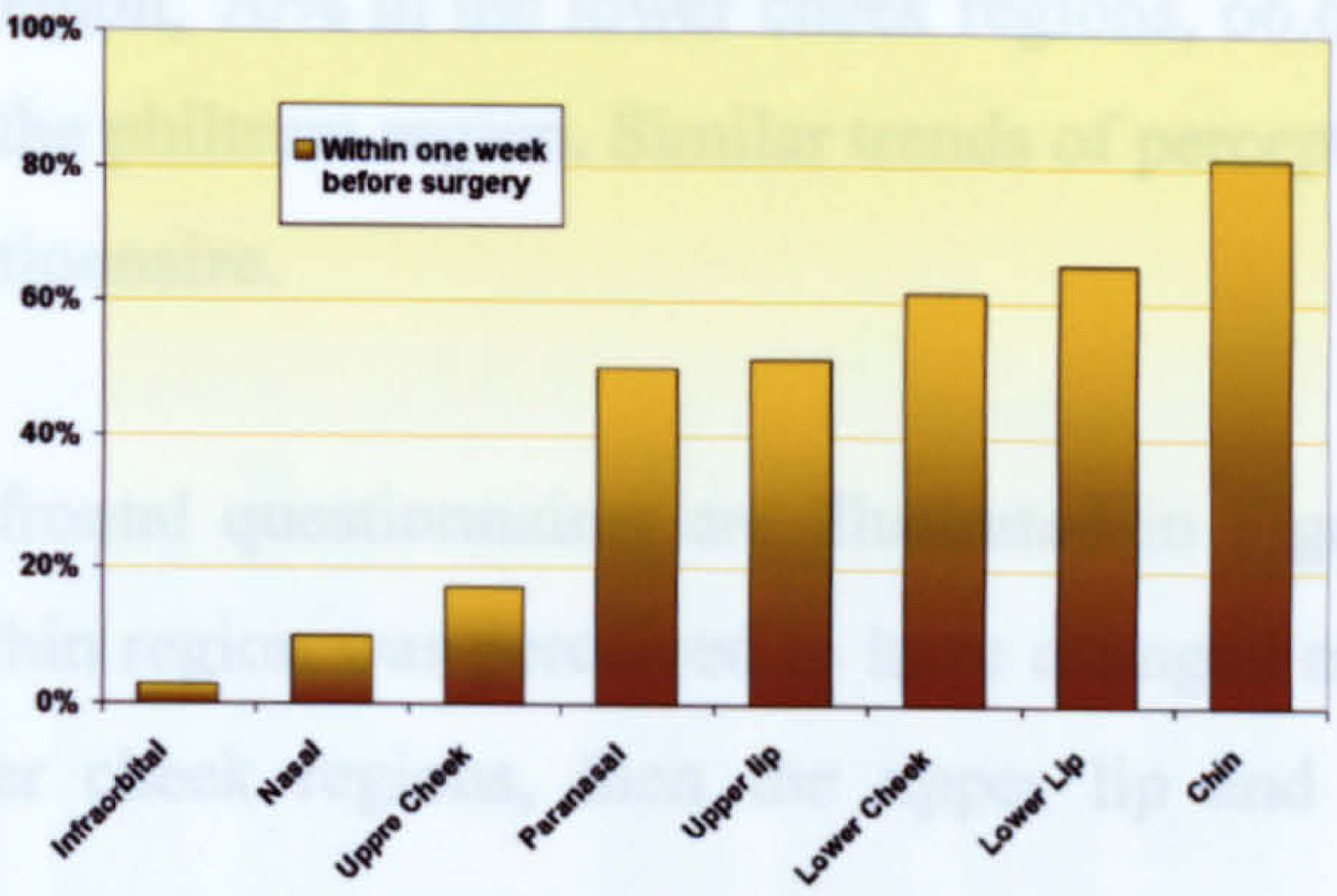
Maximum change required in the full-face view questionnaires at T1



Maximum change seen in the full-face view questionnaires at T2, T3 & T4



Maximum change required in the lateral view questionnaires at T1



Maximum change seen in the lateral view questionnaires at T2, T3 & T4

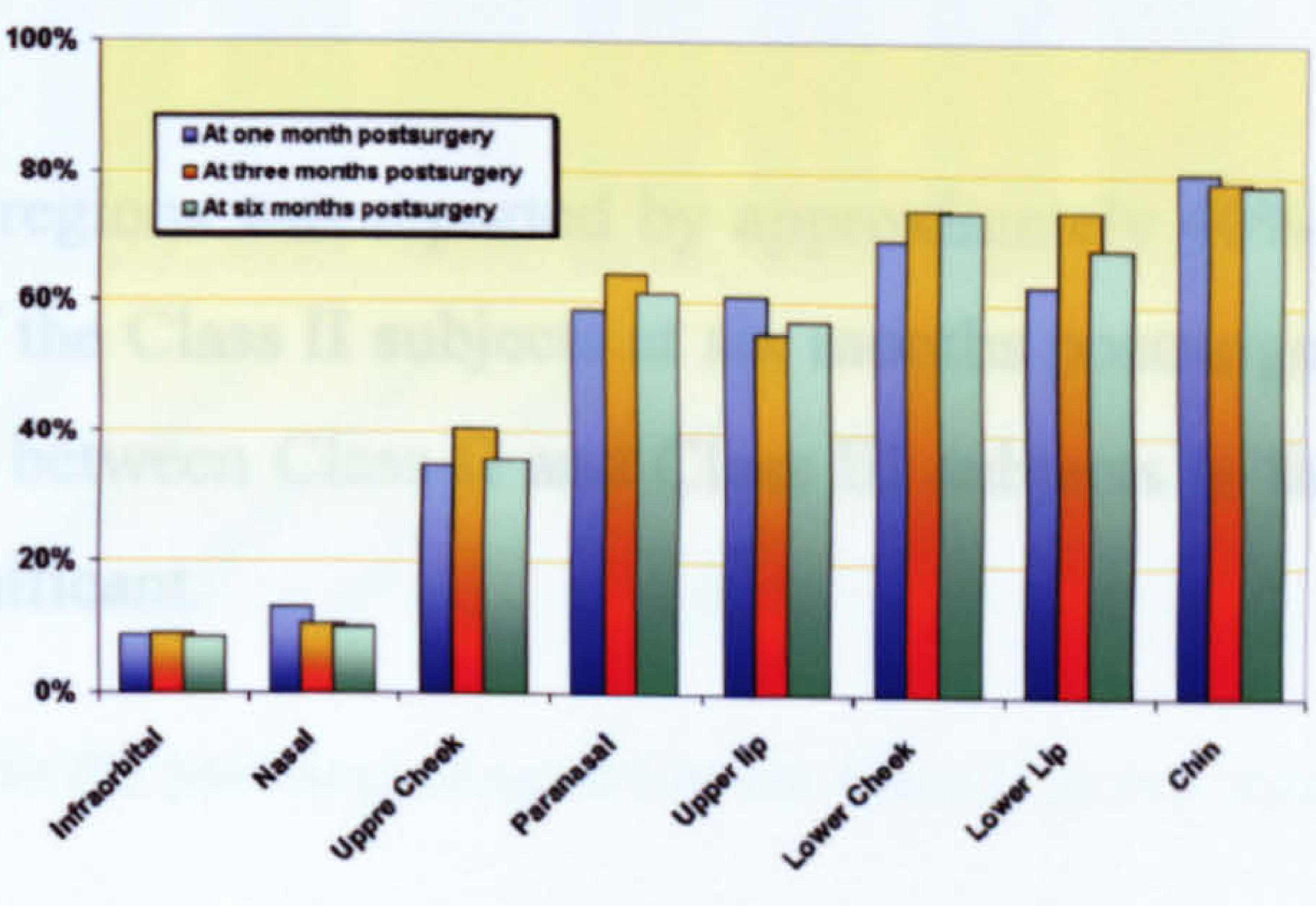


Figure 4.13 Percentages of patients who assigned 'maximum change required' or 'maximum change achieved' for the 12 facial regions in the full-face view questionnaires and for the 8 facial regions on the lateral view questionnaire at different assessment times.

4.4.1.2.2.2 Class II versus Class III

The effect of dentofacial deformity on patients' perception of facial change was evaluated and the results are shown in Figures 4.14-4.16.

Before surgery. In Figure 4.14, similar responses between the two groups were obtained generally. Some differences in perception were observed in a few facial regions. For the philtrum and the paranasal regions, Class III patients compared with Class II patients indicated their need for more substantial change (60.86% vs. 41.66% and 50% vs. 41%, respectively). In the lateral-view questionnaire, the pattern of perception, seen in the frontal questionnaire, was almost repeated. Differences between the two groups were insignificant.

Following surgery. In the full-face view questionnaire at six months following surgery (Figure 4.15), about 83% of Class II subjects noticed maximum change in the chin region, 83.33% in the lower lip region, 70% in the lower cheek regions, 66.66% in the paranasal regions and 62.5% in the philtrum region. Similar trends of perception were observed in the lateral-view questionnaire.

Postsurgical Class III results on the frontal questionnaires are illustrated in Figures 4.16. At six months postsurgery, the chin region was perceived to have changed most followed by the lower lip and lower cheek regions, then the upper lip and the paranasal regions.

Maximum change in the upper cheek regions was reported by approximately 40% of the Class III subjects and by 29.1% of the Class II subjects at six months postsurgery. However, all the observed differences between Class II and Class III subjects in their perception of facial change were insignificant.

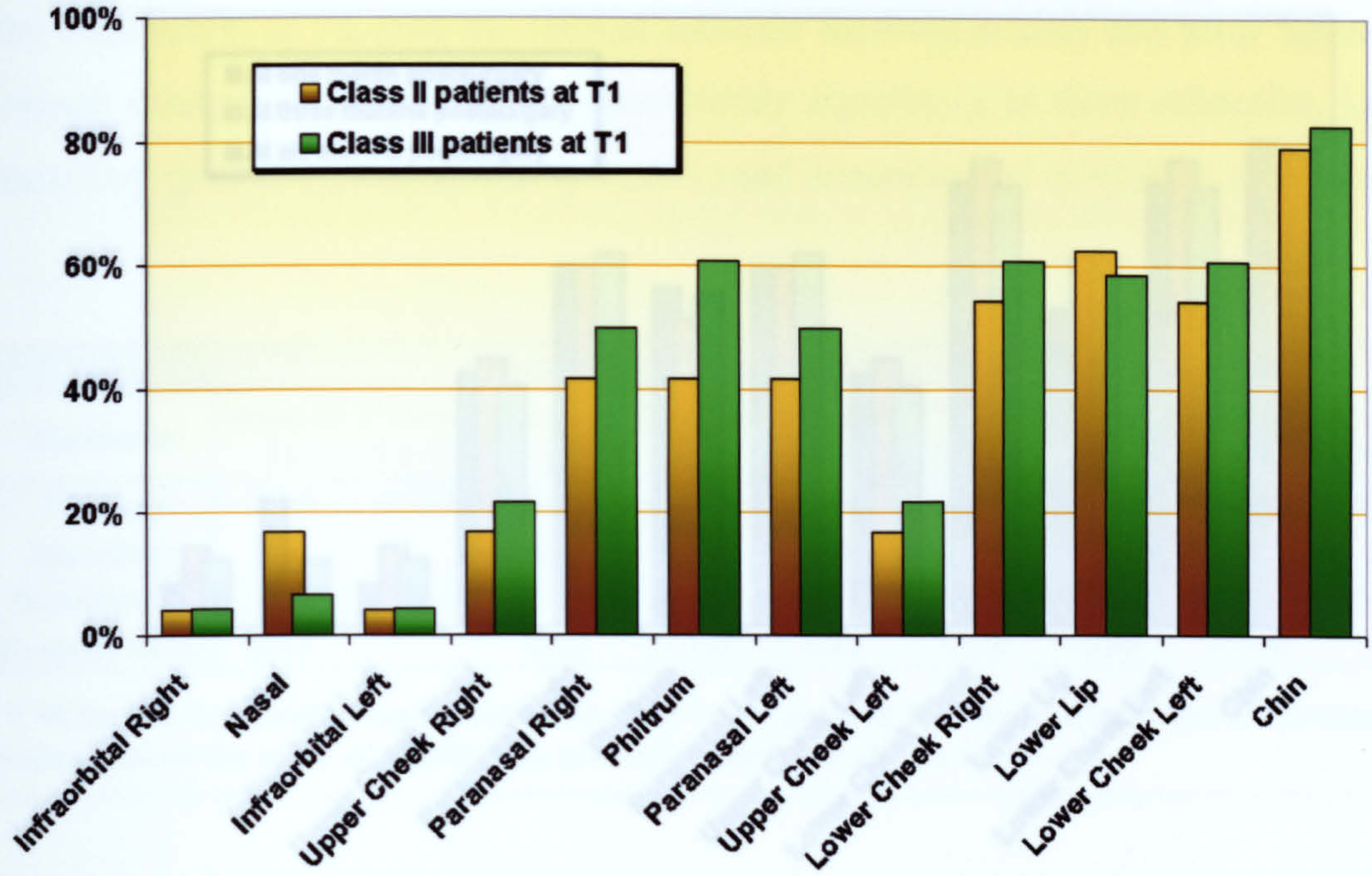


Figure 4.14 Percentages of patients who assigned 'maximum change required' for 12 facial regions tested on full-face view questionnaires administered to Class II and Class III patients at T1.

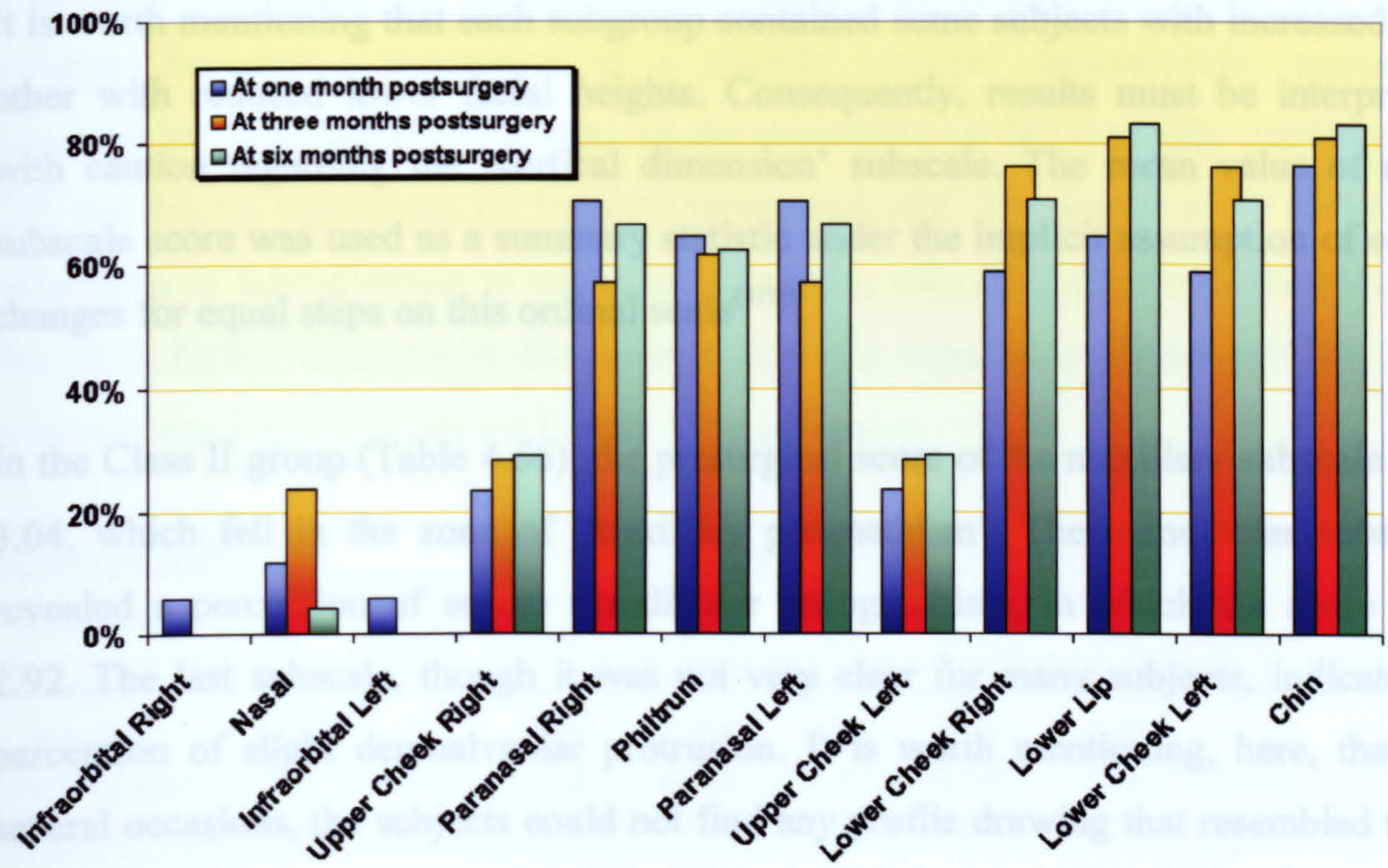


Figure 4.15 Self-perception of facial change in the postsurgical period in the Class II group using full-face view questionnaires

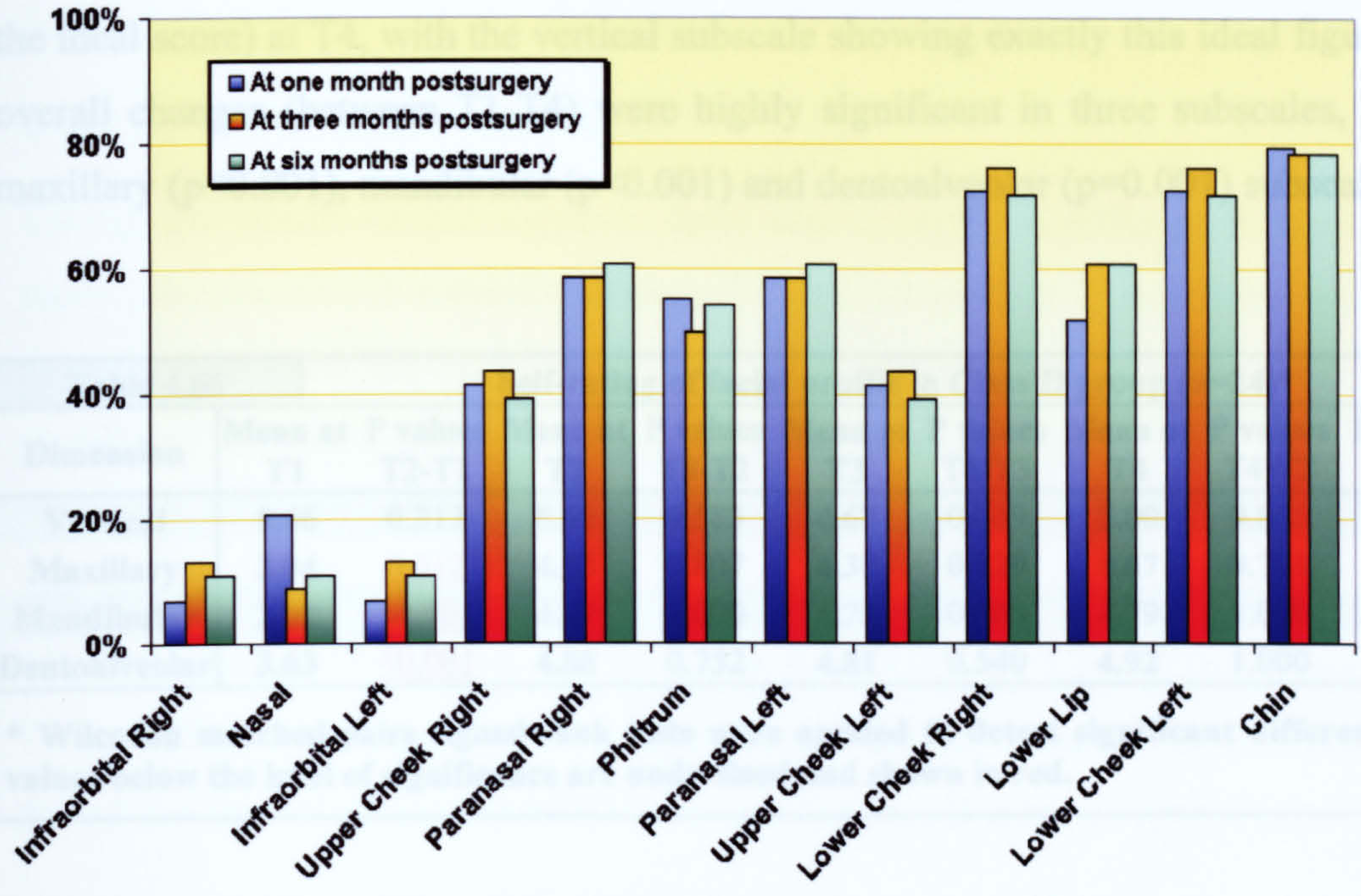


Figure 4.16 Self-perception of facial change in the postsurgical period in the Class III group using full-face view questionnaires

4.4.1.2.3 Self-perception of facial profile (Tables 4.66 and 4.67)

It is worth mentioning that each subgroup contained some subjects with increased and other with reduced lower facial heights. Consequently, results must be interpreted with caution regarding the 'vertical dimension' subscale. The mean value of each subscale score was used as a summary statistic under the implicit assumption of equal changes for equal steps on this ordinal scale[476].

In the Class II group (Table 4.66), the presurgical score of the maxillary subscale was 3.04, which fell in the zone of 'maxillary prognathism'. The mandibular subscale revealed a perception of severe mandibular retrognathism, in which the score was 2.92. The last subscale, though it was not very clear for many subjects, indicated a perception of slight dentoalveolar protrusion. It is worth mentioning, here, that on several occasions, the subjects could not find any profile drawing that resembled their case in the last subscale.

Between T1-T2, there was a significant improvement in the perception of facial profile. This was evident in the maxillary ($p=0.012$), mandibular ($p<0.001$) and dentoalveolar ($p<0.001$) subscales. Changes in the interim intervals (between T2-T3 and T3-T4) were small and insignificant. The scores were very close to '5' (which is the ideal score) at T4, with the vertical subscale showing exactly this ideal figure. The overall changes (between T1-T4) were highly significant in three subscales, i.e. the maxillary (p<0.001), mandibular (p<0.001) and dentoalveolar (p=0.001) subscales.

Table 4.66	Self-rating of facial profile in Class II group (n=24)*									
Dimension	**Mean at T1**	P values T2-T1	**Mean at T2**	P values T3-T2	**Mean at T3**	P values T4-T3	**Mean at T4**	P values T4-T2	P values T4-T1
Vertical	**5.46**	0.313	**5.18**	0.583	**4.67**	0.069	**5.00**	0.805	0.372
Maxillary	**3.04**	0.012	**4.53**	0.807	**4.38**	0.329	**4.67**	0.791	≤0.001
Mandibular	**2.92**	≤0.001	**4.77**	1.000	**4.76**	0.666	**4.79**	1.000	≤0.001
Dentoalveolar	**3.63**	≤0.001	**4.88**	0.752	**4.81**	0.540	**4.92**	1.000	0.001

*** Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P-values below the level of significance are underlined and shown in red.**

In Table 4.67 (Class III group), the subjects showed a different perception of their facial profile. At T1, the face was judged to be slightly longer than the average (mean=6.02). The maxilla was thought to be in a backward position (mean=7.22) whereas the mandible was thought to be in forward position (mean=7.32). The fourth subscale revealed a perception of a slightly retruded dentoalveolar compound (mean=6.35). The impact of surgery on the perception of facial profile (between T1-T2) was highly significant for the first three subscales. The scores at T2 revealed a perception of normalisation of the facial deformity, with all the values approximating the ideal figure. Changes in the interim intervals were insignificant and the final outcome was highly significant for all of the subscales.

Table 4.67	Self-rating of facial profile in Class III group (n=46)									
Dimension	**Mean at T1**	P values T2-T1	**Mean at T2**	P values T3-T2	**Mean at T3**	P values T4-T3	**Mean at T4**	P values T4-T2	P values T4-T1
Vertical	**6.02**	0.001	**5.31**	0.470	**4.94**	0.242	**5.11**	0.677	≤0.001
Maxillary	**7.22**	≤0.001	**5.00**	0.424	**4.87**	0.133	**4.98**	0.745	≤0.001
Mandibular	**7.37**	≤0.001	**5.28**	0.212	**5.07**	0.767	**5.09**	0.326	≤0.001
Dentoalveolar	**6.35**	0.091	**5.24**	0.352	**5.02**	0.079	**5.30**	0.161	0.005

*** Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P-values below the level of significance are underlined and shown in red.**

4.4.1.3 Personality characteristics

4.4.1.3.1 Self-esteem (Table 4.68)

Taking the whole sample together, there was a highly significant reduction in the score (increase in self-esteem) between T1 and T2 (p<0.001) and there was another reduction between T3 and T4 (p=0.033). So, the overall change was a highly significant increase in self-esteem as a result of treatment.

The improvement in perceived self-worth was also evident in Class II and Class III subjects between T1-T2 (p=0.004 for Class II, p<0.001 for Class III) and between T1-T4 (p<0.001 for each). Another significant increase occurred in the postsurgical period in Class III subjects (p=0.033) but not in Class II subjects (p=0.121).

Table 4.68	Self-esteem scores at different assessment times									
Group	N	T1	P values T2-T1*	T2	P values T3-T2	T3	P values T4-T3	T4	P values T4-T2	P values T4-T1
All	70	**21.29**	<0.001	**18.11**	0.155	**18.00**	0.033	**16.50**	0.011	<0.001
Class II	24	**21.21**	0.004	**18.53**	0.508	**18.05**	0.198	**17.25**	0.121	<0.001
Class III	46	**21.33**	<0.001	**17.86**	0.046	**17.00**	0.094	**15.50**	0.033	<0.001

(*) Statistically significant differences were detected using paired t tests. Non-parametric tests were applied on asymmetric distributions and the related p values are shown in blue. P-values smaller than the level of significant are underlined.

One of the interesting findings in the whole study group (Table 4.69) was the sex difference, which was evident at all assessment times. On the other hand, there were no significant differences between younger (< 25 years) and older (≥ 25 years) subjects before and after surgery.

Table 4.69	Sex- and age-differences in self esteem scores (n=70)			
Comparison	T1	T2	T3	T4
Male (n=17)	18.94	13.64	15.18	14.88
Female (n=53)	22.04	19.51	18.28	17.64
P value* Male vs. Female	0.065	0.003	0.034	0.034
Younger (n=47)	21.00	17.89	17.38	16.62
Older (n=23)	21.87	18.44	17.73	17.70
P value Younger vs. Older	0.547	0.743	0.926	0.452

(*) P values shown in black are related to two-sample t-tests, while those shown in blue are related to Mann-Whitney U tests. Significant results are underlined.

4.4.1.3.2 Anxiety and depression

Table 4.70 illustrates the results related to the Hospital Anxiety and Depression Scale (HADS) questionnaire. The presurgical levels of anxiety were slightly higher that the levels of depression and the difference between them remained at the postsurgical assessment times. It is worth mentioning that the levels of anxiety and depression at the first assessment time did not reach any serious clinical limits that would have necessitated psychological treatment.

In the whole study group (n=70), levels of anxiety reduced significantly between T1-T2 ($p<0.001$) and between T3-T4 (0.033) with a highly significant reduction overall (T1-T4; $p<0.001$). Although significant reductions in the depression scale were observed, the pre- and post-surgical values were within the normal range.

Table 4.70	Anxiety and Depression scores at different assessment times									
Group	**N**	**Variable**	**T1**	P value T2-T1	**T2**	P value T3-T2	**T3**	P value T4-T3	**T4**	P value T4-T2	P value T4-T1
All	70	Anxiety	**8.17**	<0.001	**6.09**	0.400	**5.91**	0.033	**5.43**	0.058	<0.001
		Depression	**3.31**	0.037	**2.48**	0.017	**1.97**	0.008	**1.57**	0.005	<0.001
Class II	24	Anxiety	**8.13**	0.028	**5.82**	0.830	**6.43**	0.020	**5.54**	0.301	<0.001
		Depression	**3.46**	0.112	**2.41**	0.466	**2.19**	0.038	**1.58**	0.209	0.001
Class III	46	Anxiety	**8.20**	0.001	**6.24**	0.225	**5.67**	0.275	**5.37**	0.067	<0.001
		Depression	**3.24**	0.164	**2.52**	0.031	**1.87**	0.080	**1.57**	0.025	<0.001

(*) Statistically significant differences were detected using paired t tests. Non-parametric tests were applied on asymmetric distributions and the related p values are shown in blue. P-values smaller than the level of significant are underlined.

In the Class II group, the anxiety score reduced significantly between T1-T2 (p=0.028), T3-T4 (p=0.020) and between T1-T4 (p<0.001). The overall reduction in the depression score was also highly significant (p=0.001). In the Class III group, the anxiety and depression scores reduced significantly between T1-T4 (p<0.001for each). As shown in Table 4.71, females were significantly more anxious than males at T1 (p=0.029) and at T2 (p=0.039). The sex-difference was not significant at T4 (p=0.061). Females were more depressed than males at T1 (p=0.001), T2 (p=0.013) and T3 (p=0.011), but this difference was lost at T4 (p=0.150). There were no significant differences between younger and older subjects in both psychometric measures.

