A Three-Dimensional Comparison of the Facial Morphology of Unilateral Cleft Lip and Palate Patients with a Control Group.

Patricia Mary Goodwin

Thesis presented for the degree of Master of Philosophy

University College

University of London

Acknowledgements

I would like to thank my principal supervisor Dr. A.D. Linney for his help support and encouragement throughout the duration of this thesis. Also my second supervisor Professor J.P. Moss for his encouragement, enthusiasm, support and many helpful suggestions over the past four years.

There are many friends and colleagues who provided invaluable encouragement both on a practical and emotional level. In particular I would like to thank Dr. D.S. Walsh for his friendship and support especially with formatting and illustrations, he knows more about this than any person I know. Dr. J.C. Campos for his friendship when I first arrived at the Medical Graphics and Imaging Group and patiently teaching me how to use the optical surface scanner.

Dr. R. Richards for writing the software which calculated my distance measurements. I would also like to thank Mr. B. Sommerlad for allowing me to use his patients for this project, and of course the patients themselves who have helped to increase our awareness and understanding of cleft lip and palate.

I would also like to thank my dear friends Chloe Hutton, Tracy Palmer and Alan Burt for keeping my spirits up when the going got tough. Special thanks to Ann Quinn and Antonia Flack, for dispensing cranio-sacral therapy, understanding, and homoeopathic remedies in equally successful measure. I am also grateful to the people in the Medical Graphics and Imaging Group for their support.

Finally I would like to thank my family for being my family.

Table of Contents

APPENDICES

Table of Figures

List of Graphs

List of Tables

Glossary

Allele: (allelic) one of two or more alternative forms of a gene.

Caucasian: of the Caucasus, of white of light skinned race.

Cephalometry: the study of facial growth by examination of standardised lateral skull radiographs of the head.

Congenital: a condition that is recognised at birth or that is believed to have been present since birth, congenital malformations include all disorders present at birth whether they are inherited or environmental.

Discriminant function analysis: a method of optimising (facial) classification based on a set of measurements.

Iatrogenic: describing a condition that has resulted from treatment, as either an unforeseen or inevitable side effect.

Mesenchyme: the undifferentiated tissue of the early embryo that forms almost entirely of mesoderm. It is loosely organised and the individual cells migrate to different parts of the body where they form most of the skeletal an connective tissue, the blood and blood system, and the smooth muscles.

Morphology: study of differences in form between species.

Multifactorial: a condition that is believed to have resulted from the interaction of genetic factors, usually polygenes, with an environmental factor or factors.

Obturator: a removable device developed to be inserted into an opening, a removable form of denture that both closes a defect in the palate and also bears artificial teeth for cosmetic purposes.

Placode: any of the thickened areas of ectoderm in the embryo that will develop into nerve ganglia or the special sensory structures of the eye ear or nose.

Primordia: cells or tissues that are formed in the early stages of embryonic development.

Prosthometer: a device designed by Corisande Smythe for the measurement of head size and the relationship of the teeth relative to the head.

Scrofula: tuberculosis of the lymph nodes, usually those in the neck.

Skeletal I: a normal relationship of the upper and lower jaws to one another and to the cranial base.

Teratogen: any substance, agent or process that induces the formation of developmental abnormalities in a foetus. Known teratogens include such drugs as thalidomide and alcohol, infections such as German measles, and also ionising radiation.

Uranoplasty: repair of the hard palate.

Uvulotomy: removal of part of the uvula

Abstract

The quest to describe and quantify three-dimensional (3D) facial form has spanned many centuries, ancient Greek sculptors designed frames for recording facial shape in order to faithfully reproduce likenesses in stone, and also contemplated the aesthetic significance of various proportionate measures. Greek mathematicians and philosophers attempted to interpret beauty in terms of divine proportions (Huntley 1970).

Historically, it has long been recognised that two-dimensional (2D) representations of human anatomy are limited. The human body is three-dimensional, and not comprised of regular geometric structures. It has no obvious internal reference system and there is no easy way of applying an external reference system, therefore the measurement of the body and its representation in 3D is not an easy task. The need for accurate measurement and representation of the face is particularly acute because of the vital importance of appearance, and this is especially so for those born with a craniofacial anomaly such as unilateral cleft lip and palate (UCLP) (Shaw 1988).

The need to objectively quantify face shape in those born with facial anomalies such as UCLP is necessary, not just in terms of clinical audit, but to determine the best treatment regimes for good aesthetic outcome. This is a subject of debate within both the orthodontic and surgical community with many inter-centre studies being carried out (Shaw *et al.* 1992; MacKay *et al.* 1994, Roberts-Harry *et al.* 1996).

A great deal of research on facial growth has been undertaken using, on the whole, 2D methods of data collection, such as lateral cephalometric radiographs and photography. The motivation for this work has arisen from the need to quantify objectively in 3D the differences in the facial soft tissue morphology between a group of children born with UCLP and an equivalent control group. This thesis studies the work of one surgeon and compares the facial morphology of those children born with UCLP with a normal population of the same age, sex and ethnic origin using a method of 3D analysis.

Recent reports suggest the need to quantify surgical outcome of children born with UCLP and assess the aesthetic and functional effects of surgery (Shaw *et al.* 1992, Shaw *et al.* 1996, Williams et al 1996)

If we want to characterise the shape of the face and its changes with growth the whole facial surface needs to be recorded in 3D. A finely sampled recording of the face in 3D is also required if the shape of the facial surface is to be determined and analysed.