Table 4.71	Sex- and age-differences in Hospital Anxiety and Depression Scale (HADS)				
Comparison		T1	T2	T3	T4
Anxiety	Male (n=17)	6.18	4.27	5.06	4.35
	Female (n=53)	8.81	6.66	6.20	5.77
P value* Male vs. Female		<u>0.029</u>	<u>0.039</u>	0.316	0.061
Depression	Male	1.59	1.18	0.88	1.06
	Female	3.87	2.89	2.34	1.74
P value Male vs. Female		<u>0.001</u>	<u>0.013</u>	<u>0.011</u>	0.150
Anxiety	Younger (n=47)	8.19	6.11	5.78	5.51
	Older (n=23)	8.13	6.06	6.18	5.26
P value Younger vs. Older		0.947	0.960	0.695	0.739
Depression	Younger	2.94	2.18	1.71	1.53
	Older	4.09	2.94	2.50	1.65
P value Younger vs. Older		0.119	0.689	0.052	0.378

(*) P values shown in black are related to two-sample t-tests, while those shown in blue are related to Mann-Whitney U tests. Significant results are underlined.

4.4.1.3.3 Other personality characteristics (MHLC and EPQ-R)

Table 4.72 summarises the results obtained from the Multidimensional Health Locus of Control (MHLC) questionnaire as well as the EPQ-R Short Scale. The belief in internal locus of control for health was stronger than the belief in 'chance' or 'powerful others' in the whole study group as well as in the different subgroups. Results related to CHLC and PHLC were generally similar in the whole group as well as in Class III subjects. Two-sample t tests revealed that Class II subjects had a stronger belief in chance as a locus of control for health than Class III subjects (p=0.005). Class II subjects, compared with Class III subjects, had a slightly higher PHLC score indicating a slightly stronger belief in powerful others (e.g. health professionals) as a source of control over health.

The EPQ-R short scale disclosed a generally high score in 'neuroticism' as well as in 'extroversion-introversion' subscales in the studied groups. The scores related to the 'psychoticism' subscale were the least among all groups. Mann-Whitney U tests revealed that Class III patients, compared with Class II patients, had more psychoticism (p=0.001) and were more extrovert (p=0.040).

Table 4.72 **Some personality characteristics scores measured in the presurgical questionnaires**

Questionnaire		Multidimensional Health Locus of Control (MHLC)			EPQ-R Short Scale			
Group	**N**	IHLC*	CHLC	PHLC	Neuroticism	Psycho-ticism	Extroversion-Introversion	Lies
All	70	25.029	18.4	17	7.129	2.8	8.314	4.386
Class II	24	24.625	20.292	17.33	7.708	2.125	7.083	4.667
Class III	46	25.239	17.413	16.826	6.826	3.152	8.957	4.239
P value† Class II vs. III		0.532	0.005	0.780	0.258	0.001	0.040	0.5327

(*) IHLC = Internal Health Locus of Control, CHLC = Chance Health Locus of Control, PHLC = Powerful-others Health Locus of Control

(†) Two-sample t tests were applied on the MDHLC variables, whereas Mann-Whitney U tests were applied on the EPQ-R Short Scale variables. P values obtained from the latter are shown in blue. P values related to significant differences are underlined.

In Table 4.73, sex- and age-differences are presented. Males, compared with females, had a stronger belief in "powerful others" as a locus of control over their health (p=0.034). No significant differences could be detected in the other two dimensions, although males appeared to have more belief in internal locus of control than females (p=0.078). No significant age differences could be detected in the MHLC questionnaire. When the four subscales of the EPQ-R Short Scale were analysed, females and males had similar scores. An age difference was found between younger and older patients in the 'extroversion-introversion' subscale, which was not surprising. Younger patients were more extrovert than older patients (p=0.032). On the other hand, older subjects were more neurotic than younger subjects, but this difference was not significant (p=0.057).

Table 4.73	Sex- and age-differences in MDHLC and EPQ-R scales						
Questionnaire	Multidimensional Health Locus of Control (MDHLC)			EPQ-R short scale scores			
Comparison	IHLC*	CHLC	PHLC	Neuroticism	Psycho-ticism	Extroversion-Introversion	Lies
Male (n=17)	26.94	17.71	19.71	6.18	2.77	8.65	4.47
Female (n=53)	24.42	18.62	16.13	7.43	2.81	8.21	4.36
P value† Male vs. Female	0.078	0.541	0.034	0.108	0.795	0.966	0.735
Younger (n=47)	24.89	18.53	17.00	6.68	2.89	9.02	4.09
Older (n=23)	25.30	18.13	17.00	8.04	2.61	6.87	5.00
P value Younger vs. Older	0.929	0.633	0.778	0.057	0.748	0.032	0.122

(*) IHLC = Internal Health Locus of Control, CHLC = Chance Health Locus of Control, PHLC = Powerful-others Health Locus of Control

(†) P values are related to Mann-Whitney U tests. Significant results are underlined.

4.4.1.4 Satisfaction following surgery

The results related to the satisfaction questionnaire are displayed in Table 4.74. Satisfaction levels were fairly high among all groups. For the whole sample (n=70), the overall satisfaction score at T2 was 6.00 indicating high satisfaction immediately following surgery. There was a significant increase between T3-T4 (p=0.040) and, subsequently, a significant increase between T2-T4 (p=0.023). When satisfaction was linked with the amount of recovery following surgery (Satisfication_3), there was a significant increase in this score between T2-T4 (p=0.018).

In Class II subgroup, satisfaction scores obtained at T2 did not change significantly at T4. The scores related to patients' willingness to undergo surgery again (if they had to make the decision again) were lower than the overall score at T2, T3 and T4. There was a significant increase in satisfaction when postsurgical healing was taken into account (Satisfaction_3) between three months and six months postsurgery (p=0.009). In the Class III group, the satisfaction scores were also high at T2. A small, but significant, increase was observed in Satisfaction_3 score between one month and three months following surgery (p=0.045).

Interestingly, no significant differences could be detected between Class II and Class III subjects, females and males as well as younger and older subjects at the three postsurgical assessment times (Table 4.75).

Table 4.74	Patient satisfaction scores at three postsurgical assessment times						
Group	Variable	T2	P values* T2-T3	T3	P values T3-T4	T4	P values T2-T4
All (n=70)	Satisfaction_1	**5.94**	0.728	**5.64**	0.260	**5.83**	0.538
	Satisfaction_2	**6.07**	0.733	**5.93**	0.343	**6.03**	0.376
	Satisfaction_3	**5.96**	0.073	**6.18**	0.099	**6.36**	<u>0.018</u>
	Satisfaction_4	**6.07**	0.201	**6.27**	0.204	**6.40**	0.085
	Overall	**6.01**	0.110	**6.00**	<u>0.040</u>	**6.15**	<u>0.023</u>
Class II (n=24)	Satisfaction_1	**5.82**	0.295	**5.24**	0.169	**5.75**	0.590
	Satisfaction_2	**5.94**	0.477	**5.91**	0.441	**5.79**	0.612
	Satisfaction_3	**5.65**	0.554	**6.00**	<u>0.009</u>	**6.58**	0.021
	Satisfaction_4	**6.00**	0.402	**6.33**	0.515	**6.46**	0.155
	Overall	**5.85**	1.000	**5.87**	<u>0.047</u>	**6.15**	0.081
Class III (n=46)	Satisfaction_1	**6.00**	0.308	**5.83**	0.677	**5.87**	0.388
	Satisfaction_2	**6.14**	0.311	**5.94**	0.121	**6.15**	0.147
	Satisfaction_3	**6.14**	<u>0.045</u>	**6.26**	0.887	**6.24**	0.414
	Satisfaction_4	**6.10**	0.374	**6.24**	0.281	**6.37**	0.307
	Overall	**6.10**	0.172	**6.07**	0.270	**6.16**	0.135

(*) Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P values below the cut-off limit of 0.05 are underlined.

Table 4.75		The effect of type of deformity, sex and age group on satisfaction score postsurgery		
Comparison		At T2	At T3	At T4
Type of deformity	Class II (n=24)	5.853	5.869	6.146
	Class III (n=46)	6.095	6.065	6.158
	P value* Class II vs. Class III	0.981	0.381	0.929
Sex	Female (n=53)	5.971	5.975	6.156
	Male (n=17)	6.114	6.088	6.147
	P value Female vs. Male	0.7947	0.8044	0.7650
Age group	Younger (n=47)	6.25	6.25	6.25
	Older (n=23)	6.375	6.375	6.75
	P value Younger vs. Older	0.5316	0.5662	0.2559

(*) Mann-Whitney U tests were applied

4.4.2 Subgroups A, B and C

4.4.2.1 Motivational patterns

Motivational patterns of subgroups A, B and C are illustrated in Figure 4.17. Similar responses were observed for many motives among the three groups. All the patients in subgroup C, however, considered the improvement of dental appearance as one of the reasons for undergoing this treatment in comparison to 75% in subgroup B and 85% in subgroup A.

The motivation to improve work and social performance was, interestingly, indicated by a higher proportion in subgroup A than in the other two groups (70% compared with 50% and 42% in subgroups B and C, respectively), but the difference was insignificant (p=0.251 from a Chi-squared test).

Another difference was noticed regarding the desire to prevent future periodontal disease, which was mentioned by 33% of subgroup C and 20% of subgroup A, while no subject in subgroup B considered this as a motive (p=0.114; Fisher's exact test). It was also interesting to see that about 58% of the subgroup C was concerned about preventing future tooth loss, compared with 30% in subgroup A and 33.33% in subgroup C, but this difference did reach significance (p=0.233; Fisher's exact test). Sinus problems and breathing problems were also mentioned by 16.67% in subgroup C, whereas both reasons appear to be totally irrelevant to the subjects in subgroup A (p=0.153 and p=0.139, respectively; Fisher's exact tests).

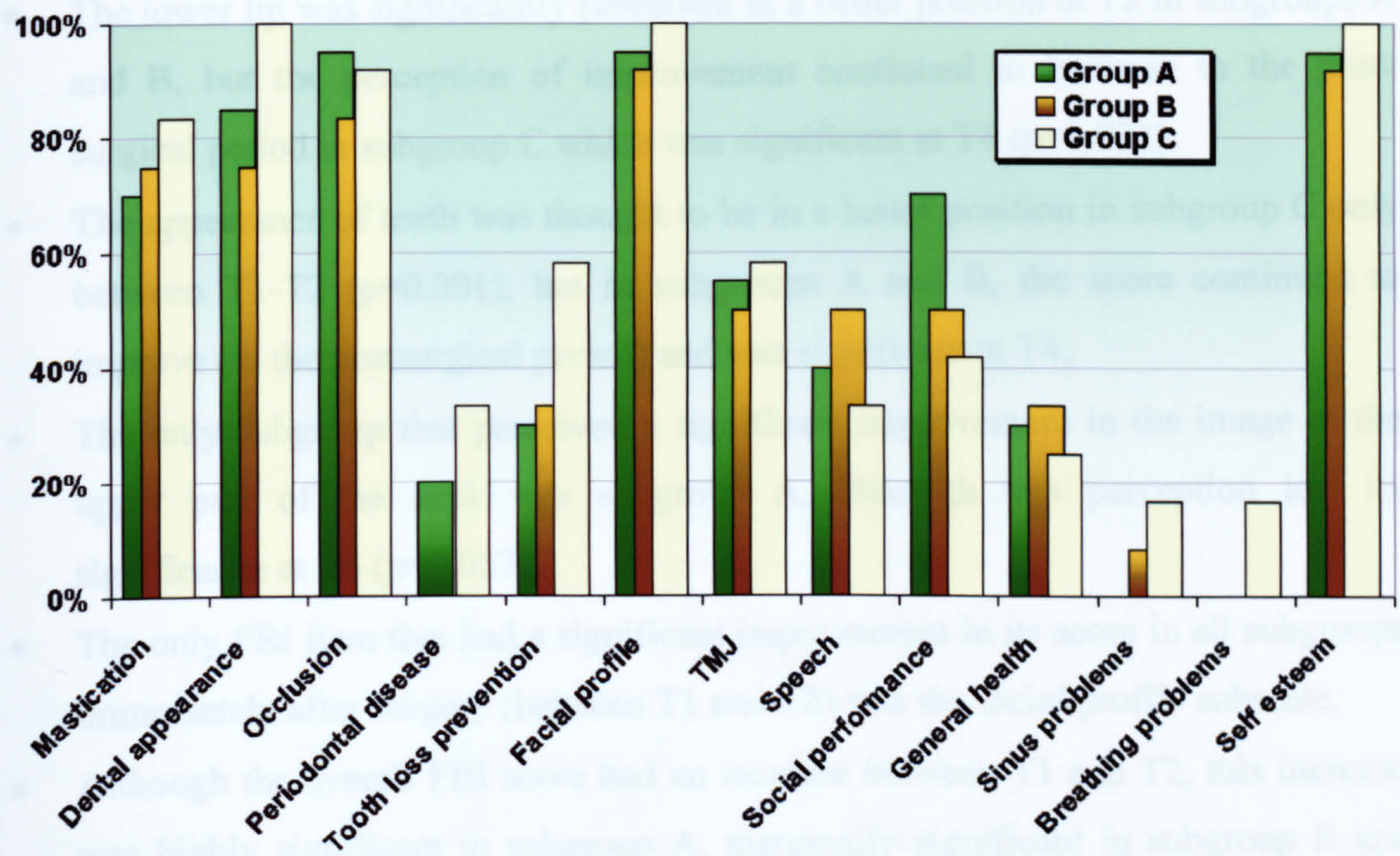


Figure 4.17 Motivational patterns in subgroups A, B and C.

4.4.2.2 Patients' perception of facial appearance and facial change

4.4.2.2.1 Facial Body Image (Table 4.76)

The general picture that can be drawn for this Table is as follows:

- FBI scores did not change due to surgery or over time with regard to the hair, forehead, eyes, ears and cheeks.
- The nose-related FBI score improved significantly in subgroup A only between T1-T2 (p=0.031) and between T1 and T4 (p=0.029).
- The upper lip score improved significantly in subgroups A and B between T1-T2 (p=0.014 for A and p=0.009 for B), but the improvement was significant for all subgroups in the final comparison.
- Changes between T2-T3, T3-T4 and T2-T4 were insignificant for almost all the facial items studied in the FBI questionnaire.
- The three subgroups shared significant increase in FBI scores in the overall comparison (between T1 and T4) for the lower lip, teeth, chin, profile, the shape of the face and the overall FBI score.

In addition to the previous observations, it can be noted that:

- The lower lip was significantly perceived in a better position at T2 in subgroups A and B, but the perception of improvement continued to increase in the post-surgical period in subgroup C which was significant at T4 (p=0.021).
- The appearance of teeth was thought to be in a better position in subgroup C only between T1-T2 (p=0.001), but in subgroups A and B, the score continued to improve (in the postsurgical period) and was significant at T4.
- The only subgroup that perceived a significant improvement in the image of the upper part of the neck was subgroup A, although this perception lost its significance at T4 (p=0.057).
- The only FBI item that had a significant improvement in its score in all subgroups immediately after surgery (between T1 and T2) was the facial profile subscale.
- Although the overall FBI score had an increase between T1 and T2, this increase was highly significant in subgroup A, marginally significant in subgroup B and insignificant in subgroup C. The three subgroups, however, had a highly significant improvement in the overall facial body image at six months following surgery.

Table 4.76 **Mean scores of facial body image (FBI) at the four assessment times in subgroups A (n=20), B (n=12) and C (n=12)**

Facial Feature	Group	T1	P values T2-T1*	T2	P values T3-T2	T3	P values T4-T3	T4	P values T4-T2	P values T4-T1
Hair	A	**3.60**	0.271	**4.36**	0.391	**3.75**	0.716	**3.80**	0.371	0.385
	B	**3.92**	0.351	**4.25**	0.598	**4.08**	1.000	**4.08**	1.000	0.339
	C	**3.58**	0.598	**4.00**	1.000	**3.80**	1.000	**3.83**	1.000	0.339
Forehead	A	**3.35**	0.724	**3.46**	0.588	**3.25**	0.804	**3.20**	0.192	0.453
	B	**3.58**	0.685	**3.63**	0.080	**3.83**	1.000	**3.83**	0.351	0.339
	C	**3.58**	1.000	**3.63**	0.611	**3.90**	1.000	**3.83**	0.351	0.339
Eyes	A	**3.90**	0.341	**4.36**	0.588	**4.10**	0.772	**4.15**	0.756	0.367
	B	**4.17**	0.351	**4.25**	1.000	**4.25**	0.723	**4.33**	1.000	0.586
	C	**4.33**	0.351	**4.25**	0.765	**4.30**	0.591	**4.50**	0.080	0.166
Ears	A	**3.70**	0.676	**3.73**	0.096	**3.25**	0.649	**3.35**	0.138	0.149
	B	**3.42**	0.732	**3.75**	0.351	**3.25**	0.082	**3.50**	1.000	0.795
	C	**3.50**	0.598	**3.63**	0.218	**4.00**	0.168	**3.83**	0.351	0.220
Nose	A	**2.60**	0.031	**3.55**	0.617	**3.40**	0.230	**3.10**	0.053	0.029
	B	**3.08**	0.197	**3.25**	0.351	**3.50**	0.615	**3.33**	0.598	0.389
	C	**2.67**	0.402	**3.25**	0.363	**3.50**	0.591	**3.42**	0.598	0.069
Upper lip	A	**2.40**	0.014	**3.64**	0.082	**3.95**	0.505	**3.80**	0.192	<0.001
	B	**2.42**	0.009	**4.00**	0.563	**3.67**	0.220	**4.00**	0.732	0.002
	C	**2.83**	0.351	**3.38**	0.363	**4.10**	0.343	**4.17**	0.080	0.021
Lower lip	A	**2.20**	0.019	**3.36**	0.046	**3.85**	0.789	**3.80**	0.082	<0.001
	B	**2.42**	0.004	**4.13**	0.685	**3.83**	0.438	**4.00**	0.451	0.006
	C	**2.92**	0.351	**3.50**	0.103	**4.30**	0.343	**4.31**	0.170	0.021
Cheek	A	**3.00**	0.296	**3.46**	0.221	**3.85**	0.825	**3.80**	0.111	0.035
	B	**3.67**	1.000	**3.63**	0.442	**3.25**	0.417	**3.58**	0.504	0.845
	C	**3.67**	1.000	**3.75**	0.175	**4.00**	0.443	**4.17**	0.197	0.082
Teeth	A	**2.20**	0.065	**3.55**	1.000	**3.70**	0.046	**4.15**	0.082	<0.001
	B	**2.00**	0.083	**3.38**	0.402	**3.00**	0.139	**3.50**	0.197	0.016
	C	**2.00**	0.001	**4.13**	0.695	**3.70**	0.434	**4.08**	0.598	0.001
Chin	A	**1.70**	0.002	**3.55**	0.192	**3.85**	0.789	**3.90**	0.553	<0.001
	B	**1.75**	0.007	**3.63**	0.763	**3.83**	0.054	**4.25**	0.104	<0.001
	C	**1.67**	0.055	**3.50**	0.203	**4.00**	0.168	**4.08**	0.504	<0.001
Neck	A	**3.15**	0.006	**3.82**	0.341	**3.40**	0.453	**3.55**	1.000	0.057
	B	**3.25**	0.451	**3.38**	0.170	**3.58**	0.166	**3.92**	0.170	0.054
	C	**3.00**	0.528	**3.63**	0.175	**4.10**	0.081	**3.75**	0.732	0.108
Profile	A	**1.55**	<0.001	**3.55**	0.089	**4.00**	0.505	**3.85**	0.617	<0.001
	B	**1.92**	0.006	**3.63**	0.785	**3.83**	0.275	**4.08**	0.197	<0.001
	C	**1.58**	0.003	**3.13**	0.235	**4.00**	0.343	**3.67**	0.275	<0.001
Shape of face	A	**2.40**	0.011	**3.91**	0.676	**3.75**	0.772	**3.80**	0.341	<0.001
	B	**2.58**	0.080	**3.88**	0.598	**4.00**	0.586	**3.92**	0.732	0.008
	C	**2.08**	0.002	**4.00**	0.465	**3.90**	0.343	**4.00**	0.451	0.001
Overall FBI	A	**2.75**	0.004	**3.71**	0.554	**3.70**	0.778	**3.71**	0.594	<0.001
	B	**2.94**	0.021	**3.75**	1.000	**3.69**	0.053	**3.87**	0.779	0.003
	C	**2.88**	0.052	**3.67**	0.463	**3.97**	0.944	**3.96**	0.237	0.003

(*) Wilcoxon matched-pairs signed-rank tests were applied to detect statistically significant differences between assessment times in each subgroup. P values smaller than the level of significance (0.05) are printed in red and underlined.

4.4.2.2.2 Self-perception of facial change (required or achieved)

Tables 4.77 and 4.78 illustrate the percentages of subjects indicating maximum change (required at T1 or achieved at T2, T3 and T4) for each facial region on both types of questionnaire. From Table 4.75 (full-face drawing questionnaires), the following observations can be made:

- The need for a maximum change in the upper lip regions was indicated by a higher percentage of patients in subgroup B (92% in the philtrum area, 83% in the paranasal regions) compared with subgroup A (75% in the philtrum area, 50% in the paranasal regions) and subgroup C (50% in the philtrum area, 58% in the paranasal regions).
- The need for a change in the chin region was indicated by a higher percentage of subjects in subgroups A (90%) and C (83%) compared with subgroup B (70%).
- Six months following surgery, patients in subgroup C perceived a maximum change in the paranasal regions in a proportion higher than subgroup B (92% vs. 50%).
- It was interesting that although no osteotomy was performed on the mandibular body or ramus in all the subjects included in subgroup B, they indicated a perception of maximum change occurring in the lower cheek regions (40%).
- The percentage regarding the chin region as an area of surgical change (62%) was not surprising in subgroup B, since several subjects had an additional genioplasty procedure.
- One of the interesting findings in subgroup C is that 25% of patients indicated the requirement for a maximum change in the nasal region (in both the full-face and the lateral-view questionnaires) before surgery, but none observed maximum change in that region at six months postoperatively.

The comparison between patients' responses on the full-face view and the lateral-view (in each subgroup) indicated 'good' to 'excellent' agreement with Kappa statistic values ranging from 0.75 to 0.99.

Table 4.77	The perception of the need for a maximum surgical change in each of the 12 facial regions assessed on the full-face drawing questionnaire				
Region	**Subgroup**	**T1**	**T2**	**T3**	**T4**
Infraorbital Right	A	5%	0%	15%	10%
	B	8%	25%	17%	25%
	C	0%	0%	0%	0%
Nasal	A	5%	18%	5%	5%
	B	0%	25%	8%	17%
	C	25%	13%	10%	0%
Infraorbital Left	A	5%	0%	15%	10%
	B	8%	25%	17%	25%
	C	0%	0%	0%	0%
Upper Cheek Right	A	35%	55%	55%	50%
	B	17%	50%	42%	42%
	C	8%	25%	40%	42%
Paranasal Right	A	50%	64%	55%	55%
	B	83%	50%	62%	50%
	C	58%	75%	70%	92%
Philtrum	A	75%	45%	50%	50%
	B	92%	58%	83%	70%
	C	50%	50%	70%	83%
Paranasal Left	A	50%	64%	55%	55%
	B	83%	50%	62%	50%
	C	58%	75%	70%	92%
Upper Cheek Left	A	35%	55%	55%	50%
	B	17%	50%	42%	42%
	C	8%	25%	40%	42%
Lower Cheek Right	A	65%	50%	62%	70%
	B	33%	38%	40%	40%
	C	75%	63%	90%	92%
Lower Lip	A	60%	55%	55%	70%
	B	75%	63%	75%	67%
	C	67%	63%	80%	92%
Lower Cheek Left	A	65%	50%	62%	70%
	B	33%	38%	40%	40%
	C	75%	63%	90%	92%
Chin	A	90%	91%	80%	80%
	B	67%	50%	62%	62%
	C	83%	75%	90%	92%

Table 4.78	The perception of the need for a maximum surgical change in each of the 8 facial regions assessed on the lateral drawing questionnaire				
Region	Group	T1	T2	T3	T4
Infraorbital	A	5%	9%	15%	10%
	B	0%	25%	25%	25%
	C	0%	0%	0%	8%
Nasal	A	5%	9%	5%	10%
	B	8%	25%	8%	17%
	C	25%	13%	10%	0%
Upper Cheek	A	30%	55%	60%	45%
	B	17%	50%	42%	42%
	C	8%	38%	40%	42%
Paranasal	A	60%	64%	60%	55%
	B	83%	60%	70%	62%
	C	50%	50%	70%	83%
Upper Lip	A	70%	55%	50%	55%
	B	75%	60%	83%	92%
	C	50%	50%	80%	75%
Lower Cheek	A	80%	60%	70%	90%
	B	33%	38%	42%	33%
	C	75%	75%	90%	92%
Lower Lip	A	70%	55%	75%	65%
	B	75%	63%	75%	67%
	C	75%	75%	90%	83%
Chin	A	90%	91%	85%	80%
	B	67%	63%	67%	58%
	C	83%	75%	90%	92%

4.4.2.2.3 Self-perception of facial profile (Tables 4.79-4.81)

Starting with subgroup A (Table 4.79), subjects at T1 considered their face somewhat long, the maxilla to be in a markedly backward position, the mandible in a markedly forward position, and the upper and lower lips slightly retruded in relation to the nose and chin. These perceptions, however, improved significantly at T2. The changes between T2-T3 and between T3-T4 were small and insignificant. The final outcome was highly significant for the four subscales with the fourth subscale reaching the optimum value. One of the interesting findings in this subgroup was the perception of an additional backward position in the mandible (represented by a reduction in the mean mandibular score from 5.18 to 4.90) between one month and six months following surgery (p=0.038).

Table 4.79	Self-rating of facial profile in Group A (n=20)								
Dimension	**Mean at T1**	P values T2-T1	**Mean at T2**	P values T3-T2	**Mean at T3**	P values T4-T3	**Mean at T4**	P values T4-T2	P values T4-T1
Vertical	**6.10**	0.019	**5.09**	1.000	**4.75**	0.748	**4.70**	0.192	0.001
Maxillary	**7.75**	<0.001	**4.91**	0.341	**4.70**	0.330	**4.80**	0.588	<0.001
Mandibular	**7.75**	<0.001	**5.18**	0.167	**4.95**	0.577	**4.90**	0.038	<0.001
Dentoalveolar	**6.45**	0.046	**4.91**	0.459	**4.75**	0.367	**5.00**	0.588	0.002

*** Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P-values below the level of significance are underlined and shown in red.**

In Table 4.80 (subgroup B), the main problems that were detected in the facial profile according to patients' perception were: a backward position of the maxilla; a forward position in the mandible; a slightly retruded position of the dentoalveolar complex in relation to the face. As a result of surgery, the scores fell indicating a normal facial profile following surgery, with the mandibular subscale showing a significant difference between T1-T2 (p=0.019). The overall improvement, however, in facial profile perception (between T1-T4) was evident in three subscales. It was surprising to have a highly significant result for the mandibular subscale although no mandibular setback procedure was performed in this subgroup.

Table 4.80	Self-rating of facial profile in Group B (n=12)								
Dimension	**Mean at T1**	P values T2-T1	**Mean at T2**	P values T3-T2	**Mean at T3**	P values T4-T3	**Mean at T4**	P values T4-T2	P values T4-T1
Vertical	**5.75**	0.104	**5.00**	0.351	**4.75**	0.166	**5.25**	0.351	0.324
Maxillary	**6.58**	0.098	**4.75**	1.000	**4.83**	0.339	**4.92**	0.351	0.012
Mandibular	**6.50**	0.019	**5.13**	0.598	**5.00**	1.000	**5.00**	0.351	0.001
Dentoalveolar	**6.92**	0.072	**5.13**	0.732	**5.08**	0.438	**5.25**	0.451	0.025

*** Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P-values below the level of significance are underlined and shown in red.**

For subgroup C (Table 4.81), the maxillary subscale indicated a perception of moderate maxillary prognathism, while the mandibular subscale showed a perception of moderate to severe mandibular retrognathism. The dentoalveolar subscale reflected a forward position of the dentition in relation to the face, although many patients described the upper dentition rather than the whole dentoalveolar complex. The improvement was evident in the third and fourth subscales as a result of surgery. The mean score (4.00) at T2 in the maxillary subscale meant that the maxillary correction was perceived incomplete, but it continued to increase gradually and reached a better value at T4 producing a marginally significant difference from the starting point at T1 (p=0.049). Between T1 and T4, the change in the mandibular subscale showed a highly significant difference (p<0.001).

Table 4.81	Self-rating of facial profile in Group C (n=12)								
Dimension	Mean at T1	P values T2-T1	Mean at T2	P values T3-T2	Mean at T3	P values T4-T3	Mean at T4	P values T4-T2	P values T4-T1
Vertical	**5.58**	0.262	**5.13**	0.363	**4.80**	0.104	**5.17**	1.000	0.516
Maxillary	**3.42**	0.634	**4.00**	0.235	**4.50**	0.726	**4.67**	0.104	0.049
Mandibular	**2.58**	0.003	**4.38**	0.465	**4.70**	1.000	**4.75**	0.080	≤0.001
Dentoalveolar	**3.92**	0.033	**5.00**	0.363	**4.80**	0.279	**5.08**	0.563	0.052

*** Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P-values below the level of significance are underlined and shown in red.**

4.4.2.3 Personality characteristics

4.4.2.3.1 Rosenberg Self-Esteem (Table 4.82)

The immediate impact of orthognathic surgery on RSE scores was evident in subgroup A and subgroup B (p=0.001 and p=0.015, respectively) but it was not very clear in subgroup C (p=0.149). In the overall assessment (between T1-T4), however, the three subgroups showed a highly significant improvement in this psychological measure (p≤0.001).

Table 4.82	Self-esteem scores at different assessment times									
Subgroup	N	T1	P value T2-T1	T2	P value T2-T2	T3	P value T4-T3	T4	P value T4-T2	P value T4-T1
A	20	**23.10**	0.001	**18.18**	0.302	**18.05**	0.505	**17.80**	0.268	≤0.001
B	12	**21.00**	0.015	**17.00**	1.000	**16.83**	0.646	**16.83**	1.000	0.001
C	12	**21.67**	0.149	**18.88**	0.611	**18.20**	0.327	**17.00**	0.050	0.001

(*) Statistically significant differences were detected using paired t tests. Non-parametric tests were applied on asymmetric distributions and the related p values are shown in blue. P-values smaller than the level of significant are underlined.

4.4.2.3.2 Hospital Anxiety and Depression Scale (HADS; Table 4.83)

There was no direct impact of surgery (between T1-T2) on the levels of anxiety and depression in subgroups A, B and C. The three subgroups, however, had significant reductions in both anxiety and depression in the overall assessment (T1-T4)

Table 4.83	Anxiety and Depression scores at different assessment times										
Subgroup	**N**	**Variable**	**T1**	P value T2-T1	**T2**	P value T3-T2	**T3**	P value T4-T3	**T4**	P value T4-T2	P value T4-T1
A	20	Anxiety	**8.55**	0.083	**7.18**	0.311	**6.45**	0.895	**6.35**	0.603	0.007
		Depression	**3.80**	0.623	**3.00**	0.014	**2.20**	0.169	**1.85**	0.096	0.007
B	12	Anxiety	**7.75**	0.265	**5.50**	0.154	**5.00**	0.127	**4.17**	0.002	0.001
		Depression	**2.50**	0.186	**1.13**	0.787	**0.83**	0.723	**1.00**	0.140	0.014
C	12	Anxiety	**8.92**	0.051	**5.38**	0.363	**7.00**	0.217	**6.08**	1.000	0.002
		Depression	**3.50**	0.327	**2.38**	0.530	**2.20**	0.418	**1.50**	0.142	0.005

(*) Statistically significant differences were detected using paired t tests. Non-parametric tests were applied on asymmetric distributions and the related p values are shown in blue. P-values smaller than the level of significant are underlined.

4.4.2.3.3 Other personality characteristics (Table 4.84)

The belief in internal locus of control for health was stronger than the belief in 'chance' or 'powerful others' in the different subgroups. Results related to CHLC and PHLC were generally similar in subgroups A and C. Subgroup C, compared with subgroups A and B, had slightly higher scores in the chance-related locus of control (p=0.282 by one-way ANOVA).

The EPQ-R short scale disclosed a generally high score in 'neuroticism' as well as in 'extroversion-introversion' subscales in the studied subgroups. The scores related to the 'psychoticism' subscale were the least among all groups. Subgroup B had a higher score in the 'extroversion-introversion' dimension compared with subgroups A and C, but this difference was insignificant (p=0.547 by one-way ANOVA).

Table 4.84		**Some personality characteristics scores measured in the presurgical assessment**						
Questionnaire		**Multidimensional Health Locus of Control (MHLC)**			**EPQ-R Short Scale**			
Group	**N**	IHLC*	CHLC	PHLC	Neuroticism	Psychoticism	Extroversion-Introversion	Lies
Subgroup A	20	25.15	17.15	17.25	7.3	2.85	8.31	3.8
Subgroup B	12	25.17	16.83	18.08	7.01	3.58	9.25	4.08
Subgroup C	12	24.41	19.52	19.42	7.91	2.33	7.58	4.33
P values†		0.815	0.282	0.712	0.719	0.231	0.547	0.815

(*) IHLC = Internal Health Locus of Control, CHLC = Chance Health Locus of Control, PHLC = Powerful-others Health Locus of Control.

(†) Applying one-way ANOVA to detect any significant difference between the three subgroups.

4.4.2.4 Satisfaction following surgery

Results related to satisfaction scores are presented in Table 4.85. When satisfaction was defined as patients' willingness to undergo surgery again (Satisfaction_1 in the Table), subgroup B had higher scores than subgroups A and C at all assessment times, but these differences were insignificant (p>0.05 by one-way ANOVA). Subgroup B subjects showed insignificant higher satisfaction scores than subgroups A and C when they were asked about the possibility of recommending orthognathic surgery to others (i.e. Satisfaction_2 in the Table). No significant change in satisfaction scores could be detected over time in subgroup B. In subgroup C, however, there was a significant increase in satisfaction between T2-T4 when postsurgical recovery and healing were taken into account (i.e. Satisfaction_3 in the Table; p=0.036).

Table 4.85 **Satisfaction scores of different groups of patients at three assessment times in the postsurgical period**

Subgroup	Variable	T2*	P values† T2-T3	T3	P values T3-T4	T4	P values T2-T4
A (N=20)	Satisfaction_1	**5.46**	0.138	**5.40**	0.139	**5.85**	0.106
	Satisfaction_2	**5.82**	0.345	**5.50**	0.093	**5.95**	0.178
	Satisfaction_3	**6.64**	0.181	**6.50**	1.000	**6.50**	0.787
	Satisfaction_4	**6.36**	0.181	**6.50**	0.893	**6.55**	0.593
	Overall	**6.07**	0.059	**5.98**	0.244	**6.21**	0.107
B (N=12)	Satisfaction_1	**6.25**	0.787	**6.00**	1.000	**6.08**	1.000
	Satisfaction_2	**6.25**	0.789	**6.25**	0.281	**6.50**	0.371
	Satisfaction_3	**5.38**	0.178	**6.00**	1.000	**6.00**	0.295
	Satisfaction_4	**5.63**	0.715	**5.83**	0.447	**6.08**	0.593
	Overall	**5.88**	0.866	**6.02**	0.328	**6.17**	0.463
C (N=12)	Satisfaction_1	**5.13**	1.000	**4.80**	0.787	**5.17**	1.000
	Satisfaction_2	**5.50**	0.855	**5.60**	0.059	**5.25**	0.465
	Satisfaction_3	**5.13**	0.178	**6.00**	0.100	**6.67**	<u>0.036</u>
	Satisfaction_4	**5.50**	0.181	**6.50**	0.855	**6.42**	0.142
	Overall	**5.31**	0.273	**5.73**	0.834	**5.88**	0.116

(*) Mean values are presented here.

(†) Wilcoxon matched-pairs signed-rank tests were applied to detect significant differences. P values below the cut-off limit of 0.05 are underlined.

4.5 3D facial changes versus perception of change

In Table 4.86, the z-displacements of four soft-tissue landmarks in the Class III subgroup are summarised. This group was divided into two subsets of patients for each facial region examined depending on their perception of change.

Patients who noticed a big change in the upper lip had a greater amount of anteroposterior displacement at the nasolabial junction. This was evident in the full-face view drawings (p=0.025) as well as in the lateral view drawings (p=0.023). The z-displacement of the superior labial sulcus was also significantly correlated with the perception of the upper lip region in the lateral view questionnaires (p=0.028).

For the Class II subjects (Table 4.87), there was no correlation between perception of change in the upper lip, the lower lip and the chin regions and the amount of displacement in the related landmarks anteroposteriorly. Of course, it should be taken into account that in these comparisons, subsets of different numbers were created (depending on their perception). It can still be seen that patients who noticed a big change in the lower lip or the chin regions (on both the full-face and lateral view questionnaires) had higher forward displacements in 'ils' and 'pog' landmarks.

Table 4.86	Z-displacements of four soft-tissue landmarks in Class III subgroup when divided into two subsets according to their perception at six months postsurgery (n=46)					
Soft-tissue landmark	**Region examined***	**Patient perception**	**N**	**Mean z-displacement**	**SD**	**P value**
sn	**Upper lip (FFV)**	**Little or no change**	**21**	**0.93**	**1.01**	**<u>0.025</u>**
		Maximum change	**25**	**1.71**	**1.25**	
sn	**Upper lip (LV)**	**Little or no change**	**20**	**0.57**	**1.23**	**<u>0.023</u>**
		Maximum change	**26**	**1.88**	**1.13**	
sls	**Upper lip (FFV)**	**Little or no change**	**21**	**0.96**	**1.07**	**0.118**
		Maximum change	**25**	**1.50**	**1.18**	
sls	**Upper lip (LV)**	**Little or no change**	**20**	**0.83**	**1.08**	**<u>0.028</u>**
		Maximum change	**26**	**1.58**	**1.11**	
ils	**Lower lip (FFV)**	**Little or no change**	**18**	**-3.44**	**5.16**	**0.559**
		Maximum change	**28**	**-4.27**	**3.75**	
ils	**Chin (FFV)**	**Little or no change**	**10**	**-4.29**	**3.45**	**0.736**
		Maximum change	**36**	**-3.84**	**4.6**	
ils	**Lower lip (LV)**	**Little or no change**	**17**	**-3.54**	**5.13**	**0.662**
		Maximum change	**29**	**-4.18**	**3.86**	
ils	**Chin (LV)**	**Little or no change**	**11**	**-4.01**	**3.41**	**0.941**
		Maximum change	**35**	**-3.91**	**4.64**	
pog	**Chin (FFV)**	**Little or no change**	**10**	**-4.72**	**3.98**	**0.589**
		Maximum change	**36**	**-3.89**	**4.81**	
pog	**Chin (LV)**	**Little or no change**	**11**	**-4.29**	**4.03**	**0.845**
		Maximum change	**35**	**-4.00**	**4.83**	

(*) Abbreviations used: FFV= Full-face views, LV= Lateral views. Two-sample t tests were applied. P values, indicating significant differences, are highlighted in red and underlined.

Table 4.87	Z-displacements of four soft-tissue landmarks in Class II subgroup when divided into two subsets according to their perception at six months postsurgery (n=24)					
Soft-tissue landmark	**Region examined***	**Patient perception**	**N**	**Mean**	**SD**	**P values**
sn	Upper lip (FFV)	Little or no change	9	0.58	1.1	0.872
		Maximum change	15	0.66	1.08	
sn	Upper lip (LV)	Little or no change	10	0.68	1.08	0.847
		Maximum change	14	0.59	1.09	
sls	Upper lip (FFV)	Little or no change	9	1.05	1.13	0.962
		Maximum change	15	1.02	1.67	
sls	Upper lip (LV)	Little or no change	10	0.94	1.13	0.774
		Maximum change	14	1.11	1.7	
ils	Lower lip (FFV)	Little or no change	4	5.28	5.36	0.746
		Maximum change	20	6.32	4.53	
ils	Lower lip (LV)	Little or no change	5	5.12	4.18	0.579
		Maximum change	19	6.39	4.73	
pog	Chin (FFV)	Little or no change	4	5.02	3.52	0.356
		Maximum change	20	7.17	5.55	
pog	Chin (LV)	Little or no change	4	5.02	3.52	0.356
		Maximum change	20	7.17	5.55	
ils	Chin (FFV)	Little or no change	4	5.55	4.2	0.784
		Maximum change	20	6.24	4.73	
ils	Chin (LV)	Little or no change	4	5.55	4.2	0.784
		Maximum change	20	6.24	4.73	

(*) Abbreviations used: FFV= Full-face views, LV= Lateral views. Two-sample t tests were applied.

Chapter Five

Discussion

5 Discussion

5.1 Sample characteristics

The need for homogeneous samples when studying soft- and hard-tissue behaviour following orthognathic surgery is well established[330]. Therefore, Class I dentofacial deformity subgroup (n=5) was excluded due to the different surgical interventions performed and its small sample size. The remaining study group, which comprised 70 subjects, had more Class III than Class II patients with a ratio of about 2:1. Different ratios of Class II to Class III patients have been reported from different treatment centres[439,478].

Several factors can be attributed to the over-representation of Class III deformities in the current sample, compared with other studies conducted in the UK[479]. It has been documented that the prevalence of Class III deformities in the West of Scotland is higher that other regions in the United Kingdom[480]. Treatment of moderate to severe skeletal Class III deformities is usually postponed until the completion of growth for several reasons: inability of orthodontics alone to camouflage for the skeletal discrepancies satisfactorily; to allow full expression of the skeletal discrepancies and to minimise the relapse potential should surgery be undertaken[481]. The current study showed that Class III patients, compared with Class II patients, were more distressed about several facial items and more keen for 'maximum change' to occur in several facial regions. Gerzanic et al[478] found that Class III patients, compared with Class II patients, felt significantly less attractive, paid more attention to their physical appearance and had stronger feelings of insecurity regarding their facial appearance. Their findings along with the findings of the current study can also explain the differences in representation between Class II and Class III subjects in this thesis.

When Class II and Class III subjects were re-grouped according to the surgical intervention performed, three subgroups were created with sample sizes greater than or equal to the statistically required sample size (i.e. 12 subjects according to the previous assumptions; Section 3.5.1). 2D and 3D morphometric analyses were restricted to these subgroups.

The female-male distribution of 3:1, in the whole study group, was similar to other published studies[418,478]. The reason for this unequal distribution is not entirely clear but could be due to a greater appreciation in women of their facial appearance[423].

The average age of 23.4 years of the whole study group was also similar to that reported for orthognathic patients[148]. Although there was a higher proportion of 'older' subjects ($\geq$ 25 years) in the Class II group than in the Class III group, the difference was insignificant. Gerzanic et al[478] explained the younger average age of Class III patients found in their study by the greater drive toward correction of the facial appearance. The current study could not detect significant differences in the aesthetic motivation, nor in the level of dissatisfaction of several facial features before surgery between Class II and Class III groups, although an insignificant pattern of more dissatisfaction with facial appearance was seen in the Class III group. The choice of 25 years as a cut-off limit between 'younger' and 'older' subjects in the psychosocial study falls in line with another study[420].

With regard to the pre- and post-surgical orthodontic treatment, more Class II patients had orthodontic treatment than Class III patients and this can be explained by the Class II cases requiring more orthodontic alignment in the presurgical phase and the requirement for closure of the anticipated bilateral posterior open bite following mandibular advancement. Nevertheless, the provision of orthodontics to only 70% of the Class II and Class III patients is obviously lower than the documented proportions in recent studies[112,113,478]. This may reflect poorer dental health among this West of Scotland sample compared to other study groups, which precluded the use of fixed appliances[482].

The effect of the placement or removal of orthodontic fixed appliances on the lip position has not been studied before. In our sample, patients who did not have any presurgical orthodontic phase before surgery and had been examined at that time had the same conditions at six month postsurgery. The majority of subjects, who had undergone a course of presurgical orthodontics and had been assessed immediately before surgery, were assessed at six months postsurgery with the fixed appliances in situ. Therefore, the need to have consistent presence or absence of fixed appliances on the labial or buccal surfaces of the teeth over the course of the study was upheld.

Comparisons based on sex or age in subgroups A, B and C was not possible due to the relatively small sample size.

5.2 Preliminary and validation studies

5.2.1 3D imaging system reliability

To consider the application of a new 3D facial imaging and measuring system in orthodontics, oral and maxillofacial surgery, certain conditions need to be met. Although the term 'reliability' has been used as a synonym for system accuracy[(160)] or measurement reproducibility[(472)] or to encompass measurement validity and reproducibility[(472)], the term is used here to express system accuracy and reproducibility.

5.2.1.1 3D imaging system accuracy

The comparison between manually extracted distances from the dummy head (using electronic digital callipers) and indirectly calculated distances from the 3D models (using the Facial Analysis Tool) revealed insignificant differences. The absolute values of errors between direct and indirect measurements did not exceed 0.22 mm in the transverse direction, 0.18 mm in the vertical direction and 0.26 in the anteroposterior direction.

These values are low and compare very favourably to other studies using 3D imaging equipment. Trocmé et al[(163)] reported insignificant differences between linear measurements obtained by a 3D cephalometric system and those obtained by callipers. Using laser scanners, Moss et al[(113)] reported a system accuracy of 0.5 mm. A value of 0.53 mm was reported by Trotman et al[(483)] using a stereophotogrammetric technique. Very recently, Kusnoto and Evans[(160)] measured the accuracy of a quick surface laser scanner using a plaster facial model and employed 21 linear measurements based on 12 pre-marked facial landmarks. They reported an accuracy of 1.9 mm, which is clearly lower than the one reported here. The surface laser scanner was less accurate in the z-dimension (the depth axis), whereas C3D gave relatively similar amounts of error in the three dimensions.

It should be noted, however, that the operator error in landmark identification has not been filtered out from measurements made by callipers or obtained from the 3D models. In direct measurements (i.e. directly on the dummy head), inconsistency in placing the calliper ends on the centre of the pre-marked facial landmarks could have added to the variability of the data. On the other hand, indirect measurements included on-screen identification of previously marked landmarks on the dummy head and the inconsistency in finding the central points of these landmarks can be considered as a source of measurement error. When evaluating system reproducibility, it was clear the amount of variability related to this source ranged from 0.03 to 0.22 mm.

Using the same 3D imaging system (i.e. C3D®), Ayoub et al[156] reported good system accuracy. They used 3D models of 21 infant facial stone casts with pre-marked facial landmarks. 3D landmark coordinate configurations recorded by the C3D® system were compared with those recorded by a coordinate measuring machine ('CMM', which had a piezo-electric semi-automated rigid-framed digitiser and was considered the gold standard). The calculations of landmark displacements, after aligning 3D landmark configurations employing Partial Ordinary Procrustes Analysis (POPA), allowed the estimation of C3D accuracy. Procrustes alignment, however, was not required for this aspect of the present study because interlandmark distances were used rather than 3D coordinates.

5.2.1.2 3D imaging system reproducibility

The question of the system's ability to produce the same 3D facial model after repeated captures or scanning (of the same object), called 'system reproducibility', was evaluated. One of the simple methods to look at the dimensional stability of the generated 3D models is to obtain some 3D measurements using well-defined landmarks.

The results shown in Section 4.2.1 confirm the high reproducibility of the C3D-based 3D models. The effect of facial expression change between successive captures was eliminated by the use of an inanimate object (i.e. the dummy head). Error in landmark identification was reduced by marking up the required landmarks prior to capture. On-screen localisation of the central points of landmarks, however, was still a source of measurement inconsistency (with a maximum SD of 0.22 mm). When the effect of repeated 3D model construction was evaluated, the variability in linear measurements increased slightly (with a maximum SD of 0.27 mm) indicating high system precision and signifying the impact of landmark identification reproducibility on the variance of the collected data.

Good reproducibility has been shown for other techniques such as the biplanar cephalometric stereoradiography (BCSR) proposed by Trocmé et al(163). Using one set of stereoradiographs, the standard deviations of mean linear measurements (when the procedure was repeated 10 times) ranged from 0.06 to 0.18 mm.

The concept of C3D model-production reproducibility is dependent on several factors: a good calibration procedure, fixed inter-camera relationships, fixed inter-pod relationships and fixed camera aperture and shutter speed. The system cannot compensate for any rough handling and its high sensitivity requires careful patient seating and discharging, otherwise the whole calibration procedure should be repeated.

5.2.1.3 3D imaging system feasibility

The C3D capture speed is one of the major advantages of this technique(155). On rare occasions the researcher has been obliged to repeat the capture because of eye blinking or sudden change in facial expression. The scanning time of 50 milliseconds is, probably, the shortest among all of the available 3D soft-tissue imaging techniques.

Many of the documented laser scanning techniques require more than 10 seconds for one facial scan which does not guarantee stable facial soft-tissue expression during this period(112,113,161,165,167). The accuracy of obtaining soft-tissue geometry when images or photographs are not captured simultaneously is clearly questionable(128,133). The structured light and Moiré topography techniques have provided shorter scanning times(148,149,158), but high patient cooperation would be required to achieve better results during the one- or two-second scanning time.

The ability of producing life-like 3D models is another feature of the system, which has increased patient response and cooperation throughout the course of data collection and reduced the numbers of withdrawals. Many of the subjects were keen to see their faces before and after the surgical correction in a 3D manner. Although it has not been assessed objectively, the recruited patients felt at six months following surgery that this had been a very informative and clear tool for showing presurgical facial appearance and the achieved postsurgical facial changes. These models were not shown to patients before they completed their questionnaires, in order not to affect their perception of any facial changes.

It has been mentioned earlier that the previous 3D techniques lacked the production of life-like 3D models, with some systems producing only 3D landmark coordinates[(131)] and others producing lifeless shaded models in which the recognition of the underlying facial features was very difficult[(113,161)]. These shaded models can help in recognising the general contours of the face, but the complete picture was lacking since no facial texture was shown. The importance of having the full colour details on the final 3D output has been recognised by many manufacturing companies and researchers have started to explore such new 3D scanning machines[(160,167)].

The third feature of this system is the short time of model construction and the ease of data archiving. Each model requires 5 minutes to be constructed from raw data. This time has been shortened further with the introduction of fast processors (≥1800 Megahertz; Pentium IV). Each C3D facial model has a file size of 50 Megabytes. The three hundred 3D models used in this project required about 15 Gigabytes of storage space. The VRML models, which have been used in the Facial Analysis Tool, required less storage memory. Each VRML model has a file size of only 5 Megabytes with a total amount of 1.5 Gigabytes for the 300 VRML models used in this project.

Taking into account the previous factors of system accuracy, reproducibility, data capture speed, 3D display quality in addition to the speed of model production, ease of data storage and retrieval and the safety of the whole procedure (i.e. no harmful radiation), it can be concluded that this 3D imaging system is a reliable, practical and feasible way for studying facial soft-tissue changes in our study group.

5.2.2 Landmark identification reproducibility on 3D models

5.2.2.1 The anthropometric landmarks used

Most of the landmarks used in the present 3D study have been defined by Farkas et al[(61)]. These landmarks have been considered as anthropometric landmarks although not all of them are dependent on anatomical properties (i.e. joins of tissues or bones). Dryden and Mardia[(212)] classified landmarks into three categories: anatomical, mathematical and pseudo-landmarks.

The anatomical landmarks are defined in a biologically meaningful way to ensure homology from case to case. Examples of landmarks with an anatomical base are the corner of the eye (Endocanthion or Exocanthion) and Otobasion inferius. The identification of nasal tip landmark, Pronasale, is an example of a mathematical landmark, which is dependent on geometric properties of the nasal tip (i.e. the most prominent point on the nasal tip in the lateral view of the face). Pseudo-landmarks, can be found in the constructed points around the chin (Subcheilion 'sbch' and Para-Menton 'pmen') which have been used as boundary landmarks in defining patches for volumetric assessment in subgroup A. Figure 5.1 illustrates the anthropometric (anatomical and mathematical) landmarks used in the current study.

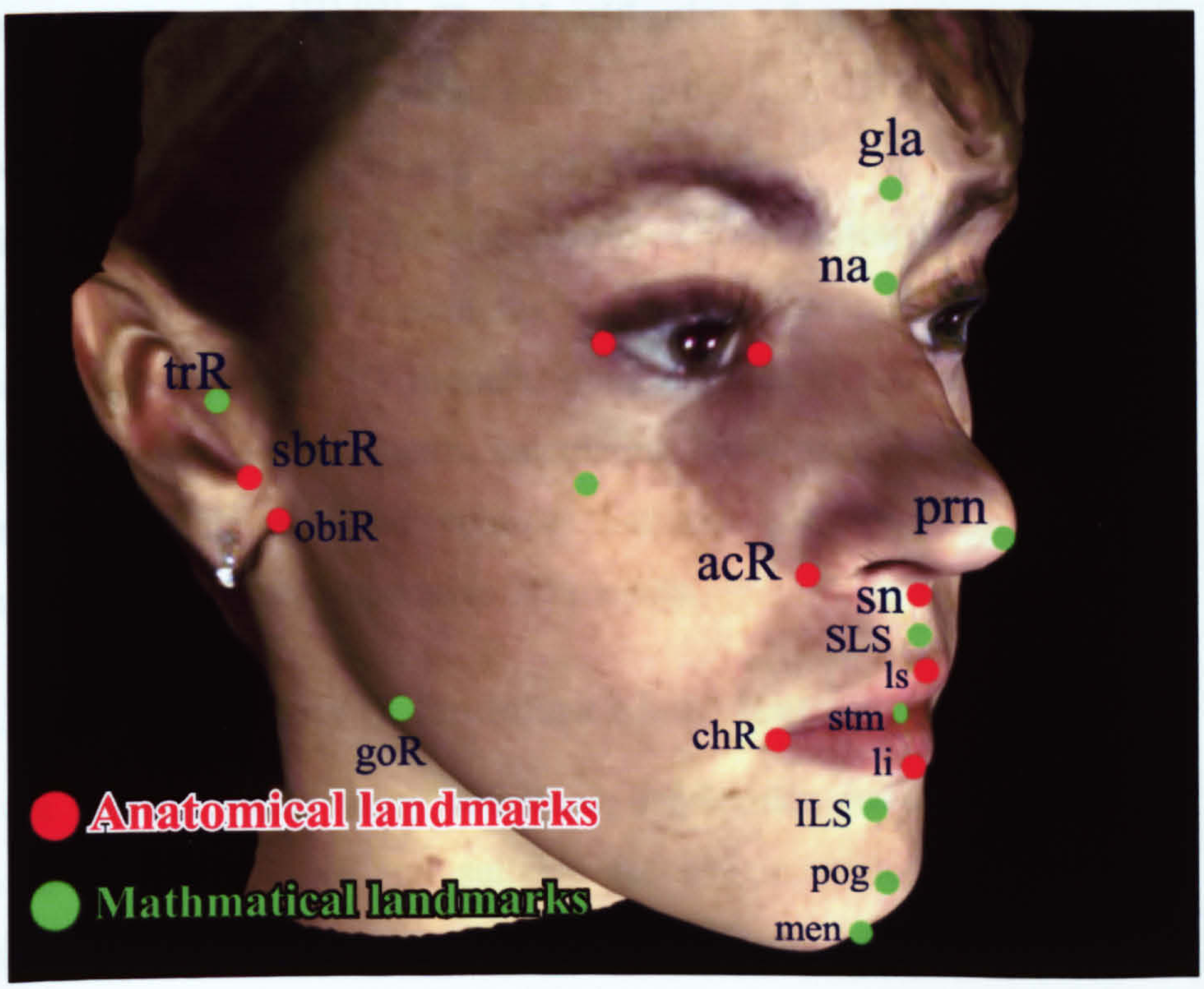


Figure 5.1 Anatomical landmarks versus mathematical landmarks.

5.2.2.2 Types of landmark identification

As has been shown in the literature review about 3D imaging techniques (Section 1.2.2), two main types of landmark identification protocols have been followed. The first protocol includes the pre-imaging identification (direct identification) of landmarks on the examined subjects followed by data acquisition. The latter is performed either by capturing 3D images with the ordinary or retro-reflective markers in place[(118,132,216,484)] or by the use of contact-based 3D landmark coordinate digitisers[(168)]. The error of inter-session landmark reproducibility is poor and has been documented to be within 2-3 mm[(133)]. Pre-imaging placement of landmarks can be of great value if the 3D system accuracy has to be evaluated[(58,156)]. On this occasion, the source of error of identifying landmarks is minimised since the operator's job is to re-identify the central point of each captured landmark to allow comparisons between direct measurements (presumed gold-standard measurements) and those obtained indirectly (using a 3D measuring software)[(156,160)]. This method has been applied in the current study when C3D accuracy was evaluated.

The second protocol is the on-screen identification (indirect identification) of anthropometric landmarks following the construction of 3D models and this has been used in several studies[(113,165)]. The identification of anatomical landmarks can be enhanced by the presence of colour details on the final 3D output which was not the case with several laser-scanning-based 3D studies[(112,113,161,165)]. The use of the identified soft-tissue landmarks was restricted to superimposing and averaging 3D models[(112,113)] while, in the present study, these landmarks were identified for several purposes: superimposing 3D models, obtaining linear and angular measurements, obtaining landmark displacements, calculating facial asymmetry scores, and defining patches to calculate enclosed volumes between corresponding patches following alignment of pre- and post-operative 3D models.

5.2.2.3 Reproducibility of landmark identification

From the initially tested thirty soft-tissue landmarks, twenty landmarks have been shown to be reproducible and suitable for use in evaluating soft-tissue changes following orthognathic surgery. With the cut-off limit of 0.5 mm between high and less reproducible landmarks, some landmarks were not included in the '3D displacements' analysis such as Glabella (SD=0.76), Otobasion left (SD=0.80), Otobasion right (SD=0.88) and Zygion left (SD=0.93) although all of them had standard deviations below 1 mm.