The hypothesis of this thesis is that there is no difference in the soft tissue facial morphology of UCLP patients who have been carefully operated on by one surgeon, compared with a control group.

In order to test the hypothesis the facial soft tissue morphology of a control group and a group of children with UCLP were studied. There were a total of 73 children in the UCLP group and 245 in the control group. The control group and the UCLP group were divided by age and sex, so that differences in soft tissue facial morphology which occur at different ages could be investigated. The facial morphology of the female and male UCLP group were then compared with each other. The female and male cleft groups were also compared to the equivalent female and male control group.

One surgeon operated on all the UCLP groups. The majority of the clefts being studied were left-sided, those with a right-sided cleft were mirror–imaged to make them left sided and were included in this study. The control groups were all Skeletal I (glossary) cases, with no history of orthodontic treatment or tooth extraction. The children in this study were all Caucasians (glossary) and the facial data were collected from our clinical centres in East and Central London.

The data used in both the UCLP and control group is cross-sectional and were collected using the non-invasive, no contact system of 3D optical surface scanning developed at University College London (UCL), (Moss *et al.* 1989). This method of data collection is ideally suited to measurement and comparison of soft tissues and also allows direct reference to equivalent control populations. The scanning of faces produces sufficient 3D co-ordinate measurements of the facial surface to allow the use of computer graphics to produce a photo-realistic image of the 3D surface, which may be measured, analysed and manipulated.

All the facial datasets within each group were averaged to produce an average face for each group. Averaging all the individual facial data in this way permits comparison between the groups. The average facial scans were then registered, which provides an objective, quantitative comparison between each group. In order to quantify the changes, the nose and specific facial distances were also measured.

Summary of Results

Female cleft compared with male cleft

The noses of the male cleft group at ages 4-8 were longer and wider than that of the female cleft group of the same age. At age 9-12 the nose of the female group was longer and wider than that of the equivalent male group. At age 13-16 the female nose was still slightly longer than that of the equivalent male group. The chin was more prominent in the male cleft group at ages 4-8 and 13-16 years, whereas at age 9-12 the chin, cheeks and lips of the female cleft group were more prominent than those of the males.

Female cleft compared with female control

The soft tissues of the female cleft groups were more retropositioned than the female control groups at all ages. The noses of the female clefts were flatter than those of the controls, alar base width was also greater in the female cleft groups.

Male cleft compared with male control

The tip of the male cleft noses in all age groups was flatter than that of the controls, alar base width was variable within the groups. The cheeks and lips of the male cleft group at all ages were more retropositioned than the controls. The chin was more prominent at ages 4-8 and 9-12 but at age 13-16 it was the same as that of the equivalent control group.

Conclusion

There was a significant difference in the facial morphology of unilateral cleft lip and palate patients compared with controls at all ages.

Chapter One

Normal Facial Growth and Development

1. Introduction

In this chapter the normal embryological growth of the craniofacial complex is discussed. Emphasis is given to the formation of the lip and palate, which is a complicated process, reliant on many different factors. The development of the soft tissues is also described.

1.1 Normal Facial Development

The growth of the craniofacial complex is a complicated and fascinating subject. The development of the face becomes apparent about four weeks after fertilisation, at this time five swellings, commonly called facial processes, appear around a shallow depression known as the stomodeum or primitive oral cavity.

The frontonasal process, situated centrally above the stomodeum, contributes to the development of the nose. The maxillary processes placed at each corner of the stomodeum form the upper jaw and lip whilst the two mandibular processes, situated laterally and below the stomodeum form the mandible and lower lip.

Near the lateral margins of the frontal prominence, are local thickenings of the ectoderm called the nasal placodes (glossary). The nasal placodes form the lining of the nasal pits and ultimately the olfactory epithelium with its sensory cells, which send nerve processes into the developing mesoderm.

These facial processes result from the accumulation of mesenchymal (glossary) cells beneath the surface epithelium. Mesenchymal cells are of neural crest cell origin and play an integral part in facial development (Johnston and Sulik 1984; Sulik and Schoenwolf 1985).

Crest cells in the head and face are responsible for the formation of all the skeletal and connective tissues of the face, including; bone, cartilage, fibrous connective tissue and all dental tissues with the exception of dental enamel.

1.1.1 Normal Development of the Primary Palate

The primary palate consists of the two merged medial nasal processes that form the intermaxillary segment, which in turn consists of two portions: a labial segment that forms the philtrum of the upper lip and the triangular palatal portion that forms the bone that includes the four maxillary incisor teeth. The primary palate extends posteriorly to the incisive foramen, or clinically to the incisive papilla.

During the fifth week all the major primordia (glossary) involved in the formation of the face and jaws become clearly distinguishable. At this stage the medial nasal and lateral nasal processes develop. The medial nasal processes play an important role in the formation of the medial portion of the upper jaw, lip and palate.

During the sixth and seventh weeks the maxillary processes, which form the lateral parts of the maxilla, grow towards the midline. The arch is completed by the merging of the medial nasal processes with each other in the midline and by their union with the maxillary processes laterally. The lateral nasal processes play no part in the formation of the upper lip, forming the alae of the nose.

Where the lateral nasal and maxillary processes meet each other there is for a short time a well marked groove, known as the nasolacrimal groove, if this fails to close an oblique facial cleft will form. As the growth of the medial nasal processes brings them downward into the space between the maxillary processes, the epithelial coverings of these two processes come into contact and a significant series of changes take place.