The reproducibility of 'Gonion' and 'Zygion' points was poor, due to the difficulty in locating these points precisely on the screen. Locating these would require palpation on the face and marking them up prior to capture. Even when direct palpation is performed, Farkas[485] has confirmed that identification of these points could be difficult when covered by thick subcutaneous tissues.

Recognizing soft-tissue 'Menton' was difficult especially in 'double chin' and retrognathic cases. The difficulty of identifying some chin points in similar cases has also been documented by Farkas[485], although one would assume better results when the identification is performed on live subjects. Looking at the underlying axial error, error was greatest in the anteroposterior direction (mean z-difference= 1.07 mm), followed by the transverse direction and least error originated from the vertical direction (mean y-difference=0.40 mm).

The reproducibility of 'Tragion' was surprisingly lower than had been expected (SD>1.00 mm). The lack of brightness and contrast in the peripheral areas of the photorealistic-rendered model may have affected the accuracy in identifying that landmark (Figure 5.2). This problem may be overcome by adding an additional source of illumination on both sides during data capture. Even in the normal conditions of illumination, direct identification of Tragion is difficult with a poorly developed Tragus[485].

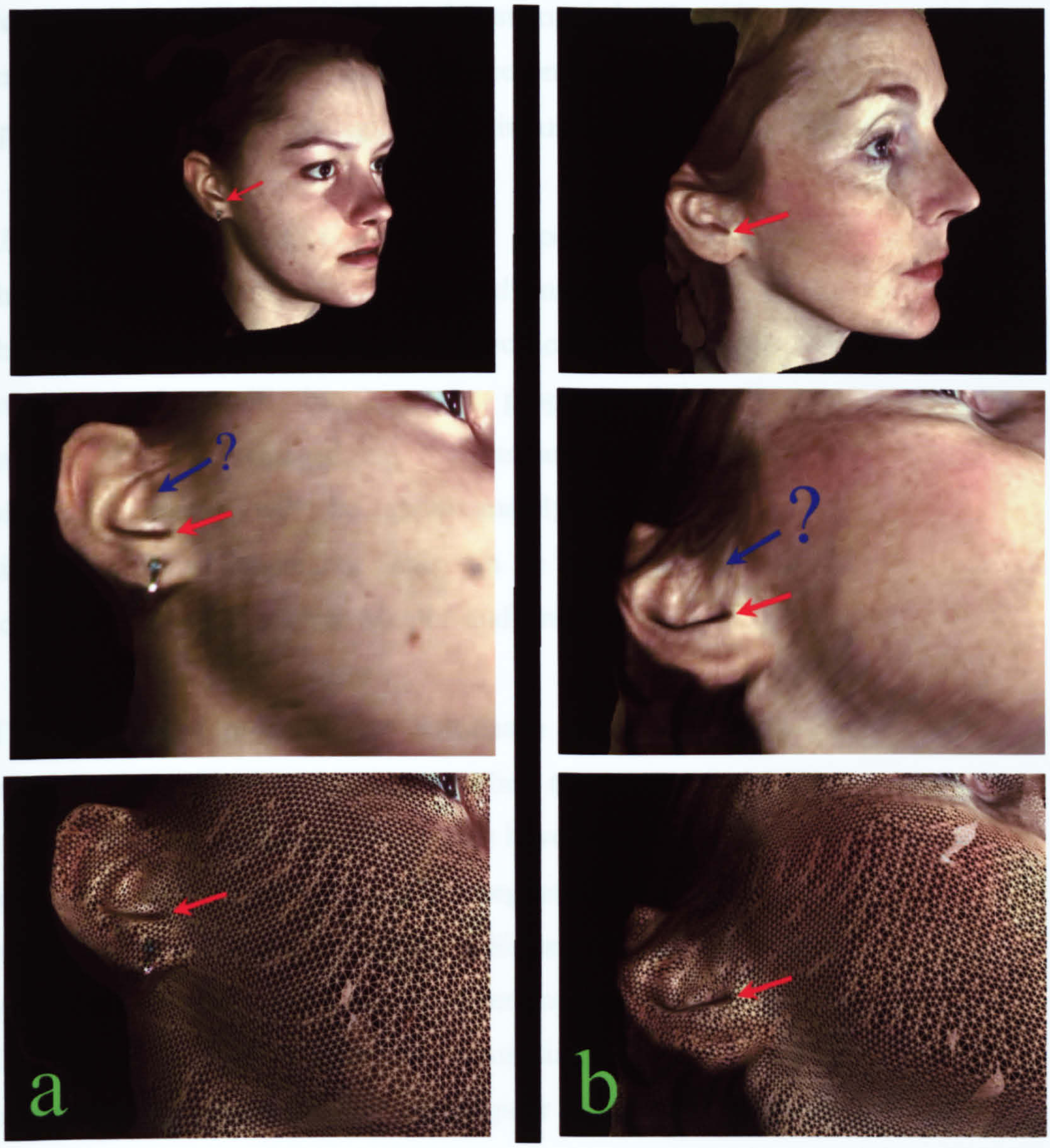


Figure 5.2 Identification of Tragion and Subtragion. (a) The identification of Subtragion (indicated by red arrows) is easier than Tragion (indicated by blue arrows) since the details above Tragus are not sharp enough. (b) On this 3D model, the anatomy in the Tragus region is vague, whereas the location of Subtragion is very clear.

Two additional ear landmarks (on each ear lobe) were more reproducible than Tragion. The first one was Otobasion with a standard deviation of 0.80 mm for the left point and 0.88 mm for the right point. The second landmark, called Subtragion (Figure 5.2), had more reproducibility than Otobasion in the three axes. The mean absolute differences after repeated digitisations were 0.075 mm in the x-axis, 0.325 mm in the y-axis and 0.485 mm in the z-axis (right and left mean values were averaged). The shadow behind the curvature in which this point lied added to its sharpness and definition. This localisation of this point is not affected by the presence of well-developed ear lobe, a problem documented in the identification of Otobasion inferius[485]. The presence of any pierce on the ear lobe does not seem to affect its spatial position since fairly rigid cartilaginous structures underlie and support it.

Using the centroid of a number of repeat placements at the same points as the landmark coordinate has the advantage that its variability will be less than singularly placed points. Specifically, the standard deviation of the averaged value will be inversely proportional to the square root of the number of values averaged, e.g. the standard deviation of the average of four-time-placed landmarks will be approximately half the standard deviation of an singularly placed landmark. This can be employed to improve reproducibility of 'difficult' landmarks such as Menton and Tragion.

This method of re-identifying soft-tissue landmarks several times to reduce the identification variability has been applied to recent research work[57] but not in the present study because alternative points have been found in the ear region (Subtragion as a substitute for Tragion), nasal root region (Nasion instead of Glabella) and the chin region (Pogonion instead of Menton). Since the malar region in the recruited subjects was outside the surgical sites, no intention was made to redigitise zygion points. Despite the importance of having a soft-tissue landmark located at the mandibular corner, Gonion reproducibility was too poor to be enhanced by repeated digitisations.

It appeared that our landmark identification reproducibility was higher than that quoted by Ferrario et al[133] who found an overall error of 2 mm. However, the reproducibility presented in this study is slightly less than that obtained by Moss et al[113] and McCance et al[112]who performed their tests using 10 soft-tissue landmarks identified on laser scans for averaging and superimpositioning purposes.

It should be emphasized that different methods of reproducibility analysis have been followed in the literature, which obstruct direct comparison with the results of other studies (see Section 1.2.2). Some researchers have looked at differences in linear and angular measurements[147,168]as an indicator of their landmark identification reproducibility. Others have used colour-millimetric maps without filtering out some additional sources of error[161], calculated differences in landmark coordinates[112,113,148,216] or calculated intraclass correlation coefficients between repeated identifications[167].

In addition, caution is required when comparing the current results with the results of other studies since different mathematical manipulations have been employed. If differences between repeated determinations can be considered as 'errors' in identification, the 'mean error' would reveal any possible systematic error[472] and this can be tested by a paired student's t test. The calculation of the 'mean error', however, allows positive differences to cancel out negative differences. This might be misleading in relation to the reproducibility of the procedure if the 'standard deviation' of the mean error is not considered. Examples of this approach can be found in the studies of Moss et al[113] and McCance et al[112]. The very high correlation coefficients presented by O'Grady and Antonyshyn[167] indicated low random error but did not provide a complete picture about the overall error. The use of the RMS (Root Mean Square) error[159], Dahlberg's formula[168] or the standard deviation of the error[474] would be more informative about the magnitude of deviations in repeated digitisations. Another simple method is to present the 'mean absolute differences' and this has also been applied in the present study when the x-, y-, z-differences of thirty soft-tissue landmarks were evaluated. Other 3D studies have used this method to evaluate the amount of error[160,165].

In the present study, a trial was undertaken to explore the reproducibility of 30 landmarks covering areas such as cheeks, gonial angles, the chin and the ear, which have not been included in several previous studies[113,147]. Landmark identification has been performed by one operator, and it would be interesting to study the variability in landmark identification between different operators working on the same 3D models[156]. This factor has not been evaluated well in some longitudinal studies that employed several operators[139,486].

For studying soft-tissue landmarks' displacements, 3D models need to be registered in a 3D manner. A list of seven landmarks was created to superimpose each couple of models using partial Ordinary Procrustes Analysis (OPA)[212]. The list included: right and left 'exocanthion', right and left 'endocanthion', 'nasion', and right and left 'subtragion'. These points were used because of their high identification reproducibility as well as their assumed stability, i.e. their locations in areas not affected by the surgical interventions[113].

5.2.2.4 Reproducibility of facial rest position

In order to compare patients' soft tissues at rest before and after surgical correction, it was postulated that the rest position of the lips (when the face is in the natural head position) was reproducible between different assessment times. The proof of this reproducibility would require a control group of subjects (preferably with dentofacial deformities) captured at two assessment times with an interval of six months similar to the interval of the original study group. Such an investigation was not performed in the current study because a recent investigation by Johnston et al[487](using the same C3D® technology) had shown rest position to be the most reproducible facial expression among five different facial expressions. Nevertheless, the results of that study cannot be applied completely to the current study because of the differences in the skeletal pattern and interocclusal relationships between the imaged subjects in each study. The subjects in the current work were asked to bite on their back teeth and to leave the lips relaxed whereas Johnston's subjects were asked to pronounce some letters and words to produce the rest position.

5.2.2.5 Natural head position and the soft-tissue drape

5.2.2.5.1 Natural head position - reproducibility

The reproducibility of natural head position (NHP) assessed cephalometrically showed an error of two degrees in young adult subjects with normal occlusion[488]. It is, however, difficult to achieve a reproducible head position in patients with abnormal profile outlines, facial asymmetry and head posturing habits[489].

No studies have been conducted to evaluate the reproducibility of the NHP three-dimensionally. The choice between Frankfort Horizontal and NHP for positioning the patient's head has been a point of controversy for a long time in the literature. Recently, Soncul and Bamber[490] evaluated the reproducibility of the head position facilitated by the use of a 'spirit level' to align the Frankfort plane parallel to the ground and found this method highly reproducible. However, the design of their study did not examine the effect of head position on the soft-tissue surface anatomy.

5.2.2.5.2 Head inclination and its effects on soft tissues

Yamada et al[162], using a 3D imaging system, reported that changes in the head position up to 45° away from the natural resting head position did not affect the collected 3D data. Garrahy[57], using a computerised stereophotogrammetric system similar to the one employed in the current study, showed reproducible 3D configurations of landmarks over a range of 60° of head inclination with an inanimate object.

The results obtained from anthropometric plastic models cannot be applied directly to live subjects. Changes in the cervical spine and head inclination are expected to result in stretching or compression of soft tissues in the lower facial regions[57] which affects the relative positions of landmarks located at these regions.

Great care was taken to capture each subject in the most natural head position. In case of postural habits or marked facial asymmetry, manual intervention depending on the subjective researcher's judgment was made to position the face in the natural head position (or the natural head orientation according to Lundstrom et al[491]). The use of pre-set facial positions in the Facial Analysis Tool was considered as an additional filter for any apparent residual abnormal head inclination.

5.2.3 Volumetric assessment on 3D models

5.2.3.1 The concept of facial volumetric change

Although it is interesting to study the 3D displacements of a group of facial anthropometric landmarks following surgical correction of dentofacial deformities, there is, on the other hand, a group of about 30 000 points (vertices) which are recovered from range data and left totally untouched, making insufficient use of the 3D models.

By superimposing 3D models using Procrustes and ICP techniques, the calculation of volumetric change at specific facial regions was facilitated. It should be taken into account that a volumetric change at the upper lip region is not equivalent to a volumetric change in the soft tissues that constitute the upper lip itself. In other words, the analysis does not measure the volume of the upper lip presurgically and compare it with the postsurgical value, but it measures the volumetric changes induced by the 3D movements of the upper labial patch in space provided the two 3D facial model under evaluation are properly superimposed. Figure 5.3 illustrates the concept of volumetric change at the upper labial region in a Class II subject treated by bimaxillary surgery. In the original back-plane construction method, the Facial Analysis Tool calculates the enclosed volume between the soft-tissue superficial patch and its projected boundaries onto a back plane. This volume does not only represent upper labial soft tissues, but also the underlying bony structures. The other method, which joins the boundaries of the presurgical patch with those of the postsurgical patch, measures the volumetric change in that region but does not convey any information about the changes in the soft tissues that make up the upper lip.

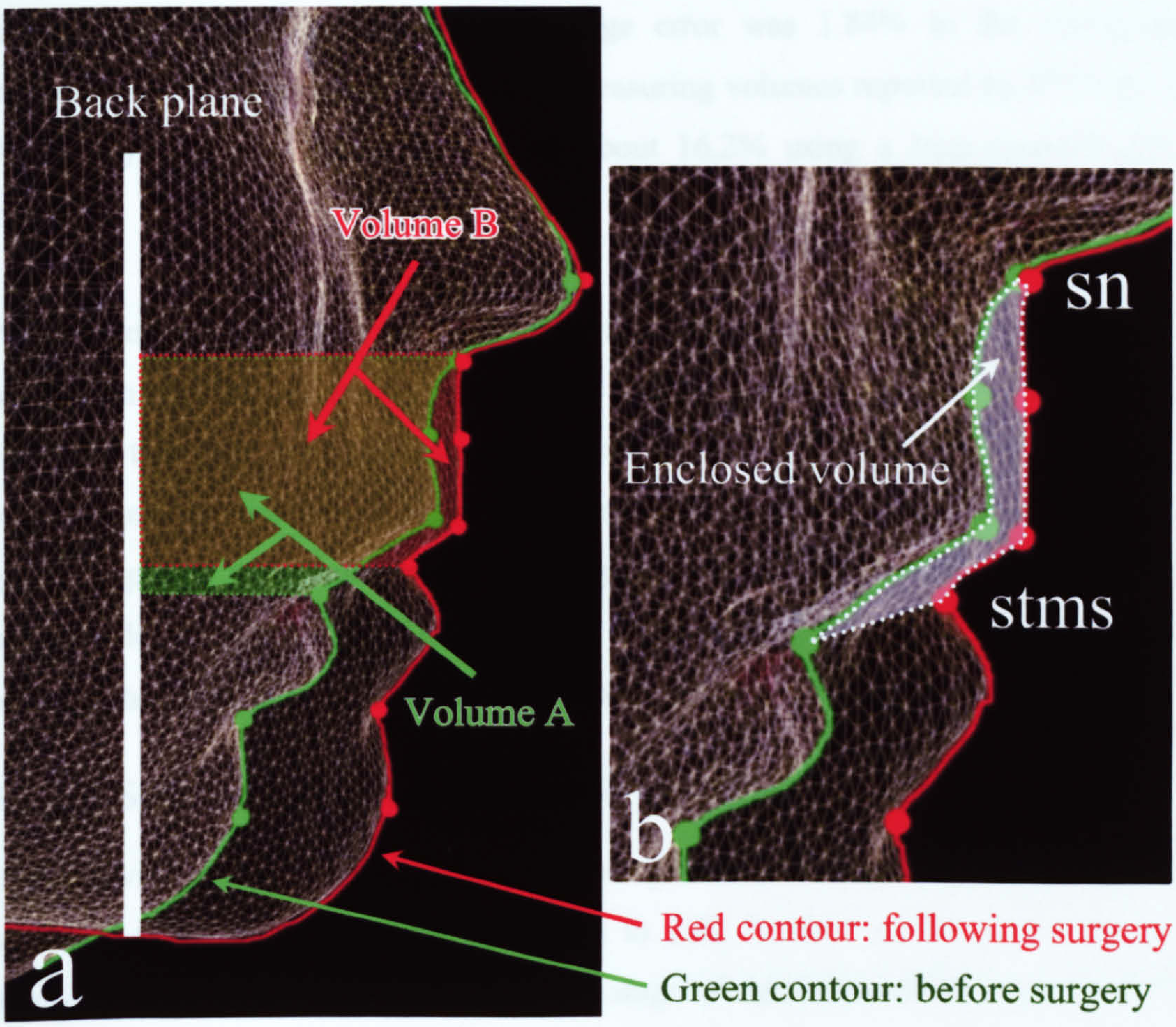


Figure 5.3 The concept of volumetric change at a facial region. (a) Volume 'A' (highlighted in green) represents the enclosed volume between the upper labial patch and the back plane presurgery, whereas volume 'B' (highlighted in red) represents the enclosed volume postsurgery. The difference between volumes 'A' and 'B' is the volumetric change in that region. (b) The other method does not depend on a constructed back plane. It 'stitches' the two patches together and calculates the enclosed volume. In both methods, the volumetric changes calculated are a function of the 3D movements of the upper labial patch in space and should not be attributed to the changes occurring in the soft tissues that constitute the upper lip.

5.2.3.2 Volumetric assessment accuracy

When the accuracy of the three volumetric algorithms was evaluated on an inanimate object, it was clear that the only method that did not produce systematic errors was the 'tetrahedron formation' method and it was superior to the 'projection method' although both used the same principle of stitching patches together. The reason for that was, perhaps, related to the arbitrary plane that was chosen as a projection plane. Volumes produced by projecting triangles onto that plane were very small, compared to those volumes obtained when projecting the same triangles onto the origin point 'in the tetrahedron method'. Calculating several small values (with an error embedded with each value) could have produced an error larger than what would be obtained from large values. The average percentage error was 1.84% in the 'tetrahedron method' and it was less than the error of measuring volumes reported by O'Grady and Antonyshyn(167) who found an error of about 16.2% using a laser-scanned plaster model.

Pre-imaging identification of landmarks facilitated the consistent construction of patches on each pair of models and reduced another source of error in this experiment. However this does not resemble the clinical situation in which patients are imaged without any localisation of facial landmarks. Different shapes of nasal, labial and genial explants were constructed and applied on the face, representing different possible deformities in 3D. The study did not take into account changes that might occur in the cheek area, and further assessment is required in this direction.

5.2.3.3 Sources of inaccuracy in the in vivo experiment

In the in vivo study, the 'tetrahedron method' proved to be superior with a mean error of 0.314 cubic cm, which was equivalent to 2.82 % error of the actual size. The increased error in the three methods in this stage of validation can be attributed to the superimposition method, rather than the accuracy of the algorithm itself.

The subject was instructed to give the same facial expression with the lips at rest and the face in the natural head position. It was expected that the inability to give the same rest position twice in two acquisitions would be another source of error and would affect the superimposition stage, and hence the accuracy of measured volumes.

However, rest position was found to be the best reproducible facial expression when assessed three-dimensionally[487]. The lack of precision in the final fit between any two superimposed models would cause either over- or under-estimation of facial soft-tissue changes. This analysis of facial volumetric changes was conducted on subgroup 'A' patients and the related results are discussed in Section 5.3.2.1.3.

5.2.4 Cephalometric study and error of the method

5.2.4.1 Timing of taking lateral radiographs

The method and the timing of cephalometric radiographic recording were not under the direct control of the researcher. This resulted in radiographs not being taken at the preferred time (i.e. the range of presurgical radiographs was within one month before surgery instead of one week), different magnification factors (using different cephalometric systems) and different interocclusal relationships (the majority of lateral cephalograms at T2 were taken with an acrylic wafer in situ).

Three assessment times were included in the study. If all the recruited subjects, however, had radiographs taken between 8 and 12 weeks postsurgery, a greater insight into the changes at that postsurgical stage would have been gained. The only postsurgical radiographic record that corresponded to the three-dimensional record was the one taken at six months postsurgery. Therefore, comparisons between the overall changes in cephalometric data (between T1 and T3) and the overall changes in the 3D data (between T1 and T4) were possible.

There are many sources of errors in cephalometric evaluations[472,492]. The 'projection error' is an inevitable error in this part of the study. This occurs when a 3D biological form is converted into a 2D image. Other sources of error, however, can be controlled and minimised[472,493,494] and these will be discussed in the following sections.

5.2.4.2 Head orientation in cephalometry

Several authors have advocated the use of the natural head position (NHP) when acquiring head films[99,239,460]. In the current study, all the cephalograms were taken in the three different hospitals using this method. It has been shown that following this standardised method reduces the amount of error in landmark identification, since rotational movements of the head mislead the identification of landmarks at maximum convexities or maximum concavities on skeletal and soft-tissue contours[460]

5.2.4.3 Centric occlusion versus mandibular rest position

Although taking the radiograph with the mandible in rest position has been recommended as the best position for the treatment planning of orthognathic patients[96,495]especially in cases with mandibular overclosure, it was felt that for the assessment of outcome, centric occlusion (or the 'habitual' occlusion) would be more appropriate for comparing successive head films. This decision was based on the well-established reproducibility of centric occlusion, the feasibility of comparing our results with the majority of studies that employed centric occlusion in the pre- and post-operative lateral cephalometric radiographs and because three out of the four Consultants in Oral and Maxillofacial Surgery preferred to take all of their presurgical and postsurgical cephalograms in centric occlusion.

The effect of mandibular overclosure on displacing soft tissues has been reported by several researchers[90,96]. This was encountered, at least, in two subjects in subgroup 'A' (see Section 5.3.2.1.3), which might have affected the calculated displacements of upper labial landmarks and caused underestimation of the effect of maxillary advancement on the related soft tissues.

5.2.4.4 Magnification factor

The comparison between different studies in terms of linear measurements and the magnitude of landmark displacements cannot be accomplished if the inherent magnification of radiographic measurements is not corrected[494]. If changes in linear measurements or landmark coordinates are presented in percentages of movements, the need for correction of magnification is eliminated[332]. Presenting a result, however, only as a percentage of change might be misleading from the clinical point of view[496], i.e. a 50% relapse in the anteroposterior displacement of 'A' point could be clinically irrelevant if 'A' point moved initially 1.5 mm. A 25% relapse of an 8-mm advancement of the chin point could be clinically significant. It is therefore, advisable, to use both methods of presentation to avoid perplexity.

Different magnification factors between the three hospitals have been found in the present study and cephalometric measurements have been corrected accordingly. The majority of studies that assessed hard- and soft-tissue changes following orthognathic surgery have ignored this problem, simply because the recruited patients were radiographed by one cephalometric system with consistent magnification factor. Consequently, direct comparisons in the magnitude of changes with other studies would be invalid.

5.2.4.5 The x- and y- coordinate system

The True Horizontal plane was advocated by some authors(497), whereas other authors suggested the use of the Frankfort Horizontal plane(98). Because of the documented inconsistencies in finding 'Porion' and 'Orbitale' on lateral cephalograms, Burstone and Legan(86) advocated the use of a constructed horizontal plane from SN rotated seven degrees from that plane. This method has been followed in the current study as well as in many other studies(233,242,243,256,257). Frankfort Horizontal plane, however, has been used widely in the orthognathic literature(228,234,236,252,253,270), while the use of the SN plane as the horizontal reference frame has been adopted to a lesser extent(232,239,262,498,499).

5.2.4.6 Transcribing and reconstructing missing landmarks

Maxillary surgery is accompanied by loss of ANS on some occasions(101), or considerable amount of remodelling at 'ANS'(232) and 'A' point(256). Researchers have mentioned the difficulties in identifying the posterior nasal spine (PNS) following Le Fort osteotomies(101,232). For these reasons, ANS and PNS has been transcribed to the postsurgical tracings using the presurgical maxillary template and the maxillary contours have been employed for superimposition, particularly the palatal vault(232,467).

In the mandible, the accompanying genioplasty procedure for several subjects in subgroups A (5 patients), B (6 patients) and C (9 patients) necessitated the dependence on B point in interpreting mandibular apical base movements(243,264). Several authors, however, have indicated that this point remodels following surgery(496). So, the identification of Genion, 'the most posterior point on the lingual cortical aspect of the symphysis above the genial tubercles and usually one to two millimetres below the level of the lower incisor apex', was adopted(496). A similar point was also suggested by Sorokolit & Nanda(264). Genion was intended to be used in case the discrepancy between B and 'Ge' exceeded 2 standard deviations of identification error of 'B' point. This discrepancy, however, was not found in the studied subgroups. The use of 'D' point, the centre of the symphysis, proposed by Steiner[70] was inappropriate because of the obvious geometric change of the symphysis in the short- and long-term.

5.2.4.7 Landmark identification reproducibility

In addition to the evaluation of systematic and random errors according to Houston [472], Dahlberg's formula was used because of the benefit of estimating the overall error for each landmark and because of its wide use in the orthodontic literature.

Caution has been made in interpreting any result dependent on the landmarks that showed marked systematic or random error in identification, particularly Glabella, Condylion and Orbitale. On the other hand, the majority of the chosen soft- and hard-tissue landmarks showed good to excellent reliability and no systematic errors.

5.2.4.8 Reproducibility of simulating mandibular closure

Many researchers who evaluated the position of mandibular landmarks following surgery overlooked the presence of the occlusal wafer at the immediate postoperative cephalogram[239,261]. Some authors focused on changes above a cut-off limit of 2 mm[268,500] and explained minor changes found postoperatively by the presence of the splint at the time of the immediate postoperative head film. Law et al[243] have shown that the vertical mandibular closure from splint removal ranged from 0.5 mm to 1.5 mm in posterior occlusion and 1.0 mm to 2.5 mm in the interincisal region. If the effects of the surgical acrylic wafer were not filtered out, the evaluation of relapse would be considerably 'masked' by this element of inconsistency plus the unavoidable range of error in landmark identification.

Two studies tried to solve this problem by autorotating the mandible around a centre of rotation located at the middle of the mandibular condyle until an interocclusal contact (either posteriorly or anteriorly) is achieved[264,266]. This procedure has been applied in the current study for patients with acrylic splints in their mouths during the acquisition of the lateral cephalogram within one week following surgery.

The test was aimed to evaluate the reproducibility of the procedure and not its validity. Validity of such simulated autorotation would require adult volunteers with two cephalograms, one with 2 mm separation between the posterior teeth and the other one taken in centric occlusion. This would not be accepted for ethical reasons. The results displayed in Section 4.2.5.2, therefore, illustrate the reproducibility of the method. The results were satisfactory and all the cephalograms (either with simulated mandibular autorotation or not) were considered together.

5.2.5 Compatibility between 3D and 2D data

The cephalometric and stereophotogrammetric records were selected from the first assessment time (before surgery) and the last assessment time (six months following surgery). This selection was made because of the relative closeness in their time of acquisition, pre- and post-operatively. The compatibility between both types of assessment was not proven. The difference was within acceptable limits regarding linear measurements, whereas three out of the four angular measurements showed significant differences.

Several potential sources of difference between the two methods can be mentioned: the data collection timing, the recording apparatus geometry, the landmark identification reproducibility, the facial expression, the reference coordinate system and the superimposition method.

- Radiographs were taken within one month before surgery, whereas the 3D images were captured within one week before surgery. The last postsurgical radiograph was not always taken on the same day as the 3D model.
- Cephalometric radiographs have inherent distortion and magnification. Although magnification was corrected, the distortion of projecting a 3D object into a 2D plane is a considerable source of error, which deprived the cephalometric measurements from being considered as the 'gold-standard'.
- Four cephalometric systems were used in three hospitals whereas one 3D-imaging system was used.
- 3D data were built using the principles of triangulation depending on two stereopairs of image. There were several potential sources of errors in the 3D imaging technique: calibration, merging and smoothing procedures and texture mapping.

- Landmark identification error in cephalometry was different from that of stereophotogrammetry. Radiographs were not all taken in a standardised position (teeth together, lips in repose). Even when this position was adopted, a subjective decision was made about the achieved rest position.
- Superimposing successive radiographs was performed visually using the cranial base and registering at Nasion, whereas the 3D models were superimposed mathematically using the principle of the 'least squares' to achieve the 'best fit'.
- The x-axis was the anterior cranial base plane rotated seven degrees around Nasion in a clockwise direction and the y-axis was a perpendicular passing through Nasion, whereas the x-, y- and z- in the 3D model were based on the captured face in the NHP.

In the light of these differences, the calculation of soft- to hard-tissue movement ratios by dividing the 3D soft-tissue displacement by the 2D skeletal displacements was deemed inaccurate. Soncul(479) in a 3D study on orthognathic patients did not find any statistically significant difference between six cephalometric-based and laser-scanning-based measurements. This enabled explanation of the midsagittal displacements of soft-tissue landmarks based on the underlying 2D skeletal changes. The skeletal data, however, in the current study provided a considerable amount of information about the underlying bony movements in each studied subgroup and the results of soft tissues changes were consistent on many occasions with the 3D soft-tissue results.

5.3 Subgroups A, B and C: morphometric and psychosocial changes

5.3.1 General considerations

When multiple comparisons are carried out using the same database, each with a significance level set at 5%, then, even in the absence of any real effects, some of the tests would be significant(476). In order to control the type I error rate (i.e. false positive rate), a similar approach to Benferroni correction was adopted(262,476). Significant results with p values greater than 1% and less than 5% were interpreted with caution and, in the study conclusions; reliance was made on highly significant results ($p<0.001$).

Few orthognathic studies attempted to assess skeletal stability or soft-tissue behaviour three-dimensionally[113,146,148,220,258,304,305,479]. Consequently, most of the present results related to stereophotogrammetry-based linear and angular measurements as well as those related the 3D assessment of facial asymmetry are unique in the literature. Some comparisons of the end results, however, are made with the 3D normative angular and linear measurements established by Ferrario et al[137] in the following sections.

No attempt has been made to evaluate prospectively the psychosocial characteristics of orthognathic patients based on the accomplished surgical interventions. Therefore, the psychosocial results related to subgroups A, B and C cannot be compared directly with the published work available.

5.3.2 Subgroup A

5.3.2.1 Stereophotogrammetry-based findings

5.3.2.1.1 Soft tissue behaviour

Soft-tissue changes in the short and longer-term

The whole face. It is well known that the profile of a skeletal Class III subject is described as concave[52]. Three points have been proposed to measure the facial profile in the literature: one located between the eyes (Glabella or soft-tissue Nasion), one located in the nasal tip or base (Pronasale or Subnasale) and one located in the chin region (Pogonion). There was a significant reduction in the mean facial convexity angle (na-sn-pog) and the mean facial profile angle (na-prn-pog) indicating a significant improvement in facial profile in this subgroup. An example of the deformity correction in this subgroup is shown in Figure 5.4.

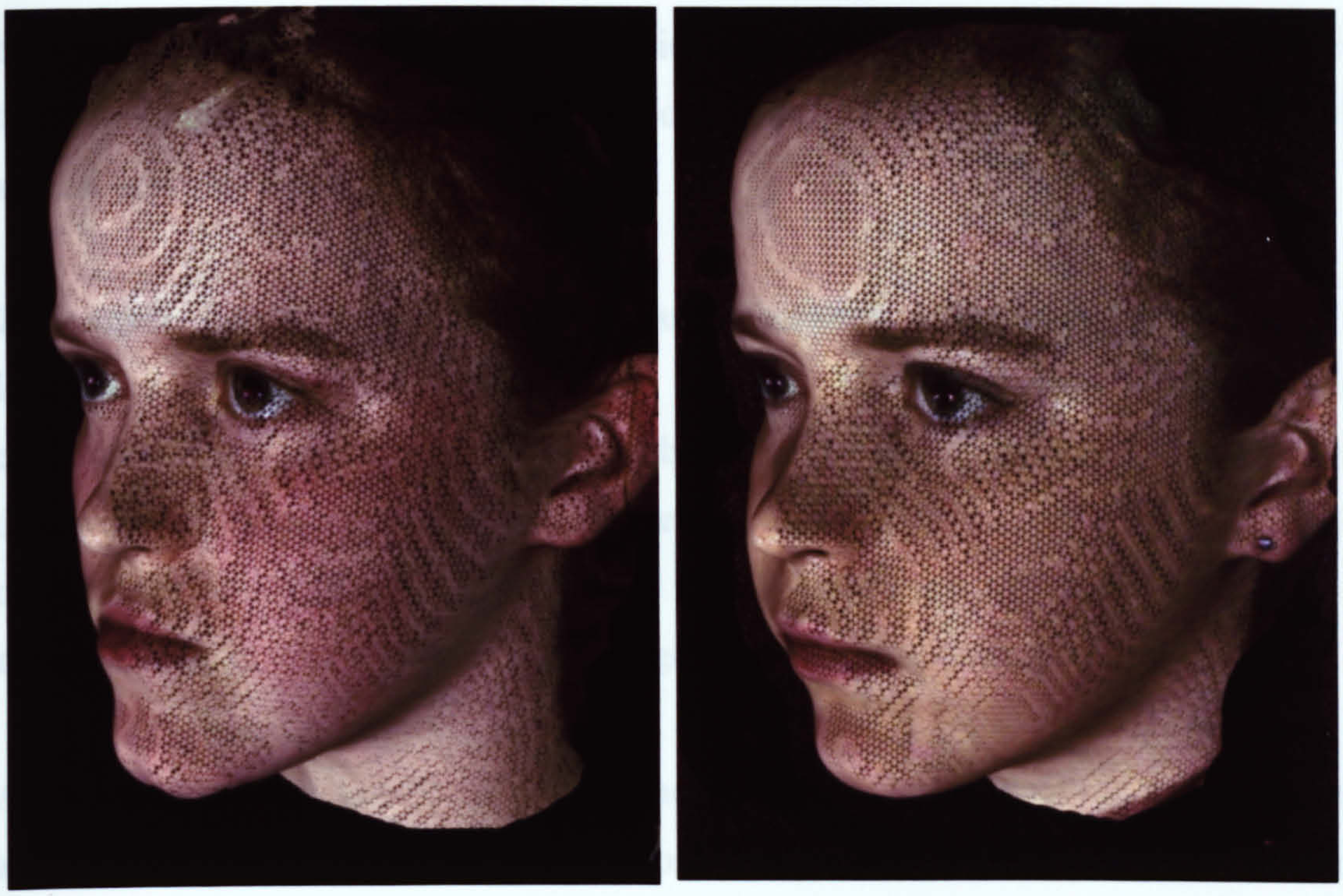


Figure 5.4 A skeletal Class III patient treated by maxillary advancement with inferior repositioning (via Le Fort I osteotomy) and mandibular setback (via vertical subsigmoid osteotomy). 3D models (photorealistic + wireframe) are used here with a 45-degree rotation around the y-axis.

Between T1-T4, two directions of landmark movements were observed: A forward movement of the maxillary related landmarks and a backward movement of the mandibular related landmarks. The magnitude of forward movement of nasal and upper labial landmarks was considerably less than the magnitude of the backward movement of lower labial and mental landmarks. Therefore, the deformity correction was more dependent on the mandibular vector of correction.

The nose. The upturning of the nasal tip documented in previous studies[360] was not significant in our sample. This may be related to the inclusion of some subjects with inferior repositioning of the maxilla, which would have cancelled out the presence of such movement. This might also explain partially the downward movements observed with the alar base landmarks ('acR' and 'acL'). The increase in the alar base was one of the clear findings in this subgroup that had a Le Fort I maxillary advancement. The lateral displacements of alar base landmarks in the transverse direction confirmed this observation. Although alar base cinch sutures were performed in 14 out of the 20 subjects (70%) of this subgroup, the significant increase in alar base width indicated base width indicated the difficulty in achieving a full control on the nasolabial soft-tissue response following the maxillary osteotomy. This finding is consistent with several previous reports[129,348,360].

The upper lip. Angular changes measured between 3 unstable landmarks (i.e. landmarks prone to movement with surgery) should always be interpreted cautiously[57]. An example of this is the change in the nasolabial angle. If the current data were not supplemented by extra information regarding the spatial displacements of the three points (Pronasale, Subnasale and Labrale superius) that constituted the nasolabial angle, interpretation of its change would include some guessing.

As a result of the maxillary advancement and the subsequent labial functional adaptation to the new dentoskeletal relationships, superior labial sulcus (sls), Labrale superius (ls) and Stomion superius (stms) showed forward and downward movements which resulted in a better oral seal and lip competence at the final follow-up assessment.

The mouth. The significant narrowing of the mouth width of approximately two millimetres, as evidenced by inward movements of 'chL' and 'chR', has not been documented before. This can be explained as follows. Before surgery and because of the Class III skeletal relationship, the lower lip and the mouth corners rested on the lower anterior teeth that formed a broad arc. Following surgery, the lower lip and the corners of the mouth were no longer supported by the mandibular dental arch but by the upper dental arch, which originally had a narrower circumference. This caused inward and backward collapse of the related soft-tissues (i.e. the lower lip and mouth corners). Therefore, a reduction in the mouth width was seen.

The lower lip. The backward movement of the central part of the lower lip was more than at the mouth commissure points. Techalertpaisarn and Kuroda[148], who analysed the z-displacements of 75 constructed facial landmarks in a group of Class III patients treated by mandibular setback only, found that the backward displacements were of maximal magnitude in the midsagittal landmarks and decreased gradually when moving towards the lateral landmarks. This has also been documented by a CT-based study[164]and by a laser-scanning-based study[479].

Two explanations can be given for this gradual reduction in movement seen in the lateral parts of the perioral tissues. The first is related to the 'horseshoe' shape of the mandibular bone (or the U-shape of the mandible). When a 10-mm setback is measured in the midsagittal plane, the actual effect on the peripheral points is less[148,164,479] (Figure 5.5).

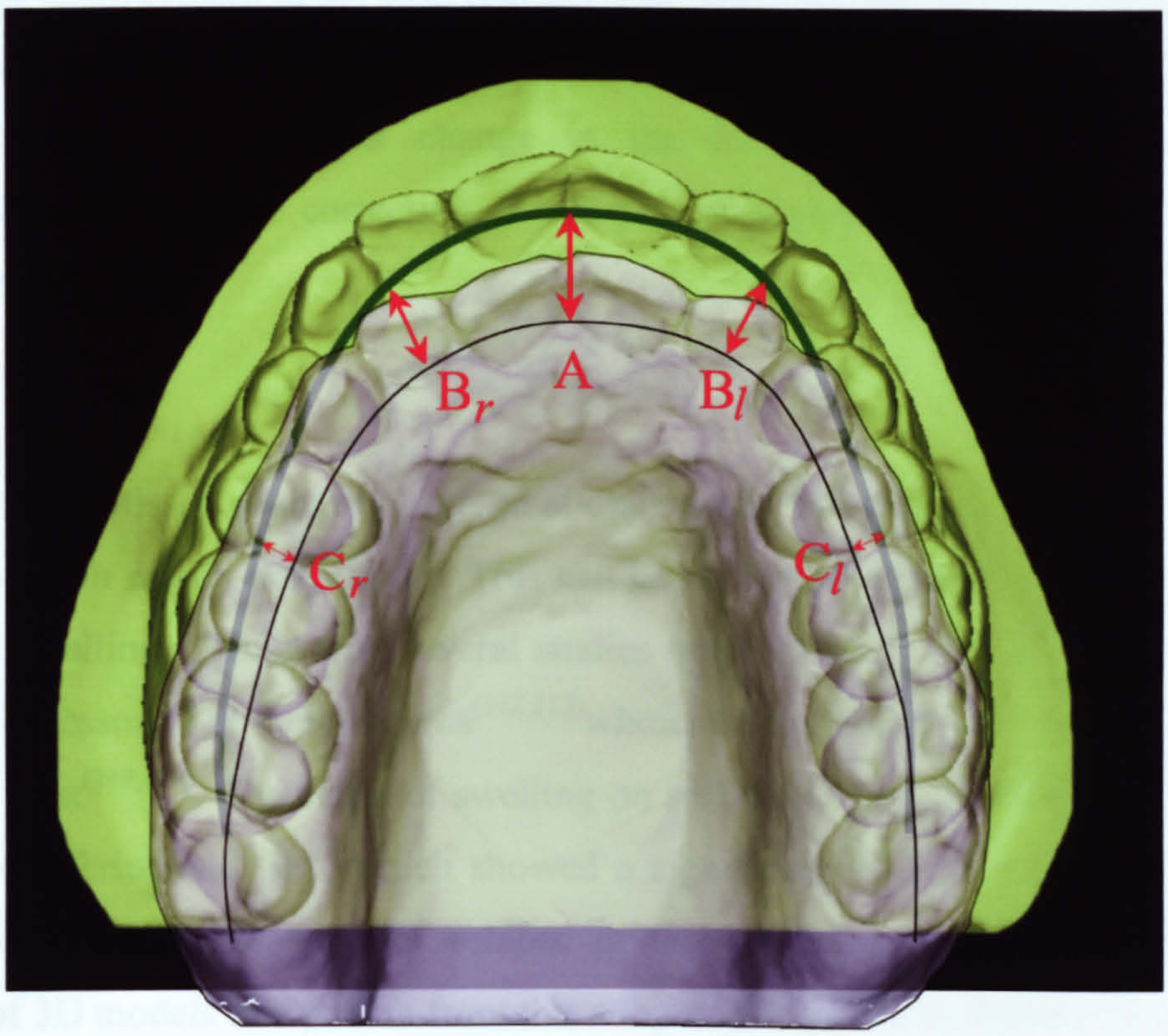


Figure 5.5 When a semi-circular shaped bone is advanced at point A, the other bilateral points on the circumference of the arc (B and C) move relatively less. In other words, the degree of projection of the bony advancement (or the bony setback) on the overlying soft tissues reduces gradually towards the back.

The second explanation is related to the anatomical muscular structure of the lips[479]. The incisive and mental slips of the orbicularis oris muscle are the deepest fibres and they are attached to the bone near the midline and the mucous membranes of the lips. This anatomical structure causes the philtral and labiomental fold tissues to follow the underlying skeletal movement more closely than the lateral parts and the free ends of the upper and lower lips.

The labiomental fold and the chin. The backward displacements of 'li', 'ils' and 'pog' (which form the labiomental angle) in the overall assessment (T1-T4) were similar (mean≈6-6.85 mm), whereas the vertical displacements of 'li' and 'pog' were opposite to each other in the overall assessment (T1-T4). This can explain the significant change in the labiomental angle, which became more acute at the final assessment time (T4; mean=138.77).

The vertical displacement in the chin region ('pog' and 'ils') showed a relatively wide variation and was affected by the vertical reduction genioplasty performed for several cases. Detection of significant change in the location of Pogonion and 'ils' transversely confirmed the correction of mandibular asymmetry, which existed in 8 subjects presurgically.

Effect of swelling on soft tissues at one month following surgery

Some of the soft-tissue changes observed at one month following surgery were lost at the third or sixth month postsurgery. This can be attributed partially to the resolution of perioral swelling. This is why several studies opted to make the first post-surgical soft-tissue assessment at three months[112,113] whereas others preferred to wait until six months at least[349,479]. The effect of swelling on soft-tissue landmarks was evident in the Labiale inferius and 'ils', which showed a significant inferior movement at one month and a significant superior relapse at three months following surgery. A sequence of 3D models of a patient from this subgroup is shown in Figure 5.6.

Relapse (short term and longer term)

Relapse in the facial profile and facial convexity angles was found and can be attributed partly to the presence of swelling at T2 in several subjects as well as the significant relapse in the position of 'pog'. The changes in linear and angular measurements as well as in soft-tissue displacements, however, between 3 and 6 months postsurgery were insignificant indicating general soft-tissue stability in this period.

Responses of soft tissues to the underlying bony changes

The significant reduction of the lower facial depth (measured between Subtragion and Pogonion) is consistent with the underlying surgical correction. In the overall assessment (between T1-T4), the anteroposterior soft-tissue displacements were consistent with the underlying skeletal movement.

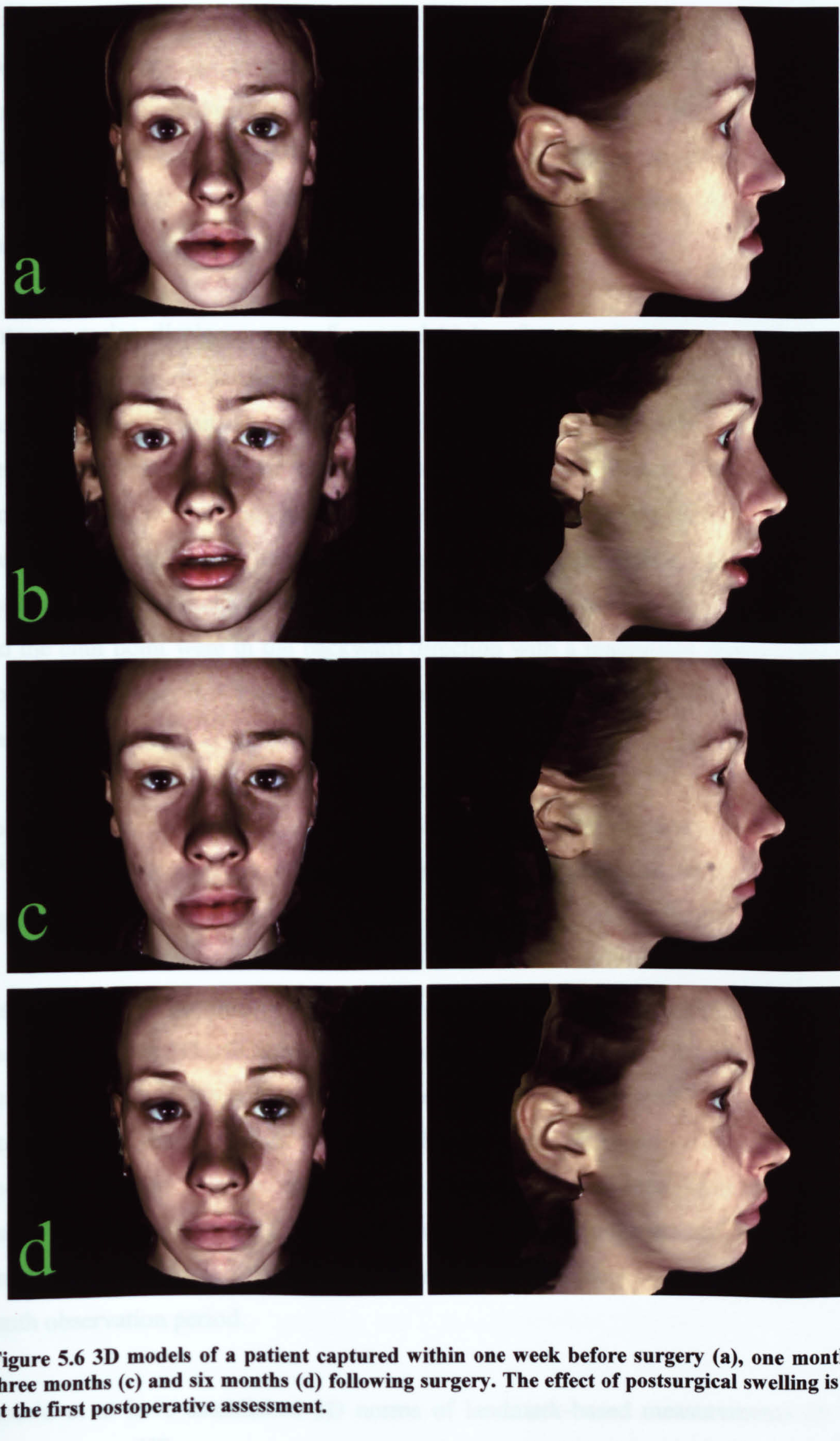


Figure 5.6 3D models of a patient captured within one week before surgery (a), one month (b), three months (c) and six months (d) following surgery. The effect of postsurgical swelling is clear at the first postoperative assessment.

Comparison with other studies

The observed increase in alar base width and upper lip height supports previous clinical observations by O'Ryan and Schendel[360-362]. Soncul[479] found a significant increase in the upper vermilion height and no significant change in the lower vermilion height following orthognathic surgery in Class III patients. Our findings are also in line with his clinical findings.

Anteroposterior displacements of upper labial soft-tissue landmarks found in the current subgroup are in agreement with the direction of 3D changes observed by McCance et al[112], but the magnitude of the results presented here is less than what they reported. It should be clarified that the colour millimetric maps, used by McCance et al, were dependent on radial measurements from the central point of the head, thus the changes in the peripheral areas of the face cannot be regarded as z-displacements. The anteroposterior displacement of the lower lip, the labiomental fold and the chin point were in the backward direction with a magnitude greater than that reported previously for males[112], whereas females in that study showed a similar magnitude of setback at the chin region.

No assessment has been made above the level of the nasal tip, whereas McCance et al[112]described changes in the inner portion of the cheek that extended up to the malar regions.

Displacements in the transverse direction reported here are unique in the literature, since no previous 3D cohort study has explored this dimension. Techalertpaisarn and Kuroda[148] studied the midsagittal changes only, whereas Soncul[479] analysed the anteroposterior displacements of landmarks on lateral-view printouts of 3D facial models. In the current study, minimal soft-tissue relapse was seen, whereas McCance et al[112] reported a relapse of 5 mm in the nasal tip, 3 mm in the maxillary regions and 5 mm over the chin and the mouth corners in male subjects over a three to twelve month observation period.

Ferrario et al have established 3D norms of landmark-based measurements for the Caucasian race[137]. The mean facial convexity angle (162.3°; SD=5.17), the mean facial profile angle (131. 98°; SD=4.53) and the mean labiomental angle (138.77°;

SD= 11.12) achieved at six months following surgery compare very well with their 3D normative values (161.68°; SD=4.89, 129.57°; SD=4.62, 140.36°; SD=11.65, respectively)[137].

5.3.2.1.2 Facial soft-tissue asymmetry

Merits and shortcomings. The values presented in the 3D asymmetry analysis were stated in terms of unit size, i.e. the size to which the facial landmarks configurations were scaled in order to allow comparisons. The use of unit size instead of millimetres might be considered a drawback[57]. The advantage of the current analysis, however, is its independence of any assumed symmetry plane to reflect (or mirror) soft-tissue landmarks.

The concept of midfacial plane of symmetry. Ferrario et al[130] using a 3D coordinate system found that the axis of symmetry was not located in the midline points. In the current analysis, the 19-landmark configurations were reflected around an arbitrary plane, and then superimposed using partial Ordinary Procrustes Analysis. The results of applying the current 3D analysis on a control group of 3-year old children proved that the reflection of images across a plane constructed from midline points is an oversimplified approach to the assessment of asymmetry[57]. The so-called 'midline' landmarks such as Nasion (na), Subnasale (sn), Labrale superius (ls), Labrale inferius (li) in healthy children were found to be incoincident when superimposed on their mirrored images[57], i.e. the median asymmetry scores for these landmarks were not equal to zero.

Facial asymmetry in subgroup A. Eight subjects had clinically obvious pre-surgical facial asymmetry located in the chin region. The median postsurgical asymmetry indicated a significant improvement following surgery either in the short- or the longer-term. An example of asymmetry correction in this subgroup is shown in Figure 5.7. This improvement is in line with the significant displacements observed for 'ils' and 'pog' in the transverse direction, but it should be taken into account that the eight subjects in this subgroup did not have the same direction of asymmetry. Positive movements in the x-axis, therefore, were partially cancelled out by negative movements. This explains why x-displacements of mental landmarks were of marginal significance and the standard deviations were relatively large, whereas the calculated asymmetry scores were not affected by the presence of two directions of transverse asymmetry.

Hierarchy of landmark asymmetry. When the facial asymmetry score was decomposed into its 19 components (landmarks), the hierarchy of landmarks (ranked in order of ascending asymmetry) showed that changes in the Pogonion and Menton were in the direction of less asymmetry. Caution should be made, however, in comparing presurgical with postsurgical median values of individual landmark asymmetry scores since these scores are the calculated components of the original facial score for each patient at each assessment time.

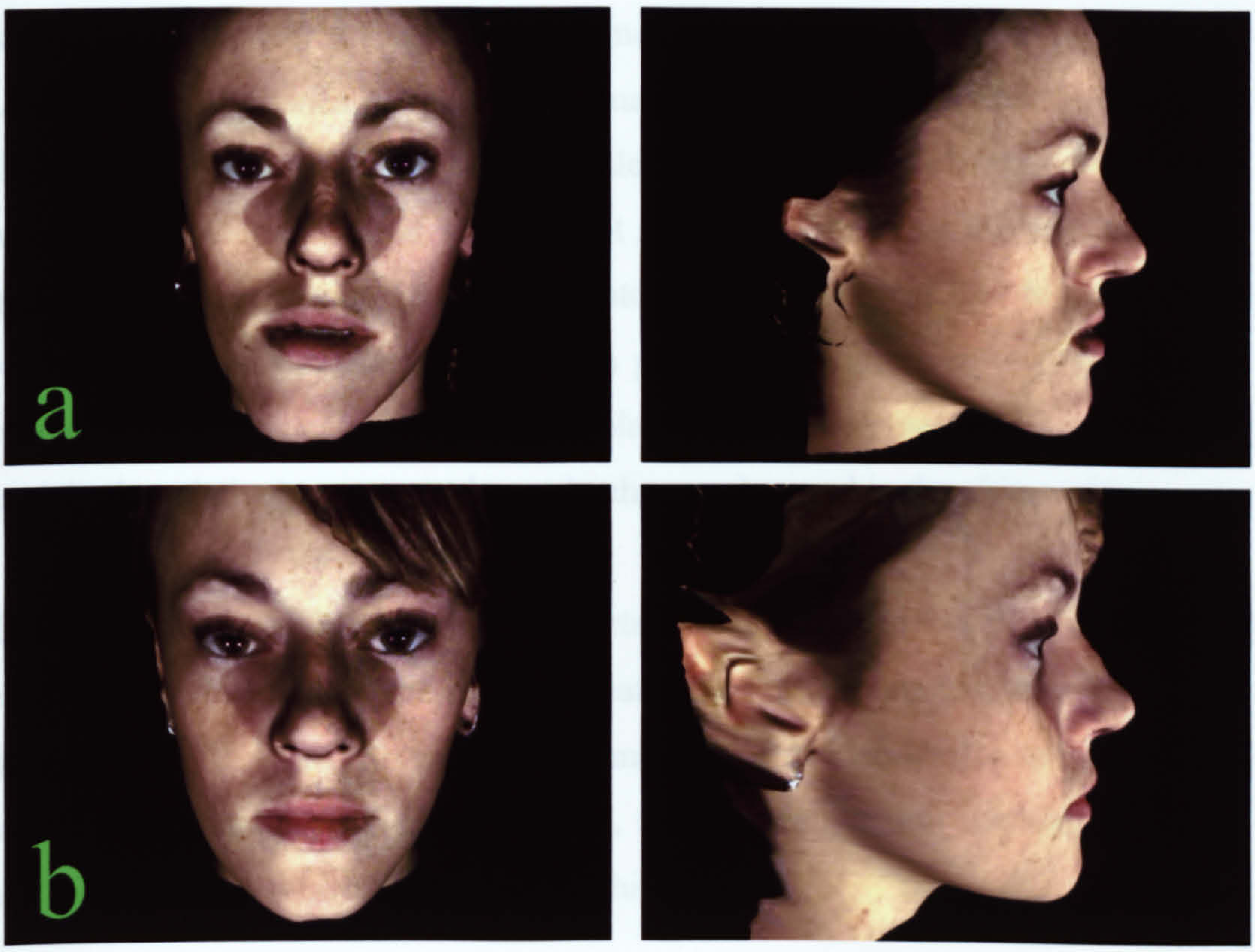


Figure 5.7 Asymmetry correction in a skeletal Class III patient. The presurgical model (a) illustrates the mandibular deviation towards the right side. Three months following surgery (b), the face became more symmetric.

5.3.2.1.3 3D volumetric assessment

Reproducibility of the method

Lower lip and chin patches employed 'constructed' points as boundary landmarks. Three assumptions were made in this part of the study: the new pseudo-landmark was expected to be highly reproducible if the original two landmarks were highly reproducible, since its creation was mathematically performed; the reproducibility of the created patch (by several boundary landmarks) would be high if its boundary landmarks were highly reproducible and the inclusion of one or two moderately reproducible boundary landmark in a patch created by multiple boundary landmarks would have little effect on the overall reproducibility of that patch. Until these assumptions are tested separately in future work, the reproducibility of the method was within the acceptable limits (average SD for the four facial regions= 0.118 cm^3).

Volumetric changes in subgroup A

Although the maxilla has moved forward and downward in this group, the volumetric difference at the upper lip region was 1.513 cubic centimetres in an anterior direction which was less than one fifth of volumetric change observed in the chin region. Looking at the mean values of maxillary and mandibular anteroposterior displacements would indicate that the calculated volumetric changes at the upper lip region were under-estimated. However, it should be noted that the original patch size in the chin region was bigger than the patch size of the upper lip (this was confirmed by looking at the surfaces areas of each patch). In addition, several subjects in this subgroup had a vertical reduction genioplasty with a bony wedge removal, which can explain the relatively greater volumetric change observed in the chin region.

The combined lower-lip and chin volumetric change was, in this subgroup, about 10.3 cubic centimetres which was slightly greater than the volumetric changes reported by Motegi et al[220]. The differences in the magnitude of mandibular setback, the design of the corresponding soft-tissue patches, the superimposition method of 3D models and the follow-up time may account for this.