In the early part of the seventh week the epithelium between the processes loses its integrity, thereby allowing the mesenchyme of the frontonasal processes and maxillary processes to become continuous and grow together. If there is a failure in this process the formation of lateral clefts of the upper lip occur.

The development of the lower part of the oral cavity is less complex as it contains the mandibular arch only. The mandibular arch originates from paired primordia caused by the rapid proliferation of underlying mesenchymal tissue. These thickenings, the mandibular processes, then extend towards the midline where they merge, completing the development of the mandible and lower lip. The lateral merging of the maxillary and mandibular prominences creates the commisures (corners) of the mouth Sperber (1989).

1.1.2 Normal Development of the Secondary Palate

The main part of the palate, the secondary palate, can be seen from the sixth week of development and is derived from the maxillary processes. The secondary palate includes at least ninety percent of the hard and soft palates, with the exception of the anterior portion that holds the incisor teeth.

The palatal shelves grow horizontally from the maxillary processes during the seventh week of development, and then grow towards the midline. At the initial formation of the palatal shelves the tongue lies between them, therefore growth is directed downwards lateral to the tongue, so that their margins lie along the floor of the mouth, on either side of the root of the tongue.

During the eighth week two significant events occur, the mechanisms of which are not clearly understood. The position of the tongue, which until now has been a physical barrier between the two shelves, moves to the lower part of the oral cavity. Secondly, the margins of the palatal shelves move from a vertical to a horizontal position, allowing them to grow towards the midline. This change in relationship between the tongue and palatal shelves is crucial for the completion of the palate. Once the shelves are elevated to the horizontal plane, there is programmed cell death of the medial edge. When the shelf edges touch, the epithelium thins and undergoes advanced stages of degeneration allowing the mesenchyme from each side to join the midline (Luke 1976). Progress towards fusion is very rapid once the tongue no longer impedes the shelves, and fusion is complete by the tenth week, Poswillo (1979).

1.1.3 Skeletal Development

Most studies on the growth and development of the facial skeleton have been carried out using cephalometrics. As a result of this research it is generally accepted that the process of facial growth is very complex, different parts of the head growing at different times and rates, the skeletal profile becoming less convex with age (Subtelny 1959).

1.1.4 Soft Tissue Development

The most commonly used method of recording and analysing the facial soft tissues has on the whole been the cephalometry (glossary). This two-dimensional method is limited, providing profile information only. Studies carried out by (Subtelny, 1959; Prahl-Andersen *et al* 1995) using lateral skull radiographs, showed that growth of the facial soft tissues is intimately related to the growth of the underlying hard tissues, and for the most part follows the same growth pattern. However, in his study, Subtelny (1959) concluded, "all parts of the soft tissues do not directly follow the underlying skeletal profile, some areas were found to diverge in soft tissue contour from underlying skeletal structures, while other areas showed a strong tendency to follow skeletal structures directly". He found the soft tissue convexity of the face increased with age, especially in the nose and maxillary region. This was particularly so in males where growth was found to be both greater, and to continue beyond the age of 18 (Subtelny, 1959, Nanda *et al* 1990).

Recently, three-dimensional analyses of the growth of the soft tissue has been undertaken which demonstrate the variability of the growth of the soft tissues across the face, Nute (1997).

Summary

- Facial development becomes apparent at about 4 weeks after fertilisation when five swellings, known as facial processes develop.
- The upper lip is formed laterally by the maxillary processes and medially by the frontonasal processes, which become continuous and grow together. If there is a failure in this process the formation of lateral clefts of the upper lip occur.
- During the sixth and seventh weeks the maxillary processes grow towards the midline, the arch is completed by the merging of the medial nasal processes with each other in the midline and by their union with the maxillary processes laterally.
- The secondary palate is formed from the maxillary processes. These processes (palatal shelves) initially lie vertically as the tongue is between them. During the eighth week the position of the tongue moves to the lower part of the oral cavity and the margins of the shelves move from a vertical to a horizontal position. This movement is essential for completion of the palate.
- Most studies on soft tissue morphology have been carried out using cephalometrics (Subtelny (1959), and Prahl-Andersen (1995) concluded that growth of the facial soft tissues is intimately related to the growth of the underlying hard tissues, but this is not the case in the region of the nose.
- More recently three-dimensional studies of the growth of the facial soft tissues Nute (1997), demonstrates the variability of the growth of the soft tissues across the face.

Chapter Two
History of Cleft Lip and Palate

2. Introduction

This chapter charts the history of cleft lip and palate from the earliest times. The progress of surgical treatments and techniques for those born with UCLP are discussed from an historical perspective. Some surgical techniques developed in the last century are still in use today with only slight modification. It is clear that debate on timing of surgery and type of surgical technique is not confined to the late 20th Century. The mechanisms involved in cleft lip and palate formation are also discussed.

2.1 History of Orofacial Clefting Syndromes

2.1.1 BC 2400-AD 390

The history of orofacial clefts can be traced back to Ancient Egypt, the first evidence of cleft lip was found in an Egyptian mummy dating between 2400-1300 BC (Smith and Dawson, 1924). Orticochea (1983) gives a description of a 2000-year-old pre-Columbian ceramic statue of a king with a right-sided incomplete cleft of the lip. An ancient African mask showing cleft lip and palate has been described by Cervenka, (1984). The first treatment of cleft lip was apparently carried out by an unknown Chinese physician in 390 AD (Boo-Chai 1966). This treatment was carried out on a young farm boy called Wei Yang-Chi, who subsequently became the Governor General of six Chinese Provinces.