Surprisingly, two subjects showed a negative volumetric difference at the upper lip region indicating that the upper lip patch moved backward. When the 3D models of these subjects were revisited, it was clear that the upper lip was initially displaced anteriorly because of mandibular overclosure (Figure 5.8). This factor has not been filtered out in the current study, since it was decided to collect all the 2D and 3D data with the teeth in centric occlusion. The effect of mandibular overclosure on upper labial soft tissues explains the wide variation observed in the anteroposterior displacement of Stomion superius in this subgroup that rendered the overall forward movement insignificant.

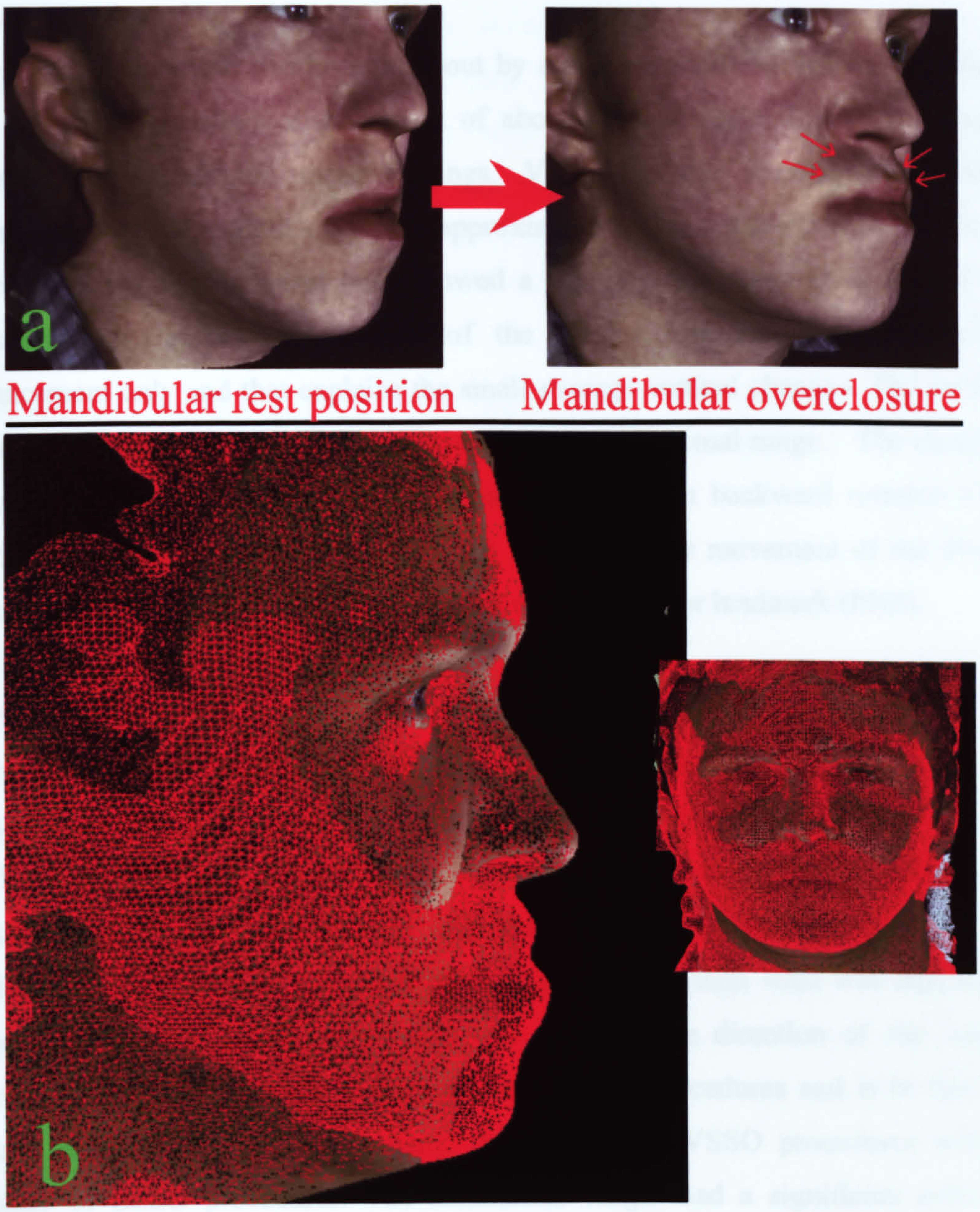


Figure 5.8 The effect of mandibular overclosure on upper labial soft tissues in skeletal Class III deformities. (a) Presurgical 3D images of this patient were taken in two mandibular positions: rest position and centric occlusion. The upper lip was displaced forward and slightly upward with mandibular overclosure. (b) When the six-month 3D model (shown in normal colour) was superimposed on the presurgical 3D model (shown in red), the upper lip showed a slight backward movement, which was opposite to the expected change.

5.3.2.2 Cephalometric findings

5.3.2.2.1 Skeletal changes

Skeletal surgical change

The surgical correction was brought about by a mean mandibular setback of about 5 mm and mean maxillary advancement of about 4mm initially. Linear and angular measurements confirmed these findings. Vertically, the maxilla was brought downward a mean amount of 1 mm approximately (when measured at the incisor edge). The mandibular apical base showed a superior movement of about 1.5 mm (measured at Genion). Fifteen out of the 20 subjects had a pure maxillary advancement only and that explains the small average vertical changes. The resultant mean ANB angle, overjet and overbite were within the normal range. The change in the maxillary-cranial base planes angle indicated a slight backward rotation of the maxillary plane, and this can be explained by the inferior movement of the anterior landmark (ANS) and the superior movement of the posterior landmark (PNS).

Skeletal stability

From the clinical point of view, the maxillary and mandibular relapse was insignificant (mean relapse at 'A'= 0.78 mm (20% of the initial change), mean relapse at 'B'=0.77 mm (15% of the initial change)). The percentage of anteroposterior maxillary relapse in this subgroup is slightly higher than that reported by other studies(239,243,248), whereas the actual mean relapse is less than what was reported by these studies. The mandibular relapse was in the same direction of the surgical change. This type of relapse is common with VSSO procedures and is in line with several studies(262,269) which compared the stability of VSSO procedures with the stability of BSSO procedures. The mandibular length had a significant reduction, which was consistent with landmark displacement findings.

Vertically, a significant elevation in Gonion was observed. Remodelling of the gonial regions in the postsurgical period might be the reason for this. This does not exclude, however, the possibility of superior movement of the proximal segment following its probable surgical downward movement. As a result of this superior movement, a significant change in the cranial base-mandibular plane angle and the maxillomandibular planes angle occurred. The overall assessment of skeletal stability when considering the 'ANB' angle, however, revealed a normal skeletal relationship at T3 in this subgroup.

The design of the cephalometric study, however, did not allow for distinguishing immediate relapse (which occurs in the first few weeks) from latent relapse (which occurs up to 6 to 12 months following surgery). If a cephalometric radiograph was acquired between the 8th week and the 12th week following surgery, a better understanding about the time of relapse would have been achieved.

5.3.2.2.2 Soft-tissue changes

Little information can be gained from comparing soft-tissue status at T2 (within one week following surgery) with the soft-tissue status at T3 (six months following surgery) because of the obvious swelling present at T2.

The magnitude of landmark displacements between the stereophotogrammetric and the cephalometric data was not exactly the same, whereas both datasets showed similar directions of movements. The factors beyond this incomplete agreement have been discussed before (see Section 5.2.5). This resulted in some changes being significant two-dimensionally and insignificant three-dimensionally and vice-versa. The increase in the upper labial height was significant in both 2D and 3D measurements whereas the decrease in the lower labial height was significant two-dimensionally and insignificant three-dimensionally. The significant decrease in the lower facial height seen two-dimensionally was unclear three-dimensionally, whereas the significant 3D change in the upper vermilion border was not detected two-dimensionally.

The overall soft-tissue anteroposterior changes observed in subgroup A are in agreement with several studies[330,333]. However the vertical changes observed in the upper lip disagrees with the observations of Mansour et al[333] who found vertical movement of Stomion superius with subsequent shortening of the upper lip. This may be attributed to the simultaneous maxillary inferior repositioning performed in this subgroup for five subjects.

The significant improvements seen in the facial profile angle and the labiomental angle are consistent with findings of other studies[360,374-376].

5.3.2.2.3 Soft-tissue to hard-tissue relationships

2D soft-tissue thicknesses

In the upper lip and the nasal base region, significant thinning of soft tissues was observed, whereas a significant thickening of soft tissue was seen in the labiomental fold and chin regions. Several reports support these findings[349,360-362]. Although the maxillary advancement tends to advance the upper labial soft tissues, the ratio is less than 100%. Therefore, caution should be made when treating patients with presurgical thin lips. If such a procedure is mandatory, an adjunctive treatment might be required to solve the possible problem of decreased lip thickness following surgery.

The increased thickness at the labiomental fold can be explained by the median horizontal movement ratio of 0.90:1 with the retraction of 'B' point. The vertical reduction genioplasty was another reason, which contributed to the bunching of soft tissue at the labiomental fold. Although the median horizontal movement ratio was one-to-one in the chin region, the vertical ratio of about 0.5:1 might explain the significant soft-tissue thickening at the chin point.

Soft-tissue to hard-tissue displacement ratio

Anteroposteriorly, the nasal tip showed the least significant ratio of movement (median= 0.29:1), whereas the 'sls' showed the highest ratio (median=0.75:1) exceeding slightly that observed at the Labrale superius level (median= 0.60:1). Similar nasal tip ratios have been reported in the literature[331,333,334,346]. The ratio found at the superior labial sulcus level is similar to the ratio documented by Carlotti et al[366] and slightly higher than ratios reported by Mansour et al[333] and Hack et al[369]. The early work of Lines and Steinhauser[367] indicated a ratio of 0.67:1 at the Labrale superius, which was also found in the present study. Other researchers, however, found higher ratios than this[345,366].

In the mandible, a ratio of 1:1 was found at the Pogonion level, while the lower labial and labiomental ratios showed lower values. The ratio of one-to-one in the chin region is well documented in the literature[359,367,376] and lower ratios were observed for the lower lip landmark[377] similar to what was found in the current study.

Since no significant maxillary movement has occurred in the vertical dimension on average, the vertical ratios related to the nasal and upper labial landmarks were insignificant. However in the chin region, a significant one-to-two median ratio of vertical movement was observed which was slightly higher that the previously reported ratios[285,364,368]. Probably, if the subjects treated with vertical reduction genioplasty were excluded from this subgroup, the vertical displacement ratios in the chin region would have been less.

5.3.2.3 Psychosocial findings

5.3.2.3.1 Motivational pattern

Three motives were mentioned by 95% of the subjects: improving self-esteem, improving the fit of upper and lower teeth and improving facial profile. This meant the three types of motivation were of almost equal importance to patients, i.e. the psychosocial well-being, the functional and aesthetic improvement. The other motives in this hierarchy were: the desire to improve the dental appearance (85%), chewing abilities (70%) and work and social performance (70%). The motivation to improve work and social performance was indicated by a higher proportion in this subgroup than in the other two subgroups. Although, the difference was not significant, some of the characteristics of this subgroup might be linked to this observation, i.e. the increased impact of this deformity on the perception of the presurgical facial appearance compared with subgroup B (which warranted a two-jaw surgical correction instead of one-jaw operation), the slightly higher mean extroversion score compared with subgroup C (which meant more outgoing and sociable patients in this subgroup).

5.3.2.3.2 Personality characteristics

There was an impact of orthognathic surgery on personality characteristics, which was revealed by several psychometric variables. Self-esteem improved significantly at the immediate postoperative and the last assessments. This is in agreement with the findings of Auerbach et al[416], Finlay et al[413] and Flanary et al[427]. There was also a significant reduction in the levels of anxiety and depression in the overall assessment, but presurgically these values were in the lower range of the scale. Cunningham et al[429] who used the same HADS questionnaire did not detect any significant difference between the pre- and post-surgical groups. Lovius et al[436], however, found a significant improvement with the use of another questionnaire. It should be stressed that different types of deformities with different types of surgical interventions were included in the previous studies, which invalidates direct comparisons.

5.3.2.3.3 Perception of facial appearance and facial change

Facial body image. The only subgroup among the three subgroups that perceived a significant improvement in the nasal appearance was subgroup A. This is consistent with the significant changes observed in the nasal region in the 2D and 3D records. Although a significant increase in the alar base width was observed in this subgroup, which has been considered as an untoward result by several authors[129,361], there was a significant improvement in the perception of nasal appearance.

Subgroup A was also the only subgroup, among the three subgroups, to perceive a significant improvement in the cheek area and this can may be due to the significant changes seen in the paranasal areas (assessed three-dimensionally) supplemented by the significant changes in the mandibular body and ramus due to the setback surgery (assessed two-dimensionally). Although subgroup C patients had also a bimaxillary procedure, it appeared that their perception of change was oriented towards other facial features (i.e. the retruded chin and the increased maxillary incisor exposure).

Self-perception of facial change. Five percent of the patients indicated the need for a maximum surgical change in the nasal region before surgery, whereas 18% noticed maximum change in this region at one month following surgery. The percentage fell to 5% at three months and six months following surgery. There was a level of agreement between the maximum changes sought before surgery and the maximum change achieved following surgery for the following regions: paranasal, lower cheek, lower lip and chin. The perception of a maximum change in a specific facial region increased in the postsurgical period (from one month to six months postoperatively) for some regions (e.g. lower lip region) and decreased for other regions (e.g. paranasal and chin regions).

Self-perception of facial profile. Orthognathic surgery had a significant impact on patients' perception of their profile, which is in agreement with the study of Kiyak and Zeitler[440] who used the same questionnaire. The presurgical assessment revealed that patients rated their profiles in the maxillary and mandibular subscales in a way similar to the actual underlying deformity. In other words, their perception of the problem was consistent with the cephalometric diagnosis of the deformity. Interestingly, they perceived significantly an additional backward movement in the lower jaw, which was also evident in the significant backward displacement of Pogonion and the further reduction in the mandibular length at six months postsurgery. This finding illustrates the sensitivity of this questionnaire to detect minor changes in patients' perception of their profile[440]. However, it is not known what information in the initial consultations may have conditioned each patient regarding the extent of the deformity and the perceived need for surgical correction.

5.3.2.3.4 Satisfaction

The satisfaction scores were high in the immediate (T2), intermediate (T3) and late (T4) assessment times. No significant increase or decrease in the satisfaction score was observed in the postsurgical follow-up period. These results support many other studies that reported a high percentage of satisfaction following orthognathic surgery [429,443,448] despite the dissimilarities in study designs, sample sizes, types of deformity and types of surgical interventions between them.

5.3.3 Subgroup B

5.3.3.1 Stereophotogrammetry-based findings

5.3.3.1.1 Soft-tissue behaviour

Soft-tissue changes in the short- and longer-term

The whole face. The slightly significant increase in the lower facial height assessed between Subnasale and soft-tissue Menton was also observed in the 2D (cephalometric) analysis with a significant increase between T1-T2. This change was no longer evident at six months postsurgery. There was a significant decrease in the facial profile and facial convexity angles, both of which became less obtuse. An insignificant slight opening of the nasolabial angle was also observed. The changes in the facial profile angle can be explained in the light of the underlying 3D soft-tissue displacements in the z-axis. Soft-tissue Pogonion moved significantly backward whereas pronasale moved significantly forward. The same can be said regarding the change observed with the facial convexity angle.

In the vertical direction and apart from the nasal tip and the subnasal points, all the remaining eleven soft-tissue landmarks showed a downward movement between T1 and T4 to varying degrees. The most variability of soft-tissue behaviour was evident in the 'ils' and 'pog' points. Although these two points displaced inferiorly on average, the relatively big variance could be attributed to the simultaneous genioplasty in several subjects and the simultaneous maxillary inferior repositioning in other subjects.

The nose. The increase in the alar base width was a significant finding in this subgroup, which agrees with the previous clinical and 2D findings[360-362] and stands alone as a 3D-based finding. This was supported by the significant divergence seen between the alar base points (acL and acR) in the x-axis.

The significant reduction in the columellar length is probably related to the upward movement of the nasal tip in addition to the differential forward movement between Subnasale and Pronasale (with more forward movement of Subnasale).

The upper lip. Based on landmark displacements analysis, the significant lengthening of the upper lip can also be explained by the opposite directional movement seen at Subnasale (mean= 0.41 mm upward) and Stomion superius (mean= 0.37 mm downward). The forward displacements of nasal and upper labial landmarks are consistent with the underlying skeletal change. These results also agree with the 3D changes observed in other studies[112,114].

The lower lip. The posterior movements observed in the lower lip regions can be explained by the soft-tissue adaptation to the new skeletal relationship to obtain a better oral seal.

The labiomental fold and the chin. Although no mandibular setback procedure was performed in this subgroup, there was a posterior movement of 'ils' and soft-tissue Pogonion, which can be attributed to two factors: the presence of five subjects treated by vertical reduction and setback genioplasty which perhaps caused a backward retraction of the mental soft tissues; and the small rotational effect of the maxillary inferior repositioning (performed in five patients) on the mandibular soft-tissue landmarks.

Relapse

Changes between 3 months and six months were insignificant indicating relatively stable soft tissues in this observational period, whereas a significant relapse was reported by McCance et al[112] in the maxillary-related soft tissues.

Comparison with 3D normative data

It was not possible to compare the mean 'total facial height' in the current study with the corresponding value in Ferrario's 3D normative data[137], due to the differences in the landmarks used for this measurement. The upper facial height, however, was measured similarly in both studies (i.e. between 'na' and 'sn') and showed that subgroup B had a lower mean value than the normative data. The relative shortness of the upper facial height did not change significantly at six months following surgery.

Comparing the achieved angular measurements at six months following surgery with the 3D-based angular norms(137) reveals that the mean facial profile and mean facial convexity angles were within one standard deviation of the average values(137).

5.3.3.1.2 3D asymmetry

There was no significant improvement in facial asymmetry with surgery. Eleven out of the 12 included subjects did not have a clinically obvious facial asymmetry at T1. However, the deterioration in the rank of the nasal tip landmark at T4 might reflect a worsening in the spatial position of this point following surgery. This might indicate that proper manipulation and examination of nasal soft tissues is required intra-operatively when a maxillary advancement procedure is carried out with Le Fort I osteotomy.

5.3.3.2 Cephalometric findings

5.3.3.2.1 Skeletal changes

Skeletal surgical change

The correction of the deformity was carried out by a mean of 3 mm maxillary advancement and a mean of 1.73 mm inferior repositioning (measured at 'A' point). Consequently, there was a significant increase in the maxillary length. The mandible showed a significant backward movement and an insignificant downward movement measured at B point indicating a slight backward rotation of the mandible. The chin-related landmarks showed also a significant backward movement, which can be explained by the concomitant genioplasty performed in five patients.

It was somewhat surprising that each of the patients in this subgroup had a maxillary osteotomy only although cephalometric measurements indicated deformities in both jaws. Several authors have stressed that the diagnosis of any dentofacial deformity should not be made solely on cephalometric findings(495) and the treatment planning decisions should not be designed necessarily to bring these cephalometric measurements in line with normal values. The soft-tissue profile is the key factor in achieving the optimum results(96,495,501). The improvement in the ANB angle was evident as a result of the maxillary correction, but the mandible remained prognathic and the anteroposterior skeletal relationship remained outwith the normal range.

Skeletal stability

The relapse in point A was about 0.5 mm in the opposite direction of the surgical change (≈14%) and it was insignificant reflecting general anteroposterior stability. A slightly greater, but insignificant, relapse occurred at several mandibular landmarks which displaced anteriorly to varying extents.

These results support several previous studies that assessed stability of maxillary advancement in the short-term (six to nine months)[236,243] and compares favourably with the longer-term studies (one year or more)[248,249,366,502].

Vertically, an almost one millimetre change was observed at 'ANS' which offset the initial inferior movement. There was no net change at six months following surgery. Mandibular vertical relapse was confirmed by the significant upward movement of some of the mandibular landmarks (i.e. Incision inferius and Genion). The combined horizontal and vertical displacements of mandibular landmarks indicated a slight anterior rotation of the mandibular apical base. However, this was not confirmed by the cranial base-mandibular plane angle.

5.3.3.2.2 Soft-tissue changes

The direction of soft-tissue displacements assessed two-dimensionally was very consistent with the direction of these displacements assessed three-dimensionally in the overall assessment. Pronasale and Subnasale moved forward and upward significantly. Generally, the upper labial landmarks showed significant forward and insignificant downward movements, whereas the lower labial and mental landmarks showed insignificant backward and downward movements.

Interlandmark linear changes in the soft tissues supported the 3D linear changes, such as the significant increase in the upper lip height, the significant increase in the lower facial height and the significant decrease in the columellar length. However, these changes lost their significance in the overall assessment (between T1-T3). With regard to the overall angular soft-tissue changes, the significant decrease observed in the facial profile angle was consistent with the significant decrease observed in 3D.

5.3.3.2.3 Soft-tissue to hard-tissue relationships

The number of significant displacement ratios found in this subgroup was less than those observed in subgroup 'A'. Even in the vertical dimension (Y axis), three out of twenty-two calculated ratios were statistically significant. This can be attributed, probably, to the small sample size of the current subgroup as well as the presence of several simultaneous maxillary inferior repositioning procedures with the main maxillary advancement osteotomy. Such simultaneous procedures comprised 41% in subgroup B, whereas they comprised 25% only in subgroup A. The few significant displacement ratios found vertically confirm the lack of correlation in this dimension reported by several authors[330,333].

The ratio of 0.88:1 seen between 'sn' and 'ANS' is higher that what was observed by Freihofer[344], Mansour et al[333], Rosen et al [345]and Hack et al[369]. The ratio obtained between 'sls' and 'A' point (1:1) was also higher than the one reported by Carlotti et al[366]. However, this ratio dropped to 0.67:1 between 'ls' and 'Pr' resembling several of the previously reported ratios[333,368]. Although no surgery has been performed to setback the mandible, the setback and vertical reduction genioplasty might explain the one-to-one displacement ratio observed horizontally between soft- and hard-tissue Pogonion.

5.3.3.3 Psychosocial findings

5.3.3.3.1 Motivational pattern

The most mentioned motives in this subgroup were: improvement in facial profile and improvement in self-esteem (91.67% for each motive). This was followed by the desire to improve the interocclusal relationship (83.4%), mastication (75%) as well as dental appearance (75%). No subject indicated the desire to prevent periodontal disease or to resolve breathing problems. This seems reasonable since the presurgical cephalometric data revealed a prognathic mandible (i.e. no expected narrowing of the nasopharynx) and a shallow overbite (i.e. no traumatic deep overbite that might threaten the periodontal status).

5.3.3.3.2 Personality characteristics

A significant impact of orthognathic surgery was observed in this subgroup regarding self-esteem, anxiety and depression scores. This was similar to the findings in subgroup A and consistent with the conclusions of Laufer et al(407), Flanary et al(427) and Finlay et al(413).

Patients in this subgroup had more internal health locus of control than the other two dimensions of the scale (the MHLC scale). They showed high scores in the neuroticism and extroversion subscales and a low score in the psychoticism subscale. These finding were very similar to those of subgroup A.

5.3.3.3.3 Perception of facial appearance and facial change

Facial body image. It was interesting to see that the overall FBI score, at T1, was the highest in this subgroup among the three subgroups evaluated. This observation is in line with the decision to correct the deformity with a less invasive procedure by a maxillary advancement only. One would assume that the magnitude of change in facial body image following a one-jaw surgical procedure would not be similar to the change following a bimaxillary procedure (e.g. subgroup A). The results related to subgroup B does not support this assumption completely. Although subgroups A and B had an increase in the overall facial body image between T1 and T2, the significance of this change was very strong in subgroup A and weak in subgroup B. Patients in subgroup B, however, had a significant improvement in the perception of the appearance of their upper lip, lower lip, teeth, chin, profile and upper part of the neck at six months following surgery. Although the maxillary deficiency was corrected similarly in both subgroups, patients in subgroup B did not have the presurgical negative feelings towards the appearance of their nose, which existed in subgroup A. Consequently, no significant change was observed in subgroup B regarding the perception of their nasal appearance.

Perception of facial change. Subgroup B indicated a higher need for a maximum change in the upper lip region compared to subgroups A and C. This can be explained by most of these patients being aware of the planned surgical intervention and, probably, informed about the expected facial outcome. This is why some researchers stressed that questionnaires related to perception of facial appearance should be administered before any clinical consultations with the patient or, at least, before deciding on the final treatment plan(440).

Perception of facial profile. Before surgery, the amount of deviation of the perceived facial profile from the ideal facial profile was greatest in subgroup A and least in subgroup B when maxillary and mandibular subscales were analysed. Following surgery, patients perceived an improvement in their facial profiles; however, they indicated the perception of change on both the maxillary and the mandibular subscales. Furthermore, the significant improvement (between T1-T2) was shown in the mandibular subscale and not in the maxillary subscale. Such an improper use of the subscales to express the perceived new profile has been documented before by Bell et al[410], Kiyak and Zeitler[440] and Maxwell and Kiyak[441].

5.3.3.3.4 Satisfaction

When compared to subgroups A and C, patients in subgroup B showed higher scores in the first and second subscales of the satisfaction questionnaire at all postsurgical assessment times (T2, T3 and T4). Although this can be attributed to less complications and less hospitalisation time, which are usually characteristic of maxillary one-jaw procedures, the differences between the subgroups were statistically insignificant.

The high satisfaction scores achieved following surgery despite the incomplete correction of the deformity and the persistence of the skeletal Class III relationship (assessed cephalometrically) illustrates that postsurgical satisfaction with the surgical result does not necessitate the correction of cephalometric measurements to the optimum values. It also confirms previous reports of the importance of dealing with patients' complaints and their aesthetic needs rather than focusing on the underlying bony measurements[440].

5.3.4 Subgroup C

Based on the presurgical clinical examination, the 12 subjects included in this subgroup were diagnosed as having vertical maxillary excess, no maxillary anteroposterior problem, mandibular retrognathism and two-thirds of the subjects showed clinical features of a backward rotation of the mandible. Two subjects had clinically obvious mandibular asymmetry.

5.3.4.1 Stereophotogrammetry-based findings

5.3.4.1.1 Soft-tissue behaviour

Soft-tissue change in the short and longer-term

The whole face. The maxillary impaction did not cause a significant reduction in the soft-tissue upper anterior facial height (measured between 'na' and 'sn), whereas a significant reduction in the skeletal upper anterior facial height was observed. The effect of this maxillary impaction on the integumental profile, however, was evident in the significant reduction in the total anterior facial height as well as in the lower anterior facial height. These changes can be attributed to the anti-clockwise autorotation of the mandible following maxillary impaction. The highly significant changes in the lower facial depth measured on both sides (as 'mandibular length') reflect the significant advancement of the mandibular apical base observed two-dimensionally.

The achievement of better facial harmony was evident in the significant increase in the facial profile and the facial convexity angles accompanied by a significant increase in the labiomental angle at six months following surgery. The change in the first two angles can be attributed to the significant forward displacement of soft-tissue Pogonion rather than the displacement in Pronasale or Subnasale, respectively.

A pattern of progressive soft-tissue advancement from the nasal tip to the mental points was observed at one month following surgery. This is because of the performed bimaxillary advancement as well as the advancement genioplasty (carried out in nine subjects). However, it should be taken into account that the magnitude of these displacements was, for several landmarks, higher than the actual bony movements and this can be attributed to the residual swelling seen at that assessment time. The backward movements of these landmarks in the postsurgical periods were insignificant indicating, generally, soft-tissue stability.

The nose. The increase in alar base width, which was one of the findings in subgroups A and B, was also observed here. This observation was supported by the significant displacements of the alar base landmarks laterally in the x-axis.

The mouth. From the 3D displacement results related to the upper lip and lower lip, the best oral seal was, perhaps, achieved at T3 (three months following surgery). Three subjects, who showed a complete oral seal (with the lips at rest) at three months postsurgery, had a slight increased interlabial gap at six months postsurgery. This was in line with the subjective opinion when the 3D facial models captured at T3 and T4 were examined visually.

The lower lip. One of the interesting observations was the gradual elevation of Stomion inferius and Labrale inferius between assessment times, with a significant upward movement for both landmarks in the overall comparison (i.e. between T1 and T4). This indicates that the lip curl, which was one of the characteristics of this subgroup pre-operatively, was minimised or eliminated (Figure 5.9).