Clefts of the lip or palate are not mentioned in the writings of Greek and Roman physicians. Uvulotomy (glossary) was practised by Susruta in the 6th century BC, and may have been the first person to describe anatomically the upper jaw including the uvula and alveolar processes (Bhishagratna 1963). Hippocrates, Celsus and Galen also described uvulotomy, but make no reference to the treatment of cleft lip and palate, Rogers (1971).

2.1.2 11th-17th Century

At the end of the fifteenth, and early in the sixteenth century, the first archetypal description of palatal syphilis appeared (Rogers 1967). Franco (1556) gave the first reference to cleft palates of congenital (glossary) origin. Although Franco repaired clefts of the lip and surgically removed the premaxilla in bilateral cleft lips, he made no attempt to surgically close cleft palates.

Perforations of the palate due to syphilis were very common at this time. The development of palatal repair did not advance for many centuries because many surgeons believed that clefts of the palate were the direct result of infection by syphilis. The Flemish surgeon, Jehan Yperman, was seemingly the first person to describe cleft lip repair in detail (Carolus 1854; Rogers 1964).

Palatal obturators (glossary) were used to treat those people suffering from syphilitic defects, gunshot palatal defects and perforations, the design of which became increasingly sophisticated in the eighteenth century.

In the 17th century Fabricus of Aquapendente (Rogers 1971) noted that many newborn infants with cleft palates were unable to suck and as a result of this many died. For the closure of cleft lip he advised the use of buccal mucosa or gingival tissue, he did not mention palatal closure.

Hendrik von Roonhuyze (1674) also recommended operating upon cleft lip in the very young, three to four months of age, but believed that if babies were operated on at an earlier age the chances for a successful outcome were reduced. Although many methods of cleft lip repair were documented during the 16th and 17th centuries, there is little evidence to suggest that any palatal repairs were being carried out. This is perhaps understandable when we consider the times in which these surgeons were living and working. They did not have the benefit of anaesthesia, and the patient would probably have been unable to withstand the pain of an intraoral operation. Difficulties for both surgeon and patient would also have been compounded by the very real risk of haemorrhage, and medical conditions such as syphilis, scurvy, scrofula (glossary) and tuberculosis, thereby affecting surgical outcome.

2.1.3 18th-19th Century

The arrival of the 18th century brought a more confident approach to palatal surgery. André Myrrhen (1721) lengthened the palate, in a technique not described, to compensate for a completely destroyed uvula. At this time most surgeons, treated palatal clefts either by the application of poultices or mercury, by the insertion of obturators or they did not treat them at all.

In the latter part of the 18th century several surgeons noted that early repair of the cleft lip helped reduce the width of the palatal cleft. Levret (1772) emphasised the importance of early lip closure in infants with cleft lip and palate, as he had observed in unoperated adults an increased width of the palatal shelves. Gerard (Rogers, 1971) supported this theory, and stressed that the early closure of the lip in infants with cleft lip and palate served as an early orthopaedic mechanism to narrow the palatal shelves.

Von Graefe (1817) and Roux (1819) are credited with introducing a simple method of closure for the congenital soft palate. Von Graefe's first attempt failed, possibly because of the techniques used, however successful closure was achieved after modification of the technique.

In 1819 Roux successfully closed the cleft velum of a Canadian medical student, John Stephenson who subsequently became Professor of Surgery at McGill University in Montreal. The work of Von Graefe and Roux created an interest in new surgical approaches to repair of the cleft palate and lip and the remainder of the 19th century saw the introduction of many new techniques and revisions of methods.

Many palatal repairs failed, usually because of tension caused by the straining of the palatal muscles after suture and possibly by too early removal of the sutures. An example of these failures was given in a report by Roux who had performed 105 operations of which successful closure had been achieved in two thirds of cleft velum cases, but only one third of hard and soft palate clefts were successful (Roux 1843).

Dieffenbach (1828) was probably the first to recommend that clefts of the hard palate could be closed by separating palatal mucosa from the bone and advised lateral relaxation incisions in the soft tissue of the hard palate region to close clefts of the velum and hard palate.

The reports of Von Langenbeck (1859, 1861) provided the first major solution to the disruption problems of cleft palate repair, by emphasising the need to elevate periosteum with the palatal mucosa, creating mucoperiosteal flaps. This provided surgeons with a technique by which clefts of the hard palate could be closed more successfully than ever before. A modified version of this technique is still in use today.

2.1.4 20th Century

Over the years, surgeons have introduced methods of surgical repair for those born with cleft lip and palate, with many reviews and revisions of technique. In the twentieth century more emphasis has been placed on the effect of surgery on facial growth, with special importance being given to timing of repair and specific surgical techniques.

Some authors have advocated early palate closure, primarily for social and psychological reasons and the development of good speech and language skills (Semb 1991; Lohmander Agerskov *et al.* 1995; Lohmander Agerskov *et al.* 1996). Other researchers have defended the late closure of the palate as this produces better maxillary growth (Hotz and Gnoinski 1976, 1979; Schweckendiek 1978; Friede *et al.* 1987).

Many researchers have studied facial growth in relation to type of surgery, timing of surgery and surgical outcome using UCLP and control groups (Smahel and Mullarova 1994(a), Smahel and Mullerova 1994(b); Smahel and Mullerova 1995; Markus and Precious 1997, Rohrich *et al.* 1996).

2.2 The Aetiology of Cleft Formation

2.2.1 Cleft of the Primary Palate (Cleft Lip)

Several hypotheses have been put forward as to the developmental causes of cleft lip and much of the embryological information on the development of cleft lip has been carried out using mice. The first visible deviation from the norm is seen in the nasal fin, where there is a more or less complete failure of fusion of the epithelia of the median nasal and lateral nasal processes at the posterior end of the nasal pit.

There may be several degrees of failure of fusion; partial degrees of failure may lead to incomplete cleft lip. More extreme failure of fusion is followed by breakdown of the bridge joining medial nasal, lateral nasal and maxillary processes thus resulting in a complete cleft of the lip and hard and soft palate.

It has also been suggested that in normal embryological growth the apposed epithelia between the medial and lateral nasal processes are penetrated by mesenchyme, resulting in fusion of the two processes. When this fails to happen there may be no fusion of the two processes resulting in a cleft.

Johnston (1964, 1966) showed that the descendants of cells that have migrated from the neural crest populate facial processes. When the appropriate area of the neural crest in the chick embryo is extirpated (removed), a facial cleft results on the same side. It is therefore possible that changes in the neural crest cells, their rate of migration or direction of migration could contribute towards cleft lip by either altering the relation of the processes to one another or by reducing the size of one or more processes.

Evidence was produced by Trasler (1968) which suggested that the predisposition to cleft lip in the mouse was related to facial shape. She showed that in the resistant strain the mouse embryo has a relatively wide face, the medial nasal processes are well separated from each other and diverge sharply to give good contact with the lateral nasal and maxillary processes. In the susceptible strain however the opposite is found, the face is narrow and the medial nasal processes are close together and divergence is not so great, therefore the degree of contact with the other processes is relatively less.

Several studies have demonstrated an association between facial shape in parents and the presence of orofacial clefts in their children (Ward *et. al.* 1994, Suzuki *et. al.* 1999, AlEmran *et al.* 1999). It has been assumed that facial shape is one predisposing factor among many in a multifactorial (glossary) model of inheritance. Ward *et al.* (1994) carried out cephalometric analysis of a family with five generations of affected individuals, and concluded that facial shape can be used to identify presumed carriers of a major gene associated with an increased risk for orofacial clefts. Discriminant function analysis (glossary) indicated that at-risk individuals could be recognised through a combination of increased midfacial and nasal cavity widths reduced facial height and a flat facial profile. AlEmran *et al.* (1999) found significant differences in faces of parents of children with cleft lip and palate and normal controls. The males had wider nasal cavity and narrower maxillary width with facial asymmetry whilst the females showed a smaller facial dimension as a whole and asymmetry of the face.

Suzuki *et al.* (1999) compared the dento-craniofacial morphology of parents of children with cleft lip and/or palate with that of parents of children without cleft lip and/or palate. They found that the parents of children with cleft lip and/or palate showed a distinct craniofacial morphology: wider interorbital width, intercoronoid process distance and nasal cavity width, larger anterior cranial base length and cranial base length

2.2.2 Cleft of the Secondary Palate

There may be many mechanisms by which a cleft of the secondary palate occurs; Fraser (1967) suggests the following that can be demonstrated experimentally. A structural abnormality of the shelves prevents them from moving to the horizontal position or from extending to the midline in time to meet and fuse; reduced shelf force where movement of the shelf to the midline is delayed beyond the time when they are still able to meet; an unusually wide head, making it more difficult for the shelves to reach each other. Anything that interferes with displacement of the tongue from between the shelves could delay shelf movement and therefore prevent closure.

The successful closure of the secondary palate appears to involve a combination of the following factors: Intrinsic shelf force that results in the movement of the palatal shelves from a vertical position on either side of the tongue to a horizontal position overlying the tongue. The resistance of the tongue to the movement of the shelves. Downward movement of the tongue from between the shelves, this is assisted by the palatal shelves which are moving over the tongue, forcing it forward and downward, by the growth of the mandible in a forward and downward direction. Flattening of the shelves with extension of the shelves in the midline with fusion and dissolution of their epithelia at the point of contact.

Clefts of the primary and secondary palates occur together in about one-half of all cleft cases. A common mechanism of production has been sought and it has been suggested that the tip of the tongue becomes wedged in the labial cleft produced by failure of fusion of the median nasal and maxillary processes (Trasler and Fraser 1963).

Summary

In this chapter a review of the history of cleft lip and palate and the development of surgery has been given from the earliest times to the present day. The mechanisms involved in the development of cleft lip and cleft palate formation has also been given.

- The history of oral clefts can be traced back to Ancient Egypt.
- Greek and Roman physicians do not mention cleft lip and palate in their writings but describe surgical removal of the uvula.
- The first description of palatal syphilis was given (Rogers 1967). Franco (1556) gave the first reference to clefts of congenital origin.
- Methods of cleft lip repair were documented during the 16^{th} and 17^{th} centuries, but little evidence to suggest that repair of the palate was being carried out.
- Von Graefe (1817) and Roux (1819) are credited with introducing a simple method of closure for the congenital soft palate.
- Von Langenbeck (1859) provided the first major solution to the disruption problems of cleft palate repair. A modified version of his palatal repair technique is still in use today.
- The 20^{th} century has seen the introduction of many methods of cleft lip and palate repair. However more emphasis is being placed on the importance of timing of facial surgery. There are those who advocate early palate closure as this produces better speech results, and those who believe that late palatal closure is preferable as this produces better maxillary growth.
- The development of cleft lip is thought to be caused by the failure of fusion of the medial nasal and lateral nasal processes. More extreme failure of fusion between the

medial nasal, lateral nasal and maxillary processes results in the formation of a complete cleft of the lip and palate.