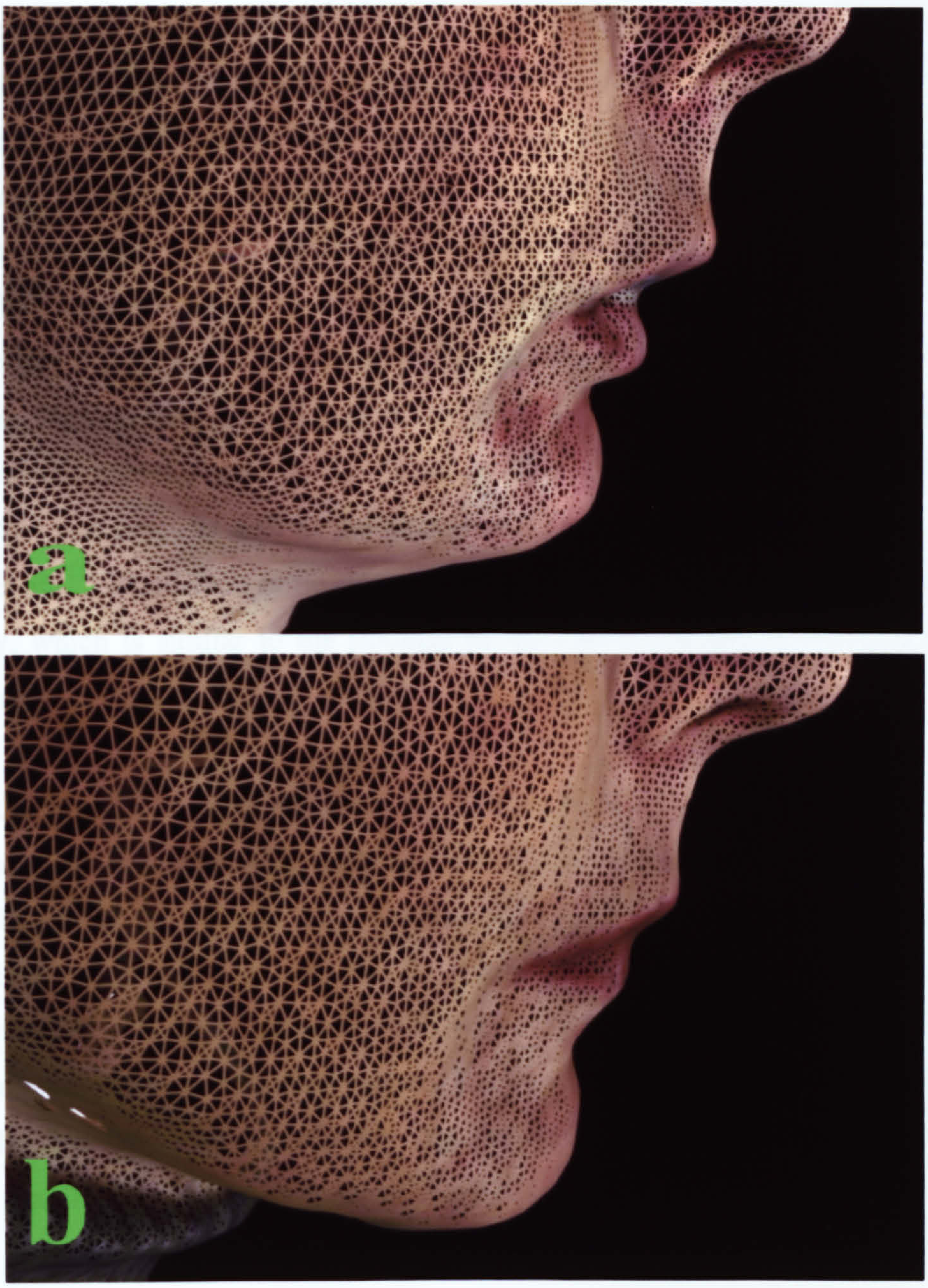


Figure 5.9 An example of a skeletal Class II patient pre- and post-operatively. (a) The lip curl and lip incompetence were observed in the pre-operative 3D model. (b) The lower lip was uprighted and the oral seal was achieved at three months postoperatively.

The labiomental fold and the chin. Labiomental angle became more obtuse indicating an improvement in the balance between the lower lip and the chin button and a more upright position of the lower lip. This was confirmed by the significant superior movement of Labrale inferius between T1 and T4. A relatively large variance was seen in the chin region, which prevents any conclusions regarding the vertical displacements of mental landmarks.

Comparison with other studies

Increase in alar base width and the superior movement of the nasal tip are consistent with many clinical observations of the effect of maxillary impaction on nasal structures[361]. Moss et al[113], in a study of the 3D soft-tissue changes following orthognathic surgery, found approximately 3-mm advancement in the upper lip region and a 5-mm general advancement in the chin region. Although the same direction of movements was found in the current study, the magnitude of change in the lower lip and chin regions was greater than theirs. This might be related to the greater bony advancement accomplished by the BSSO in 10 cases and the inverted L-osteotomies in another two cases as well as the advancement genioplasty. With regard to relapse, Moss et al[113] found little or no relapse between three months and one year following surgery, which is similar to the findings of the current subgroup but with a shorter observation period.

Since this group consisted, unexpectedly, of female patients only, the comparison with Ferrario's 3D norms is made with the female-related values[137]. The upper anterior facial height in the current subgroup was within their normal range pre- and post-operatively. This might indicate that the diagnosis of vertical maxillary excess or the assessment of soft-tissue outcome following maxillary impaction should not rely on this particular soft-tissue measurement. There are several clinical and cephalometric variables that can be used, preferably together, to detect increased vertical proportions of the maxilla such as the amount of maxillary incisor show, skeletal anterior facial height and millimetric distances from the incisal edges and molar cusps to the palatal plane.

The achieved facial profile, facial convexity and labiomental angles at six months following surgery fell within the 3D normal range[137]. The nasolabial angle showed an insignificant reduction from a mean of 132.14° at T1 to 130.31° at T4. This confirms the appropriateness of the selected surgical approach in the treatment of this subgroup, which led to better facial harmony (assessed in 3D).

5.3.4.1.2 3D asymmetry

The general facial asymmetry score did not reveal any significant change following surgery. This was expected since there was no patient with severe facial asymmetry in this group and there were only two subjects with an asymmetric face. However, exploring individual landmark asymmetry scores indicated that some landmarks became slightly asymmetric such as 'prn', 'men' and 'pog' at six months following surgery. The reason for this is not entirely clear, but it might clarify that care should be taken when impacting the maxilla in order to avoid nasal septum deviations, which might affect adversely the related soft tissues. The same caution should be made when performing large mandibular advancements in which the position of the chin point in relation to the midsagittal plane should be checked.

5.3.4.2 Cephalometric findings

5.3.4.2.1 Skeletal change

Skeletal surgical change

A mean maxillary impaction of 3.9 mm and a mean advancement of 3.22 mm accompanied by a mean mandibular advancement of 10.87mm were the components of the deformity correction in this subgroup. The impaction of about 4 mm did not produce a similar magnitude of vertical displacement of mandibular anterior landmarks because the anti-clockwise autorotation of the mandible (due to the maxillary impaction) was partly counteracted with a forward and downward movement of the mandibular body. However, the skeletal total anterior facial height decreased significantly which was in line with the corresponding 3D soft-tissue measurement. The upper facial height, however, decreased significantly. This result was not evident in the corresponding 3D soft-tissue measurement. The variation in the vertical skeletal hard-tissue displacements in the chin region was relatively large. Consequently, no significant change was detected vertically.

The occlusion improved significantly indicated by the significant correction of the overjet, while the deep overbite was reduced. The advancement of the maxillary bone might be justified when looking at the presurgical value of SNA which indicated a slightly retrognathic maxilla. The quite large skeletal Class II discrepancy, measured by the ANB angle, explained the large amount of mandibular advancement performed in this subgroup. Two-thirds of the study group were clinically diagnosed as having a backward mandibular rotation. The steep cranial base-mandibular plane angle confirmed this clinical impression. However, following surgery, angular measurements showed a marked correction of the dentofacial deformity.

Skeletal stability

Horizontally, the advanced maxilla did not relapse while the advanced mandible relapsed significantly. Vertically, no significant change was detected in both maxillary and mandibular anterior bony landmarks. The maxillary stability following advancement is consistent with the findings of several studies[228,236,243]. The percentage of mandibular horizontal relapse when measured at B point was 26% which was similar to the findings of several reports that assessed mandibular stability following surgical advancement by BSSO[321,325,328]. It is worth mentioning, however, that the endpoint of the assessment of skeletal stability in this study was six months, whereas many studies followed their patients for longer periods[323,328].

With regard to the performed advancement genioplasty, bony Pogonion relapsed a mean of 3.54 mm in the backward direction, while 'B' point (presumably not affected by genioplasty or postsurgical remodelling) had a mean backward relapse of 2.83 mm. The difference between these values might indicate the amount of genioplasty relapse (≈0.7 mm), which represented approximately 16% of the initial surgical movement. This figure is very similar to the percentage of relapse (17%) reported by Polido and Bell[282], but it should be noted that large advancements had been included in their study with a longer observation period.

The significant reduction in the posterior facial height and the ramus height may be attributed to the remodelling at the gonial angle, which resulted in a significant superior movement of Gonion between T2 and T3. In addition, postsurgical changes in the condyle-fossa relationship might have contributed to vertical relapse.

Mandibular anteroposterior relapse was detected in several ways: the significant backward movement of 'B' point and Genion, the significant reduction in mandibular length and facial axis length and the significant decrease in 'SNB' and 'SNPog' angles. Although significant changes were observed in the overall assessment, the mean 'ANB' angle reflected a skeletal Class II relationship at six months following surgery.

5.3.4.2.2 Soft-tissue change

Progressive anterior displacements of soft-tissue landmarks observed in 3D were also found in 2D. Vertically, the lower labial points showed a significant upward movement and this also agrees with the previously observed pattern in the 3D data.

The overall soft-tissue linear and angular changes complimented the findings drawn from the 3D data. The lower labial height increased significantly while the interlabial gap decreased significantly confirming the previous picture of a better lip competence following surgery. The severe presurgical facial convexity was lessened as depicted from the significant increase in the facial profile angle. This was also observed in the 3D-based data.

5.3.4.2.3 Soft-tissue to hard-tissue relationships

2D soft-tissue thicknesses

Thinning of soft tissues at Labrale inferius level was observed and can be attributed to the more upright position of the lower lip. The thinning in soft-tissue Pogonion did not reach significance, but the measurement at the Menton level (performed vertically) showed a significant reduction in soft-tissue thickness. This might indicate that large mandibular advancement should be avoided in patients with presurgical thin mental soft tissues. Alternatively, an adjunctive procedure might be required to augment the affected soft tissues and to avoid the possible untoward aesthetic result.

2D soft-tissue to hard-tissue displacement ratios

A pattern of increased soft-tissue to hard-tissue displacement ratios when moving from the nasal tip (prn) to the upper lip (represented by Labrale superius) was found in the x-axis. However the ratio dropped down to a median of 0.76:1 when Stomion superius (soft tissue landmark) and Incision superius (hard tissue landmark) were considered. In the mandible, the horizontal ratio at the level of labiomental fold was generally one-to-one. However at the level of soft-tissue Pogonion, the ratio dropped to a median of 0.87:1 and this explains the thinning observed at this level, although it was not significant. Linking the movement of soft-tissue Pogonion with Genion or 'B' point was of little benefit as Genion and 'B' point moved in response to one surgical procedure, but hard-tissue Pogonion had double advancements.

Similar to findings in subgroups A and B, the significant median ratios in the vertical dimension were few (six out of the 22 calculated ratios). Soft tissues tended to move one third of the vertical movement of the underlying bony landmarks in the upper jaw, whereas they tended to move greatly more than the underlying bony movements in the lower jaw. When a functional adaptation occurs, i.e. establishment of an oral seal and lip competence, the lower lip vertical ratios would convey misleading information and this was the situation with the obtained median vertical ratios of about 1.8:1. Here, the superior movement of the lower lip exceeded the vertical change seen at B point or Genion. With regard to Pogonion, the reason might be based on the change in soft-tissue chin morphology with the consequent superior location of soft-tissue Pogonion according to its definition (i.e. the most prominent point on the chin contour). Bony Pogonion might not have migrated vertically to the same extent even with the presence of superficial remodelling.

5.3.4.3 Psychosocial findings

5.3.4.3.1 Motivational pattern

The desire to improve facial and dental appearance as well as to improve self-esteem was indicated by 100% of the subjects in this subgroup. These aesthetic motives are consistent with the clinical and morphometric (3D and 2D) findings of very convex profiles with retruded chins, excessive incisor show and lip incompetence. Compared with subgroups A and B, higher proportion of patients mentioned the prevention of periodontal disease and future tooth loss as moderate to strong motives, but these differences in proportions were insignificant. One of the explanations for this observation, though insignificant, is that several subjects had initially deep overbite. They may have had the perception that surgical correction would provide better dental and occlusal relationships with less likelihood of periodontal disease and tooth loss in the future.

5.3.4.3.2 Personality characteristics

Significant improvement in self-esteem and reduction in anxiety and depression scores were observed. These improvements were similar to the findings in subgroups A and B. It seems reasonable to say that the impact of orthognathic surgery on patients' self-esteem, anxiety and depression scores was not affected by the type of surgical intervention performed in these three subgroups.

5.3.4.3.3 Perception of facial appearance and facial change

Facial body image. The significant maxillary impaction and the significant reduction in incisor display as a result of surgery might account for the significant improvement in the teeth-related FBI score at one month following surgery, whereas subgroups A and B did not perceive a significant improvement in this subscale at that time. The three subgroups, however, perceived significant changes in the longer-term assessment.

Lip competence and the final labial shape were not achieved immediately after surgery (confirmed by the morphometric data). This might explain the absence of significant improvement in the perception of the upper and lower labial appearance at T2 but the related scores increased at T3 with an overall significant improvement perceived at T4.

Perception of facial change. The nose-related FBI score had an insignificant increase in the overall assessment (between T1-T4). A similar finding was observed in the drawing-based questionnaires, where all patients perceived little or no change in the nasal region at the final assessment. It should be noted, however, that the question about the facial change in a particular facial region was not equivalent to the question about the perceived improvement in that region. In other words, the change could be desirable or undesirable. This caused confusion to some patients, who noticed worsening in some facial regions (e.g. increase in alar base width after Le Fort I osteotomy or the double-chin appearance following setback genioplasty) and they were uncertain if this could be considered a change. Therefore, the results of this questionnaire cannot be compared directly with those from the other two questionnaires. If this confusion had emerged in the pilot study, the word 'improvement' would have replaced 'change' in the questionnaire.

Perception of facial profile. The perception of a slight maxillary prognathism (despite the underlying slight retrognathism) on the maxillary subscale confirms the previous finding by Kiyak and Zeitler[440] who noticed the tendency of patients to characterise mandibular deformities as maxillary deformities in the opposite direction. It is noteworthy that the mandibular and maxillary scores in this subgroup did not reach the ideal figure (score 5), whereas in subgroup A the corresponding values approached the ideal figure to a greater extent. In other words, patients in the current subgroup were aware that their achieved facial profile was not optimal at six months following surgery. This compares favourably with the cephalometric results that indicated a residual skeletal Class II relationship at the final follow-up.

5.3.4.3.4 Satisfaction

When reviewing the type of surgical interventions applied to the three subgroups, subgroup C had the maximum number of simultaneous multiple osteotomies with additional bone harvesting from the hip for grafting purposes. On the other hand, 95% of the patients of subgroup A, who were also treated by a bimaxillary approach, had vertical subsigmoid osteotomies for mandibular setbacks. It is well established that the VSSO procedures (performed predominantly in subgroup A) have less complications than the BSSO procedures (performed predominantly in subgroup C) in the correction of mandibular deformities[(269)]. For these reasons, it is not surprising to find that subgroup C, among the three subgroups, had the lowest score at one month postoperatively and the highest score at six months postoperatively in terms of satisfaction with healing and recovery.

5.4 Class II and III patients

5.4.1 3D assessment of facial asymmetry

The insignificant differences between Class II and Class III subjects in the presurgical facial asymmetry scores might indicate that facial asymmetry was not specific to any anteroposterior discrepancy in the current sample. The slightly higher presurgical median scores in the Class III group can be explained by the higher proportion of Class III subjects with facial asymmetry compared to Class II subjects (33.3% versus 16.7%, respectively). Despite the inclusion of asymmetric and apparently symmetric faces, the analysis showed a significant improvement in symmetry for Class III subjects either in the short-term (T1-T2) or in the longer-term (T1-T4).

Kobayashi et al[146] attempted to evaluate the amount of facial asymmetry in 28 Class III orthognathic patients using the 'directional index of asymmetry'. The index was calculated simply by subtracting the soft-tissue volume of the right mandibular section from the soft-tissue volume of the left mandibular section, and then dividing this difference by the volume of the whole mandibular section. The application of this method to their study group demonstrated a reduction in this index following surgery. The analysis, however, was based on the assumption that a midfacial symmetry plane would split the face into two equal sections, which is not the assumption in the current analysis.

Before trying to employ the new 3D-based facial asymmetry analysis in the clinical practice, it might be reasonable to evaluate the level of compatibility between its scores and the professional clinical diagnosis. On the other hand, it might be useful to determine whether an agreement exists between this 3D analysis of asymmetry and patients' perception of facial asymmetry in future research work.

5.4.2 Psychosocial characteristics

Several studies evaluated the psychosocial characteristics of orthognathic patients regardless of their initial facial deformity[413,431]. However, the assumption of no differences between the different types of deformities in their psychological profiles was not supported in the current study. Several significant differences emerged between Class II and Class III subjects, which is in agreement with the findings of a recent study by Gerzanic et al[478].

Presurgical orthodontic treatment has been shown to have minimal effect on the psychological characteristics of patients undergoing orthognathic surgery[439]. Cunningham et al[439], using a multivariate multiple regression analysis on sixty-two patients, found that the use of presurgical psychosocial measurements as the baseline for prospective studies was reasonable and justifiable. In the light of these findings, the presence or absence of orthodontic fixed appliances at T1 (the baseline assessment) was considered of little importance in the measurement of psychometric changes.

5.4.2.1 Motivation

5.4.2.1.1 General overview

Improving self-image and facial appearance was the highest motivation in the current study which is consistent with several previous reports(407,415,420) and contradicts the findings of Frost and Peterson(419) and Forssell et al(421) in which functional reasons were mentioned more. The impact of patients' previous discussions with the treating staff or other health care workers is not known and future studies should be designed so that patient motivation is assessed at the first clinical appointment(420).

Among the explanations for the diversity in the results concerning motivational patterns in the orthognathic literature are the questionnaire design, the method of presentation and the statistical methods employed. When a 4-point scale was used, 87% of the seventy patients indicated the improvement in facial profile as a 'strong' motive. The percentage increased to 95.45% when the scale was modified in which the 'moderate' and 'strong' motives were combined together. Another example can be seen in the 'improvement of dental appearance', which was considered a 'strong' motive by 67% of the patients, and this percentage rose to 88% in the combined scale. Jacobson(409) requested his patients to give 'the most single important reason to undergo surgery', whereas patients were allowed to give multiple reasons for their decision to undergo surgery in other studies(408,420,421). Phillips et al(420) applied a principal factor analysis on a lengthy 24-item list and obtained six factors (or six dimensions) of motives. Then, the median value of each dimension was presented. Forssell et al(421) presented their results in terms of percentages of patients who indicated the highest score for each motive, and this, clearly, gave relatively less percentages for each motive and overlooked patients who mentioned the same motives but with less strength.

5.4.2.1.2 Class II versus Class III

Few studies have looked at the motivation for surgery in one specific facial deformity, but all are retrospective(407,423,424). No prospective study, to date, tried to differentiate between Class II and Class III patients in their motives for orthognathic surgery.

Class II patients were more concerned about the periodontal health and the prevention of future tooth loss. Subgroup C (a subdivision of the Class II group) showed the same trend. The deep overbite in twenty out of the 24 subjects might explain these concerns. The excessive incisal show, increased overjet and the protrusion of the upper teeth accounted for the higher proportion of Class II subjects who indicated an improvement in dental appearance as a motive for treatment compared to Class III subjects. On the other hand, the difference observed in the motivation to improve speaking abilities, although insignificant, can be attributed to the known misarticulation of several consonants in Class III orthognathic patients[3,503,504].

5.4.2.1.3 Females versus males

Females were significantly more concerned about improving self-esteem than males which confirms the findings of Kiyak et al[408] but contradicts those of Phillips et al[420]. The insignificantly greater concerns about preventing pain and damage to the TMJ reported by females in the current study was also found in Kiyak's study[408], and the difference was statistically significant in Phillips' study[420]. Males were more concerned about speaking abilities than females, but the difference was insignificant. Such an insignificant difference was also recorded by other workers[420].

5.4.2.1.4 Younger versus older

Older subjects compared to younger were more concerned about breathing and sinus problem, improving work and social performance and preventing TMJ disease. These differences, however, were insignificant. Phillips et al[420] found three significant differences between older and younger subjects in oral function (e.g. fit of upper and lower teeth), future health (e.g. tooth loss and periodontal disease) and TMJ dimensions. Consequently, the only age-related difference observed in both studies is related to the TMJ concerns.

5.4.2.2 Personality characteristics

5.4.2.2.1 Self-esteem

The presurgical values of self-esteem were within the normal range in the whole study group, but significant improvement occurred following surgery. A previous study by Finlay et al[413] conducted 10 years ago on orthognathic patients treated at same centre of the current study showed that the presurgical average score of self-esteem was slightly lower than the normative data. The Rosenberg Self Esteem questionnaire, however, was not used in that study. Kiyak et al[431] and Cunningham et al[429] found no significant improvement in self-esteem score between the first and the last assessment times.

When females were compared with males, it was interesting to see that self-esteem was always significantly lower in females at the four assessment times. Presurgically, the female score was in the upper limits of the normal range and it improved gradually until six months following surgery. The gradual change in self-esteem seen in the female subjects is in agreement with the findings of Kiyak et al[408]. However the sex difference in self-esteem contradicts their findings of similar mean values for both sexes.

5.4.2.2.2 Anxiety and depression

Anxiety scores were higher than depression scores at each assessment time in the Class II and Class III subjects. The same trend was observed in subgroups A, B and C. Although the HADS questionnaire does not allow distinction between state and trait anxiety types, patients would normally have increased levels of anxiety when they are faced with the prospect of an invasive procedure, its possible complications, a new facial appearance and its impact on social relationships.

There was a significant drop in the levels of anxiety measured at one month, which continued to decrease till six months following surgery. The gradual change in such scores was documented in several other studies[408,430]. The overall difference between the first and the last assessment time was not significant in one previous study[429], which applied the same questionnaire (HADS). The cross-sectional design of that study may not have helped in the detection of small differences between the two groups which were compared although data on a relatively large sample were analysed.

The significant differences observed in the depression subscale do not hold any clinical importance, since all the average scores were below 4 points in this subscale (which ranged from 0 to 21). By convention, scores that exceed 8-10 are regarded as being of clinical significance. The relative absence of depression at one month following surgery contradicts the findings of Kiyak et al[444] as well as the observations of Stewart and Saxton[445] who reported a transient period of depression for three weeks following surgery or for three weeks before fixation removal. There might be two explanations for not recording such depression in the current study. Either the transient depression was missed because of the administration of the first postoperative questionnaire at one month following surgery or because of the use of rigid internal fixation and the reduction in IMF duration, if required. Cunningham et al[2] mentioned that if patients were forewarned of a possible transient depression, the impact of this response might be reduced. The current psychosocial assessment, however, did not include details about the type and the amount of information that had been given before surgery to the patients recruited in this study.

The significantly higher scores of anxiety in females compared with males is consistent with the findings of Kiyak et al[408] and Flanary et al[427], although the differences were not significant in the latter study. It was surprising that the sex difference persisted in the one-month assessment. This can be attributed to slightly increased tension following surgery because of the new facial appearance and the new psychosocial adaptations with the surrounding environment[446].

5.4.2.2.3 MHLC and EPQ questionnaires

A significant difference emerged between Class II and Class III patients in the MHLC questionnaire, with the Class II patients having significantly more belief in 'chance' as a locus of control for their health. Also they had more belief in the effect of 'powerful others' (such as doctors or nurses) in the process of healing and recovery following surgery. These characteristics have not been documented before in the orthognathic literature. With the EPQ-R Short Scale, Class III subjects scored higher in the extroversion-introversion subscale and in the psychoticism subscale than Class II subjects. It seems logical that an extrovert person with less fear of social activities would be self-confident and self-dependent in reaction to different experiences and the locus of control of reinforcement in such a person is expected to be 'internal' more than 'external'. This might explain the significant differences observed between Class III and Class II subjects. This also supports the previous finding of a high motivation in the Class III group to improve speaking abilities. Gerzanic et al[478], however, found that Class II subjects had a significantly higher score in the 'attractiveness/self-confidence' scale before surgery, a finding which does not support our assumption.

5.4.2.3 Perception of facial appearance and facial change

5.4.2.3.1 Facial body image

General overview. When examining the combined group (of seventy subjects), no significant improvement in appearance was noticed over time in the areas outside the surgical sites (i.e. hair, forehead, eyes and ears). However, there was a tendency for the related FBI scores to rise following surgery, which reflects the general feelings of satisfaction with the new facial appearance. The other items in the facial body image questionnaire had significant improvements in the overall assessment. Several studies have also reported similar findings[(403,412,443)].

When percentages of subjects indicating positive, neutral and negative feelings were evaluated, orthognathic surgery had a positive impact on facial body image for several items with 70% of the subjects indicating an overall satisfaction with their facial appearance at six months following surgery. This percentage is lower than that documented by Cheng et al[(448)] who used a different design of questionnaire and assessed the overall satisfaction with appearance retrospectively.

Class II versus Class III. Presurgically, negative feelings towards the teeth were higher in Class II subjects than Class III subjects. The same finding was observed in subgroup C compared to the other two subgroups A and B (subdivisions of the Class III group). Although Class III patients had more negative feelings than Class II patients towards some facial elements in the final assessment, this did not appear to have an effect on the overall satisfaction with surgery.

5.4.2.3.2 Perception of facial change

Presurgery, Class III patients when compared to Class II patients were more willing to have large changes in the upper lip region. This is in line with the clinical findings in each group. Following surgery, more Class III subjects noticed considerable changes in the upper cheek regions than Class II subjects. The 3D morphometric evaluations, however, were not extended to the upper cheek regions and, consequently, no comparison could be made between patients' perception of change and the actual surgical changes in these regions. The perception in the full-face drawing questionnaire had 'good' to 'excellent' agreement with the perception in the lateral view-drawing questionnaire in the pre- and post-surgical assessment forms in Class II and Class III groups.

5.4.2.3.3 Perception of facial profile

The Class II subjects perceived the upper jaw in a forward position, although the clinical examination revealed it to be normally positioned. This might be explained by the improper use of the scale as well as patients' attempts to find a similar facial profile without paying attention to the origin of the problem. Such responses were documented by Kiyak and Zeitler[(440)]. Significant improvement was evident in the maxillary, mandibular and dentoalveolar subscales.

In the Class III group, the average perception of the maxillary and mandibular positions was similar to the clinical diagnosis. Kiyak and Zeitler[(440)] concluded that the use of such questionnaires in the assessment of patients perceptions was better than the use of the modified version of Secord and Jourard's Body Cathexis Scale (or what was termed in the current study as the 'Facial Body Image' questionnaire). No attempt, however, was made in the current study to compare objectively the closeness of patients' perceptions obtained by either method (i.e. the FBI and the SPFP questionnaires) to the 2D (or 3D) morphometric variables.

5.4.2.4 Satisfaction

The results of the current short-term study support those recorded at a mean time of 18 months following surgery by Ostler and Kiyak[(418)]. The highest scores in the areas of 'healing' and 'general satisfaction' conform to those recorded for 'satisfaction_3' and 'satisfaction_4' in the current study.

One of the interesting findings, not reported in the previous study[(418)], was the significant increase in 'satisfaction with healing and recovery' scores during the post-surgical observation period. It seems that patients' satisfaction was not 'saturated' at one month postsurgery due to the known complications in the early weeks of recovery (e.g. swelling, paraesthesia, chewing difficulties). However, with the passage of time, the satisfaction increased in both the Class II and Class III groups.

5.4.3 3D change versus perception of change

Class II and Class III groups were considered in this analysis because of their larger sample size compared to the smaller subgroups A, B and C. Increasing sample size improves the power of the statistical test, but in the current study, the addition of several patients meant increased heterogeneity regarding surgical interventions. In the Class III group, a relatively low standard deviation was observed in the upper labial comparisons and a relatively high standard deviation in the lower labial and mental comparisons. Those who perceived maximum change in the upper lip had more anterior displacements of upper labial landmarks, but this was not the case in the lower lip and chin regions due to different vectors of surgical movements.

For the Class II group, it should be born in mind that unequal numbers of subjects were created in each subset (depending on their perception: maximum change/little or no change). The power of the statistical tests was affected adversely by the lower numbers seen in some subsets, particularly in the lower lip and chin comparisons. Nevertheless, the results of this analysis may indicate that the perception of change in facial appearance is a complex concept in which several factors play a role. The magnitude of soft-tissue changes, the psychosocial interaction between the patient and environment, the comments and feedback received from family, friends or relatives are just some of these factors.

Chapter Six
Conclusions & Future Recommendations

6 Conclusions and recommendations

6.1 Conclusions

Conclusions drawn from the study, in relation to each aim, are given below:

6.1.1 First Aim

To test the reliability of the stereophotogrammetry-based 3D imaging system (C3D) and the applicability of landmark-based morphometric analyses in studying facial soft-tissue morphology and the change in morphology following orthognathic surgery.

Conclusions:

- The stereophotogrammetry-based 3D imaging system (C3D) is a reliable method for imaging adult orthognathic patients with high accuracy and reproducibility.
- More than twenty soft-tissue landmarks can be identified on 3D facial models with high reproducibility.
- The 3D landmark-based morphometric analysis is a useful method for studying soft-tissue changes following orthognathic surgery.
- The 3D landmark configurations can be analysed in terms of interlandmark distances and angles, 3D landmark displacements and can be used for calculating facial asymmetry scores.
- With the aid of a software-based facial analysis tool, volumetric differences in facial regions can be assessed with high accuracy in vitro and with acceptable accuracy in vivo.