- An association between facial shape of parents and the presence of oral clefts in their children has been demonstrated (Ward *et. al.* 1994, Suzuki *et. al.* 1999).
- Cleft palate associated with cleft lip occurs when the tip of the tongue becomes wedged in the labial cleft produced by failure of fusion of the medial nasal and maxillary processes. A reduction in size of both the labial maxillary prominence and the palatine process of the maxillary prominences is thought to be a more reasonable explanation.

Chapter Three

Factors Affecting Cleft Lip and Palate Formation

---

3. Introduction

Researchers have devoted a great deal of time investigating the aetiology of cleft lip and palate. In chapter two the formation of UCLP was discussed. A discussion of the most likely teratogens (glossary) that may influence cleft formation is given in this chapter. It is clear that the causes of UCLP do not follow a simple Mendelian mode of inheritance and that a combination of genetic and environmental causes is involved. The most commonly studied agent in relation to birth defects is cigarette smoking. The effects of antiepileptic drugs, antiemetic agents, vitamins, minerals, agricultural chemicals and maternal metabolic factors have also been investigated as possible teratogens. The effect of maternal life event stress and congenital anomalies has also been studied (Carmichael and Shaw 2000). Differences in the incidence of cleft lip and palate are also well documented and many researchers have looked at the incidence in different ethnic groups.

3.1 Cigarette Smoking

The effects of cigarette smoking on pregnancy outcome were described by Simpson (1957) who found a higher incidence of premature births in mothers who smoked. Lowe (1959), who also concluded that the lower birth weight was due to retarded foetal growth, confirmed these findings. Russell *et al.* (1968) found an increased risk of spontaneous abortion in pregnant smokers and Butler *et al.* (1969) found an increase in stillbirths and neonatal deaths. One of the first studies looking at the effect of tobacco smoking and birth defects was carried out by Fedrick *et al.* (1971). Wyszynski *et al.* (1997), reviewed

11 published papers and found that cigarette smoking in the first trimester resulted in a small but significant increase in the risk of the foetus developing cleft of the lip and palate or cleft palate. Lieff *et al.* (1999) studied the effects of cigarette smoking in children with cleft lip, cleft lip and palate, isolated cleft palate, cleft lip with additional malformations cleft lip and palate with additional malformations and isolated cleft palate with additional malformations. They found a relationship between maternal cigarette smoking and oral clefts with associated malformations.

3.2 Diet

Strauss (1914) gave the first report that dietary deficiencies could be involved in the aetiology of cleft palate. He noted that 32 jaguar cubs born in captivity from the same dam and sire had cleft palate. The diet was changed and fresh meat given after which no further cubs with cleft palate were born from the same parents. A report by Pickerill (1914) showed that 99% of the lion cubs born at Regent's Park Zoo in London suffered from cleft palate, however when the diet of the lionesses was altered only two litters were born with cleft palate.

Research into the effects of vitamin A have been carried out by several investigators. In his work with pigs Hale (1937), reported that vitamin A deficiency during pregnancy caused a wide variety of defects such as accessory ears, cleft lip and or cleft palate and malformed hind legs. He also reported that vitamin A deficiency in rats caused congenital blindness in the offspring.

The first experimental work on rats given excessive vitamin A was carried out by Cohlan, (1953; 1954), and resulted in a marked reduction in the number of litters carried to term. Gross anomalies of the skull were also found, including cleft lip and cleft palate, demonstrating experimentally that a deficiency or excess of vitamin A in the diet of pregnant animals can cause a wide variety of deformities in the offspring. Studies carried out by Peer *et al.* (1958) indicated that vitamin B6, folic acid or both was effective in reducing the teratogenic effects of cortisone in rats.

Studies carried out by (Briggs 1976) Tolarová (1982) and Khoury *et al.* (1989) concluded that supplemental vitamins given to women during the first trimester of pregnancy resulted in the reduction of babies born with cleft lip and palate. More recent studies into the role of folic acid in oral clefting and multivitamin supplementation and the risk of birth defects have been carried out (Hartidge *et al.* 1999, Werler *et al.* 1999).

Natsume *et al.* (1995) found that mothers who ate vegetables rich in β -carotene significantly reduced the risk of having a child with UCLP compared with those who ate little or none of these types of foods.

3.3 Drugs

Research carried out by Trasler (1965) into the effect of aspirin on two strains of mice found an increase in frequency of lateral clefts in the susceptible strain and of median clefts in the resistant strain.

The studies of Janz and Fuchs (1964) and Meadow (1970) revealed the likelihood that antiepileptic drugs (AEDs) could have teratogenic effects. It was noted through these and other studies that children of epileptic mothers exposed to AEDs in utero have a two-to-threefold increased risk of birth defects.

A correlation between maternal epilepsy and children with isolated clefts was found by (Calzolari *et al.* 1988; Niswander and Wertelecki, 1973; Friis, *et al.* 1981). Smithless (1976) found an association between cleft lip and palate and maternal anticonvulsant therapy. Carmichael and Shaw (1999) studied the association between maternal corticosteroid use and the risk of selected congenital anomalies. They found that corticosteroid use was associated with an increased risk for isolated cleft lip with or without cleft palate and isolated cleft palate.

Some authors claimed that there were possible tendencies for cleft lip to be more common in towns than rural areas. The teratogenic effects of environmental factors such as petroleum, oil wells and gas flares on the incidence of clefting have been studied, (Datubo-Brown and Kejeh 1989) concluded that there was no proof of cause and effect between deformities and industrial pollution. Many studies have been undertaken into the effect of organic solvents on birth defects. Holmberg *et al.* (1982) found that exposure to organic solvents in the first trimester resulted in an increase of orofacial clefts. In their extensive study Gordon and Shy (1981) found a statistically significant association between oral clefts and exposure to all chemicals (fertilisers, insecticides and herbicides).

3.4 Seasons

Research into the influence of seasons and the incidence of cleft lip and palate appears to be contradictory. The study of cleft lip and palate in Finland between 1948 and 1975 by Rintala *et al.* (1983) found there was a significant seasonal difference in the cleft lip and palate group, the highest incidence occurring in children born in April and the lowest in those born in September. Coupland and Coupland (1988) studied the seasonality of cleft lip and palate in the Trent Region of England between 1973 and 1982. They found that the number of cases of cleft lip and palate occurring between November and February to be more than twice the standard deviation above the mean.

3.5 Genetics

Despite considerable research into the aetiology of cleft lip and palate, and although evidence exists for both hereditary and environmental aetiologies, the actual cause of this defect remains unclear (Chung *et al.* 1986, Murray, 1995).

Romitti *et al.* (1999) studied the genotype-environment interactions of nonsyndromic cleft lip and palate and cleft palate only. They examined allelic variants for three genes and their interactions with maternal cigarette smoking and alcohol consumption. From the results of their study they suggest that the development of cleft lip and palate and cleft palate may be influenced independently by maternal exposures but more significantly by the interaction of the exposures and specific allelic variants.

3.6 Demographic studies of the Incidence of Cleft Lip and Palate

In a review of the incidence of oral clefts Derijcke *et al* (1996) looked at epidemiological studies on the incidence of oral clefts, mainly in Europe. Czechoslovakia had the highest incidence of 1.81/1000 followed by France 1.75/1000, Finland 1.74/1000, Denmark 1.69/1000, Belgium and the Netherlands 1.47/1000, Italy 1.33/1000, California 1.12/1000 and South America 1/1000.

Many of the studies on the incidence of cleft lip and palate included stillbirths and abortions, which would increase the incidence as the risk of clefts in these groups are three times higher than that found in live births (Derijcke *et al.* 1996; Vanderas *et al.*1987). All the studies reviewed showed a higher incidence of cleft lip and or palate compared with cleft palate only. More males were affected by cleft lip and palate than were females and the cleft was two times more likely to be found on the left side than the right (Derijcke *et al.* 1996, Vanderas *et al.* 1987).

The current incidence of cleft lip and palate in the UK is 1 in every 600 to 700 live births (Clinical Standards Advisory Group 1998). Recent trends in the UK show a reduction in the incidence of facial clefting. This reduction may be due to increased intake of multivitamins and folic acid, (Tolarová, 1982, Schubert *et al.* 1990), a decrease in the number of live births in the UK population, an increase in pregnancy terminations following ante-natal diagnosis. Precise information on the incidence of facial clefting in the UK is difficult as reporting is carried out on a purely voluntary basis.

Denmark has a mandatory reporting system, and the incidence of facial clefting is reported to have risen from 1/667 live births in 1942 to 1/529 in 1981 (Jensen *et al.* 1988). Reasons for this increase may include better reporting and recording, decreased neonatal mortality, and increased levels of environmental teratogens.

3.7 Racial Differences

Many studies have been undertaken to investigate the incidence of cleft lip and palate in different ethnic groups. Vanderas *et al.* (1987) carried out a review on the incidence of cleft lip and palate among the races. He comments that these studies should be carried out separately for each group, live births, stillbirths and abortions as inclusion can distort the findings. He further states that reporting of clefts without associated malformations should be studied separately from those with associated malformations and syndromes, as they are etiologically different.

The frequency of UCLP in Native American Indians appears to be the highest of any group in the world with an incidence of over 3.6/1000 live births reported. The Japanese, Moaris and the Chinese follow this (Vanderas *et al.* 1987).

Studies carried out by Fraser, (1980), Owens *et al.* (1985), Tolarová (1987), generally indicate that the more severe the defect, the greater the number of males affected. Derijcke, *et al.* (1996) stated that all the studies they reviewed showed UCLP was more common in males than females, while CP was more common in females. The most commonly affected side was the left and that there was a higher incidence of UCLP compared with isolated cleft palate. Shapiro *et al.* (1999) found that males had a significantly higher rate of cleft lip and palate while females had a higher rate of isolated cleft palate. Unilateral clefts of the primary and secondary palate were found to occur over three times more frequently than bilateral clefts and left side predominance was demonstrated. Recent estimates in the UK suggest that unilateral cleft lip and palate occurs in about 15-20% of all cases of facial clefting (Gregg *et al.* 1994, Sommerlad *et al.* 1994).

3.8 Classification of Cleft Lip and Palate

A standardised and universally accepted classification of cleft lip and palate does not exist, yet there is a need for such a classification to help facilitate good communication between the different disciplines involved in the treatment of those with cleft lip and palate. The most useful classification divides the palate into its anatomical parts.