Null Hypotheses (1-3):

- The C3D system is not reliable in capturing and producing 3D facial models.
- Landmark identification on 3D facial models is not reproducible.
- The assessment of volumetric changes of facial regions on C3D-produced 3D models is inaccurate.

On the basis of the results, these three null hypotheses are rejected.

6.1.2 Second Aim

To determine the effect of orthognathic surgery on the 3D soft-tissue morphology and to test the stability of the 3D soft-tissue morphology at three months and six months following surgery

Conclusions related to the three subgroups A, B and C:

- The bimaxillary correction in subgroups A and C and the one-jaw correction in subgroup B resulted in significantly better facial appearance and harmony.
- Changes assessed by linear and angular measurements, as well as landmark displacements, were significant for several variables following surgery.
- Soft-tissue relapse occurred between one month and three months but it was insignificant for the majority of the linear and angular measurements as well as for landmark displacements.
- The maximum displacements were observed in the z-axis, followed by the y-axis and the x-axis.
- Some of the displacements of landmarks between T1-T2 were affected by the facial swelling at some perioral regions, which was observed at one month following surgery.
- Facial asymmetry in subgroup 'A' reduced significantly in the overall assessment, whereas in subgroup B and C no change was detected.
- In subgroup 'A', significant forward volumetric differences were observed in the nasal and upper lip regions and significant backward volumetric differences were observed in the lower lip and chin regions.
- Facial soft-tissue changes in the overall assessment were consistent with the underlying skeletal changes.

Null Hypotheses (4-5):

- There are no statistically significant differences in soft-tissue morphology following orthognathic surgery.
- There are no statistically significant differences in soft-tissue morphology in the postsurgical period.

On the basis of the results: the fourth null hypothesis is rejected for most of the variables tested, while there is insufficient evidence to reject the fifth null hypothesis since most of the tested variables showed insignificant differences.

6.1.3 Third Aim

To assess skeletal changes following orthognathic surgery and the possible relapse up to six months postsurgery

Conclusions related to subgroups A, B and C:

- In subgroup A, horizontal relapse was small but significant in the maxilla, while it was insignificant in the mandible. The inferior repositioning of the maxilla relapsed significantly with a vertical significant upward movement of the mandible.
- In subgroup B, the skeletal Class III relationship was not corrected completely. Insignificant maxillary relapse occurred horizontally and vertically. The mandible showed significant vertical relapse in some landmarks.
- In subgroup C, maxillary relapse was insignificant anteroposteriorly and vertically, whereas the mandible showed a significant relapse anteroposteriorly.

Null Hypotheses (6-7):

- There are no statistically significant differences in maxillary and mandibular positions following surgery.
- There is no statistically significant relapse in the maxillary and mandibular positions in the postsurgical period.

On the basis of the current results, the sixth null hypothesis is rejected. The seventh null hypothesis is rejected for the following surgical procedures: maxillary advancement and maxillary inferior repositioning in subgroup A (Class III patients), mandibular advancement in subgroup C (Class II patients). The seventh null hypothesis is accepted for the following procedures: mandibular setback in subgroup A (Class III patients), maxillary advancement and impaction in subgroup C (Class II patients).

6.1.4 Fourth Aim

To evaluate soft-tissue to hard-tissue displacement ratios in the overall assessment (between the first and the last assessment times)

Conclusions related to subgroup A, B and C:

- In subgroup A, more significant soft-tissue to hard-tissue displacement ratios were found in the anteroposterior dimension than in the vertical dimension. The least significant median ratio was found between the nasal tip and anterior nasal spine, whereas several mandibular soft-tissue to hard-tissue comparisons showed a one-to-one ratio. Generally, one-to-two vertical displacement ratios were found in the chin area.
- In subgroup B, less significant median ratios were found in the anteroposterior dimension compared with subgroup A. The upper lip followed the underlying hard-tissue very closely, whereas significant one-to-one median ratios were observed in the chin region. Vertically, chin soft tissue followed the underlying bony tissues very closely (1:1).
- In subgroup C, the nasal tip showed the least significant median displacement ratio anteroposteriorly and a gradual increase was found from the nasal tip to the free end of the upper lip. Vertically, the upper labial soft tissues were displaced one third of the vertical movement of the underlying bony structures. In the lower lip and the chin, vertical soft-tissue displacements exceeded the corresponding hard-tissue landmarks.

Null Hypothesis (8):

- There are no statistically significant displacement ratios between facial soft tissues and the underlying hard tissues.

On the basis of the results: this null hypothesis is rejected for many soft-tissue/hard-tissue displacement ratios in the anteroposterior direction, whereas vertically, there is insufficient evidence to reject it for the majority of the calculated ratios.

6.1.5 Fifth Aim

To ascertain the impact of orthognathic surgery on patients' perception of their facial appearance and their psychosocial characteristics, and to evaluate any possible postsurgical changes in these variables

Conclusions related to subgroups A, B and C:

- In subgroup A, significant improvement in self-esteem and significant decrease in anxiety and depression scores, was found. Facial body image improved significantly as well as the self-perception of facial profile.
- In subgroup B, changes in self-esteem, anxiety and depression scores were similar to subgroup A. Facial body image improved significantly, while the perception of improvement in facial profile was not indicated accurately on the relevant subscales of the questionnaire.
- In subgroup C, similar results were found regarding the significant changes in self-esteem, anxiety and depression scales. This subgroup was the only one to notice significant improvement in the teeth-related facial body image questionnaire at one month following surgery. Perception of improvement in the lip region was not significant until three months following surgery. Inaccurate self-rating of facial profile was found in the maxillary dimension.

Conclusions related to the whole study group, Class II and Class III groups:

- Significant improvement was observed in several items of the facial body image. No significant improvement was observed in areas outwith the surgical sites. The teeth-related facial body images showed a significant improvement in the postsurgical follow-up.
- Before surgery, Class II subjects perceived their facial profile as being composed of maxillary prognathism and mandibular retrognathism, whereas Class III subjects perceived a composition of maxillary retrognathism and mandibular prognathism. The perception in both groups improved significantly following surgery with no significant change between one month and six months postsurgery.

- Significant improvement in self-esteem and significant reduction in anxiety and depression scores were observed in the whole study group as well as in Class II and Class III groups.

Null Hypotheses (9-10):

- There is no impact of orthognathic surgery on patients' perception of their facial appearance.
- There are no statistically significant changes in the psychosocial measures in the postsurgical observation period.

Depending on the current results, the ninth null hypothesis is rejected, whereas the tenth null hypothesis is accepted for the majority of the psychosocial variables.

6.1.6 Sixth Aim

To explore the effect of dentofacial deformity, sex and age on the psychosocial characteristics

Conclusions:

- No significant differences were found between Class II and Class III patients in terms of self-esteem, anxiety and depression pre- or postsurgically. Some small but significant differences were found in the multidimensional health locus of control and the extroversion-introversion scales. Satisfaction was similar between both types of deformities.
- Females had less self-esteem than males at all assessment times. Females were more anxious than males in the preoperative and one-month postoperative assessments. No significant differences in satisfaction were observed in the postsurgical follow-up period.
- There were no significant age-related differences in self-esteem, anxiety and depression scores. Younger patients were significantly more extrovert than older patients. Both age groups had similar satisfaction scores following surgery.

Null Hypothesis (11):

- Three are no significant differences between Class II and Class III patients, females and males, older and younger patients in their psychosocial profiles pre- and post-operatively.

On the basis of the results, the null hypothesis is rejected for several psychosocial comparisons.

6.1.7 Seventh Aim

To evaluate the extent of compatibility between the cephalometric and the three-dimensional measurements

Conclusions:

- 2D linear measurements were similar to 3D linear measurements, whereas three out of four angles tested showed significant differences.

Null Hypothesis (12):

- There are no statistically significant differences between measurements obtained two-dimensionally and three-dimensionally.

On the basis of the results, this null hypothesis is rejected.

6.1.8 Eighth Aim

To determine if the magnitude of facial anteroposterior soft-tissue changes affects the perception of facial changes at different facial regions assessed by the perception questionnaires at six months following surgery

Conclusions:

- Class III patients who perceived maximum change in the upper lip region had more anterior displacements of Subnasale and superior labial sulcus. However, patients' perception of facial changes was not generally affected by the magnitude of z-displacements of facial landmarks.

Null Hypothesis (13):

- For each facial region, patients who perceived a maximum change did not have the same magnitude of z-displacement of facial landmarks compared with patients who perceived little or no change at six months following surgery.

On the basis on the results, this null hypothesis is rejected for the Class III group for two landmarks in the upper lip region, whereas for the remaining comparisons and for all comparisons in the Class II group, the null hypothesis is accepted.

6.2 Recommendations for future research work

Several research questions have emerged during the course of the current work, which require further investigations. Some of the recommendations could be carried out using the current database and others would require repeat examination of the patients up to two to five years following surgery.

To optimise the 3D output, general illumination of the captured faces should be improved by adding another source of illumination around the head. The recent introduction of high-resolution cameras cancels the need for projecting textures on the subject's face and reduces the capture time to less than 10 milliseconds. The development of a portable 3D imaging system would allow data collection to be carried out in different centres and locations. Automation of facial landmark identification would probably improve the reproducibility of this procedure and save time and labour. The development of an automated system requires additional work.

Assessment of changes in facial expression and animation following surgery would be an interesting area to consider in the future. The possibility of superimposing 3D soft-tissue data on the underlying 3D skeletal data would improve our understanding of the complex relationship between soft tissues and hard tissues and the early experiments in this field are encouraging.

In the current study, we concentrated on a few surgical interventions to study changes in soft-tissue morphology and it would be preferable if this could be extended to cover the whole spectrum of orthognathic surgical interventions. Larger scale studies are, of course, required. The heterogeneity in the surgical procedures performed in the chin area in the current study should be removed in future investigations. If 3D soft-tissue data are to be compared with cephalometric data, both records should be obtained simultaneously to reduce the sources of error in facial expression.

The need for establishing British 3D normative data in adults to allow direct comparison between the results following cosmetic or orthognathic surgery and the 'ideal' values cannot be underestimated.

The follow up in this study was relatively short and longer-term observations should be performed. The patients recruited in this study could be recalled to assess the stability of soft and hard tissues as well as the change in their psychosocial profiles after one year, two years and five years following the orthognathic correction.

More investigations should be made to link the psychosocial characteristics in the recruited subjects with the documented 3D and 2D morphometric parameters and the time limitation of the current project did not allow for such expansion of theses analyses to be undertaken.

Chapter Seven

Appendices

Appendices

Appendix I: Information sheet for the pilot study

Psychosocial aspects of patients undergoing orthognathic surgery & their perception of their facial appearance

Dear ...., Date:...................

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives and your GP if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

There are several reasons why patients wish to undergo surgery. How you see your face is an important factor in your decision to undergo surgery and this may also affect your satisfaction with the surgery. There are certain parts of the face which patients will be satisfied with, while others they would wish changed to improve the attractiveness of the face. An improved appearance may sometimes have a great influence on patient's self-confidence. There are other personality factors that may affect one's satisfaction with the surgery. It has been noticed that, sometimes, psychological problems can affect the outcome following surgery.

Our pilot study will take into consideration patients who are going to have surgery within the next month. A sample of 5 patients before the operation and 5 patients after operation will be invited to participate. A questionnaire will be given to you to complete in relation to:

- **Your reasons for treatment.**
- **How you view your face (using some drawings of the face)**
- **How you feel about yourself, i.e. self-esteem**
- **How you feel about several areas of your face**
- **Some of your personality characteristics**
- **Your psychological health**

You will need about 30 minutes to fill in the questionnaire. All information which is collected about you will be kept strictly confidential and will comply with the Data Protection Act (1998).

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this **information sheet** to keep and be asked to sign a **consent form**. If you decide to take part, you are still free to withdraw at any time and without giving a reason. This will not affect the standard of care you receive.

The information and results we get from this pilot study will help us to make any important alterations to the questionnaire that will be forwarded to 100 patients with similar problems in a more elaborate study commencing in April 2000. We will inform you at the end of the whole study where you can get a copy of the published results.

If you have any questions regarding this study, please do not hesitate to call:
Dr Mohammad Y. Hajeer
Orthodontic Department; Tel: 0141 211 9766;
E-mail: 9909531h@student.gla.ac.uk

Thank you very much for taking part in this study,

M. Y. Hajeer DDS
PhD Research Student
Orthodontic Department
Glasgow Dental Hospital & School

Appendix II: Consent form for the pilot study

Centre Number:
Study Number: Pilot Study
Patient Identification Number for this study:

CONSENT FORM

Title of the pilot study: Psychosocial aspects of patients undergoing orthognathic surgery and their perception of their facial appearance

Name of Researcher: Dr. Mohammad Y Hajeer

1. I confirm that I have read and understood the information sheet dated .... for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that sections of any of my medical notes may be looked at by responsible individuals from Glasgow Dental School or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records. ☐

4. I agree to take part in the above study. ☐

Name of Patient		**Date**	**Signature**
Researcher	**Mohammad Y Hajeer**	**Date**	**Signature**

1 for patient; 1 for researcher; 1 to be kept with hospital notes.

Appendix III: Information sheet for the main study

Three-dimensional soft-tissue, two-dimensional hard-tissue and psychosocial changes following orthognathic surgery

Dear ...., Date:...................

You are invited to take part in a research study. Before you decide, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with friends, relatives, and your GP if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part.

The success of any surgery to correct the way your jaws and teeth meet depends on accurate recording of the shape and size of your face before surgery. Many recent techniques have been developed to record the shape and size of your face in three dimensions. I intend to use the new three-dimensional imaging system that has been developed as the result of collaboration between Glasgow University Dental School and the Turing Institute to assess how your face changes with surgery.

How you see your face is important in your decision to undergo surgery and may also affect your satisfaction after surgery. We are the first to employ the 3D imaging technique to assess actual three-dimensional facial changes following surgery and to see how these relate to your view of the changes in your face with surgery.

Our study will take into consideration patients who have surgery on their face to correct the way their jaws and teeth meet at *Canniesburn and Monklands Hospitals* from June 2000 until June 2002. A sample of 100 patients will be invited to participate. Three-dimensional pictures of your face will be taken at three different times: (1) immediately before surgery, (2) 3 months after your operation, and (3) 6 months after your operation. At the same times, a questionnaire will be given to you to assess:

(1) Your reasons for treatment.
(2) How you view your face (using some drawings of the face).
(3) How you feel about yourself, i.e. self-esteem.
(4) How you feel about several areas of your face.
(5) Some of your personality characteristics.
(6) Your psychological health.

It takes just half a second to take a three-dimensional picture of your face, but we will need to record several images. We will need 5 – 10 minutes to do this. You will need about 30 minutes to fill in the questionnaire. The camera system has two pairs of video cameras, and exposures you to no harmful radiation. The procedure is extremely safe and fast. All information which is collected about you during the course of the research will be kept strictly confidential and will comply with the Data Protection Act (1998).

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this **information sheet** to keep and be asked to sign a **consent form**. If you decide to take part, you are still free to withdraw at any time and without giving a reason. This will not affect the standard of care you receive.

The information and results we get from this study may help us treat future patients with similar problems and plan their treatment better. We will inform you at the end of the study where you can get a copy of the published results.

If you have any questions regarding the study, please do not hesitate to call:

Dr Mohammad Y. Hajeer
Tel: 0141 9766 (Orthodontic Dept.)
E-mail: 9909531h@student.gla.ac.uk

Thank you very much for taking part in this study,

M. Y. Hajeer DDS
PhD Research Student
Orthodontic Department
Glasgow Dental Hospital & School

Appendix IV: Consent form for the main study

Centre Number:
Study Number:
Patient Identification Number for this study:

CONSENT FORM

Title of Project: Three-dimensional soft-tissue, two-dimensional hard-tissue and psychosocial changes following orthognathic surgery

Name of Researcher: Dr Mohammad Y Hajeer

1. **I confirm that I have read and understand the information sheet dated .... for the above study and have had the opportunity to ask questions.** ☐

2. **I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected.** ☐

3. **I understand that sections of any of my medical notes may be looked at by responsible individuals from Glasgow Dental School or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records.** ☐

4. **I agree to take part in the above study.** ☐

5. **I agree to the use of my 3D image in any medical publication (written and visual) that may result from this work.** ☐

Name of Patient		**Date**	**Signature**
Researcher	**Mohammad Y Hajeer**	**Date**	**Signature**

1 for patient, 1 for researcher; 1 to be kept with hospital notes.

Appendix V: Rosenberg self-esteem questionnaire

Here is a list of ten items describing different emotions and feelings towards yourself. Please, read each of these items carefully and try to circle the choice that almost meets the degree of agreement or disagreement you have.

1) On the whole, I am satisfied with my self.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

2) At times I think I am no good at all.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

3) I feel that I have a number of good qualities.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

4) I am able to do things as well as most other people.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

5) I feel I do not have much to be proud of.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

6) I certainly feel useless at times.

   1. Strongly agree
   2. Agree
   3. Disagree
   4. Strongly disagree

7) I feel that I am a person of worth, at least on an equal plane with others.

1. Strongly agree
2. Agree
3. Disagree
4. Strongly disagree

8) I wish I could have more respect for myself.

1. Strongly agree
2. Agree
3. Disagree
4. Strongly disagree

9) All in all, I am inclined to feel that I am a failure.

1. Strongly agree
2. Agree
3. Disagree
4. Strongly disagree

10) I take a positive attitude toward myself.

1. Strongly agree
2. Agree
3. Disagree
4. Strongly disagree

Appendix VI: Motives for treatment

Motives for treatment

Each patient has his own motive for undergoing combined orthodontic-orthognathic surgery. However, there is a wide range of reasons and motives. You are requested to read each of the following and circle the appropriate choice that almost meets your situation using the response scale.

Response Scale:

1. **Not at all a motive for me.**
2. **Not much of a motive**
3. **Somewhat a motive**
4. **Very much a motive**

1. Improvement of chewing ability	1	2	3	4
2. Improvement of appearance of teeth	1	2	3	4
3. Improvement of fit of upper and lower teeth	1	2	3	4
4. Prevention of periodontal disease	1	2	3	4
5. Prevention of tooth loss in the future	1	2	3	4
6. Improvement of facial profile	1	2	3	4
7. Prevention pain or damage to jaw joint	1	2	3	4
8. Improvement of speaking ability	1	2	3	4
9. Improvement of work or social performance	1	2	3	4
10. Improvement of general health	1	2	3	4
11. Improvement of sinus problems	1	2	3	4
12. Improvement of breathing	1	2	3	4
13. Feeling better about myself	1	2	3	4

Appendix VII: Facial body image

On this page, a number of facial characteristic of yourself or related to you are listed. You are asked to indicate which features you are satisfied with exactly as they are, which features you worry about and would like to change if it were possible, and which features you have no feelings about one way or the other.

Consider each item listed below and circle the number which best represents your feelings according to the following scale:

1. **Have strong feelings and wish change could somehow be made.**
2. **Don't like, but can put up with.**
3. **Have no particular feelings one way or the other.**
4. **Am satisfied.**
5. **Consider myself fortunate.**

Facial items:

1. Hair	1	2	3	4	5
2. Forehead	1	2	3	4	5
3. Eyes	1	2	3	4	5
4. Ears	1	2	3	4	5
5. Nose	1	2	3	4	5
6. Upper Lip	1	2	3	4	5
7. Lower Lip	1	2	3	4	5
8. Cheeks	1	2	3	4	5
9. Teeth	1	2	3	4	5
10. Chin	1	2	3	4	5
11. Upper part of the neck	1	2	3	4	5
12. Profile	1	2	3	4	5
13. Shape of face	1	2	3	4	5

MULTIDIMENSIONAL HEALTH LOCUS OF CONTROL SCALE (FORM A)

Name: *Appendix VIII: Mutlidimensional Health Locus of Control*....

Date: .... **Record Number:**..

This is a questionnaire designed to determine the way in which different people view certain important health-related issues. Each item is a belief statement with which you may agree or disagree. Beside each statement is a scale which ranges from strongly disagree (1) to strongly agree (6). For each item we would like you to circle the number that represents the extent to which you disagree or agree with the statement. The more strongly you agree with a statement, then the higher will be the number you circle. The more strongly you disagree with a statement, then the lower will be the number you circle. Please make sure that you answer every item and that you circle **only one** number per item. This is a measure of your personal beliefs: obviously, there are no right or wrong answers.

Please answer these items carefully, but do not spend too much time on any one item. As much as you can, try to respond to each item independently. When making your choice, do not be influenced by your previous choices. It is important that you respond according to your actual beliefs and not according to how you feel you should believe or how you think we want you to believe.

	Strongly disagree	*Moderately disagree*	*Slightly disagree*	*Slightly agree*	*Moderately agree*	*Strongly agree*
1. If I get sick, it is my own behaviour which determines how soon I get well again.	1	2	3	4	5	6
2. No matter what I do, if I am going to get sick, I will get sick.	1	2	3	4	5	6
3. Having regular contact with my doctor is the best way for me to avoid illness.	1	2	3	4	5	6
4. Most things that affect my health happen to me by accident.	1	2	3	4	5	6
5. Whenever I don't feel well, I should consult a medically trained professional.	1	2	3	4	5	6
6. I am in control of my health.	1	2	3	4	5	6
7. My family has a lot to do with my becoming sick or staying healthy.	1	2	3	4	5	6
8. When I get sick, I am to blame.	1	2	3	4	5	6
9. Luck plays a big part in determining how soon I will recover from an illness.	1	2	3	4	5	6
10. Health professionals control my health.	1	2	3	4	5	6
11. My good health is largely a matter of good fortune.	1	2	3	4	5	6
12. The main thing which affects my health is what I myself do.	1	2	3	4	5	6
13. If I take care of myself, I can avoid illness.	1	2	3	4	5	6
14. When I recover from an illness, it's usually because other people (for example, doctors, nurses, family, friends) have been taking good care of me.	1	2	3	4	5	6
15. No matter what I do, I'm likely to get sick.	1	2	3	4	5	6
16. If it's meant to be, I will stay healthy.	1	2	3	4	5	6
17. If I take the right actions, I can stay healthy.	1	2	3	4	5	6
18. Regarding my health, I can only do what my doctor tells me to do.	1	2	3	4	5	6

Code 4920 10 4

Appendix IX: EPQ-R	Age	Sex M / F	P	E	N	L

INSTRUCTIONS: **Please answer each question by putting a circle around the 'YES' or 'NO' following the question. There are no right or wrong answers, and no trick questions. Work quickly and do not think too long about the exact meaning of the questions.**

■ PLEASE REMEMBER TO ANSWER EACH QUESTION

PAGE 1

1	Does your mood often go up and down?	YES	NO
2	Do you take much notice of what people think?	YES	NO
3	Are you a talkative person?	YES	NO
4	If you say you will do something, do you always keep your promise no matter how inconvenient it might be?	YES	NO
5	Do you ever feel 'just miserable' for no reason?	YES	NO
6	Would being in debt worry you?	YES	NO
7	Are you rather lively?	YES	NO
8	Were you ever greedy by helping yourself to more than your fair share of anything?	YES	NO
9	Are you an irritable person?	YES	NO
10	Would you take drugs which may have strange or dangerous effects?	YES	NO
11	Do you enjoy meeting new people?	YES	NO
12	Have you ever blamed someone for doing something you knew was really your fault?	YES	NO
13	Are your feelings easily hurt?	YES	NO
14	Do you prefer to go your own way rather than act by the rules?	YES	NO
15	Can you usually let yourself go and enjoy yourself at a lively party?	YES	NO
16	Are *all* your habits good and desirable ones?	YES	NO
17	Do you often feel 'fed-up'?	YES	NO
18	Do good manners and cleanliness matter much to you?	YES	NO
19	Do you usually take the initiative in making new friends?	YES	NO
20	Have you ever taken anything (even a pin or button) that belonged to someone else?	YES	NO
21	Would you call yourself a nervous person?	YES	NO
22	Do you think marriage is old-fashioned and should be done away with?	YES	NO
23	Can you easily get some life into a rather dull party?	YES	NO
24	Have you ever broken or lost something belonging to someone else?	YES	NO
25	Are you a worrier?	YES	NO

26	Do you enjoy cooperating with others?	YES	NO
27	Do you tend to keep in the background on social occasions?	YES	NO
28	Does it worry you if you know there are mistakes in your work?	YES	NO
29	Have you ever said anything bad or nasty about anyone?	YES	NO
30	Would you call yourself tense or 'highly-strung'?	YES	NO
31	Do you think people spend too much time safeguarding their future with savings and insurance?	YES	NO
32	Do you like mixing with people?	YES	NO
33	As a child were you ever cheeky to your parents?	YES	NO
34	Do you worry too long after an embarrassing experience?	YES	NO
35	Do you try not to be rude to people?	YES	NO
36	Do you like plenty of bustle and excitement around you?	YES	NO
37	Have you ever cheated at a game?	YES	NO
38	Do you suffer from 'nerves'?	YES	NO
39	Would you like other people to be afraid of you?	YES	NO
40	Have you ever taken advantage of someone?	YES	NO
41	Are you mostly quiet when you are with other people?	YES	NO
42	Do you often feel lonely?	YES	NO
43	Is it better to follow society's rules than go your own way?	YES	NO
44	Do other people think of you as being very lively?	YES	NO
45	Do you always practise what you preach?	YES	NO
46	Are you often troubled about feelings of guilt?	YES	NO
47	Do you sometimes put off until tomorrow what you ought to do today?	YES	NO
48	Can you get a party going?	YES	NO

■ PLEASE CHECK THAT YOU HAVE ANSWERED ALL THE QUESTIONS

Impression number 13 12 11
Year 2003 2002 2001 2000

Appendix X: Hospital Anxiety and Depression Scale

Hospital Anxiety and Depression Scale (HADS)

NFER-NELSON
INFORMING YOUR DECISIONS

Name: ______________________ Date: ____________

FOLD HERE

Clinicians are aware that emotions play an important part in most illnesses. If your clinician knows about these feelings he or she will be able to help you more.

This questionnaire is designed to help your clinician to know how you feel. Read each item below and **underline the reply** which comes closest to how you have been feeling in the past week. Ignore the numbers printed at the edge of the questionnaire.

Don't take too long over your replies, your immediate reaction to each item will probably be more accurate than a long, thought-out response.

FOLD HERE

D | A | D

I feel tense or 'wound up'
- Most of the time
- A lot of the time
- From time to time, occasionally
- Not at all

I still enjoy the things I used to enjoy
- Definitely as much 0
- Not quite so much 1
- Only a little 2
- Hardly at all 3

I get a sort of frightened feeling as if something awful is about to happen
- Very definitely and quite badly
- Yes, but not too badly
- A little, but it doesn't worry me
- Not at all

I can laugh and see the funny side of things
- As much as I always could 0
- Not quite so much now 1
- Definitely not so much now 2
- Not at all 3

Worrying thoughts go through my mind
- A great deal of the time
- A lot of the time
- Not too often
- Very little

I feel cheerful
- Never 3
- Not often 2
- Sometimes 1
- Most of the time 0

I can sit at ease and feel relaxed
- Definitely
- Usually
- Not often
- Not at all

I feel as if I am slowed down
- Nearly all the time 3
- Very often 2
- Sometimes 1
- Not at all 0

I get a sort of frightened feeling like 'butterflies' in the stomach
- Not at all 0
- Occasionally 1
- Quite often 2
- Very often 3

I have lost interest in my appearance
- Definitely 3
- I don't take as much care as I should 2
- I may not take quite as much care 1
- I take just as much care as ever 0

I feel restless as if I have to be on the move
- Very much indeed 3
- Quite a lot 2
- Not very much 1
- Not at all 0

I look forward with enjoyment to things
- As much as I ever did 0
- Rather less than I used to 1
- Definitely less than I used to 2
- Hardly at all 3

I get sudden feelings of panic
- Very often indeed 3
- Quite often 2
- Not very often 1
- Not at all 0

I can enjoy a good book or radio or television programme
- Often 0
- Sometimes 1
- Not often 2
- Very seldom 3

Now check that you have answered all the questions

A | D

TOTAL

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Appendix XI: Satisfaction questionnaire

For each of the areas below, circle the number, which best describes your present level of satisfaction with your decision to undergo treatment, from 1 (not at all satisfied) to 7 (very satisfied).

1. If you had to make the decision again, how likely would you be to undergo orthognathic surgery?

1	2	3	4	5	6	7
Not at all likely			Neutral			Very likely

2. Considering that this was an elective procedure, how likely would you now be to recommend orthognathic surgery to others?

1	2	3	4	5	6	7
Not at all likely			Neutral			Very likely

3. At present, how satisfied are you with your recovery from surgery?

1	2	3	4	5	6	7
Not at all satisfied			Neutral			Very satisfied

4. Considering everything, how satisfied are you now with the results of surgery?

1	2	3	4	5	6	7
Not al all satisfied			Neutral			Very satisfied

Chapter Eight

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