Cleft Lip (CL).

This may be right or left sided with or without involvement of the alveolus. This cleft includes minimal involvement such as notching, or may be more extensive affecting the lip and alveolus.

Unilateral Complete Cleft Lip and Palate (UCLP).

Right or left sided.

This cleft passes either right or left of the premaxilla, extending back through the incisive foramen, to include the hard and soft palate.

Bilateral Cleft Lip and Palate (BCLP).

This cleft passes down both the right and left sides of the premaxilla and extends backwards to include the hard and soft palate.

Cleft Palate (CP).

This cleft may extend forward as far as the incisive foramen, this group also includes submucous clefts, or soft palate clefts.

Summary

In this chapter various environmental agents that might influence the development of UCLP have been discussed.

- Cigarette smoking is the most commonly studied agent in relation to birth defects. Wyszynski *et al.* (1977) in a review of 11 studies found that cigarette smoking in the first trimester resulted in a small but significant increase in risk of the foetus developing cleft lip and/or palate.
- Diet has on the whole been found to have positive benefits to the developing foetus. Studies have shown that vitamin B6, folic acid or both was effective in reducing the number of babies born with cleft lip and palate. Vitamin A should be treated with caution as excess or deficiency can cause deformities in offspring.
- Drugs such as AEDs and other environmental agents such as fertilisers, insecticides and herbicides have been associated with the formation of cleft lip and palate.

- The aetiology of cleft lip and palate remains unclear, it appears that the multifactorial theory must stand until research becomes clearer. Studies on gene-environment interaction could provide an answer.
- The incidence of cleft lip and palate in the United Kingdom is approximately 1 in every 600/700 live births. The reduction in the incidence may be due to the increased intake of multivitamins and folic acid, an increase in pregnancy terminations and a decrease in the number of live births in the UK population.

Chapter Four

Treatment of Cleft Lip and Palate

4. Introduction

In chapter two the history of cleft lip and palate surgery was discussed where the emphasis concentrated on closing the lip defect and later the palatal defect. At this time some surgeons noted that closing the cleft lip as early as possible helped to reduce the width of the palatal cleft. No emphasis was given to the impact that palatal surgery would have on facial growth as surgeons struggled with the complexities involved in successful palatal repair. As surgical techniques have advanced during this century surgeons and orthodontists have increasingly tried to address the issue of facial disproportion seen in those born with UCLP. This chapter concentrates on the findings of researchers who have studied groups of patients with UCLP with regard to timing and type of cleft repair.

Controversy continues with respect to the timing of cleft palate closure. Many researchers advocate early palatal closure, which gives improved speech, versus those who support late palate closure, which results in improved facial growth. A multi-disciplinary approach to the treatment of cleft lip and palate is essential and the team should include plastic surgeons, maxillofacial surgeons, ear, nose and throat surgeons, speech and language therapists, orthodontists and psychologists. Aesthetic outcome is very important for the patient. What the orthodontist or surgeon might deem a satisfactory outcome in terms of function and aesthetics may not correspond with the hopes and aspirations of the patient, and what they consider to be an attractive or a satisfying clinical outcome (Giddon 1995).

4.1 Surgical Aims of Cleft Lip Repair

Within the entire range of cleft lip types there are varying degrees of deformity both of the lip and nose including tissue absence and asymmetry. Generally there is an inherent vertical shortness along each side involving both the lip and nose and the aim of the surgeon is to straighten and lengthen the columella, straighten the septum and improve the symmetry of the alar arches and bases.

There have been many advances and modifications in techniques of cleft lip repair and there is probably no best single method. In his study on the repair of the cleft lip Ross (1987) found that timing of lip repair did not significantly affect future facial development. However he did emphasise that if repair of the alveolus was carried out at the same time growth was less favourable, especially in the vertical dimensions. Type of lip repair was found to be of less significance than management of the alveolus and anterior hard palate.

4.2 Surgical Aims of Cleft Palate Repair

There are basically three major aims to cleft palate repair; to produce normal speech, to produce anatomical closure, to minimise maxillary growth retardation and dentoalveolar deformity. The social and psychological effects on the individual and the parents of the affected child must also be taken into consideration.

As previously stated, it was the Berlin surgeon Von Langenbeck (1861) who described a new method of hard palate repair. Von Langenbeck described his procedure for uranoplasty (glossary) very precisely in his article published in 1861. A modified version of this technique is still used by many surgeons today including the surgeon of the UCLP group under discussion in this thesis.

In a survey carried out by Lewin (1964) on the management of cleft palate in the United States of America and Canada, results showed that over half the participating surgeons used a form of Von Langenbeck repair. Lindsay (1971) describes a comparison of a Von Langenbeck palatal repair and a pushback repair (Dorrance). The results showed that there was good speech development, fewer incisal crossbites and less buccal segment collapse using the Von Langenbeck method.

It was the conclusion of Blocksman *et al.* (1975) that maxillary growth and speech is as good as other procedures when using the Von Langenbeck repair, and Kaplan (1975) found speech after Von Langenbeck to be acceptable, stating that only twenty percent had velopharyngeal incompetence.

4.2.1 Facial Growth in Cleft Lip and Palate Patients

One of the dilemmas the surgeon faces is the role which surgery plays in restricting antero-posterior, vertical and lateral growth. Many studies on the facial morphology of children with cleft lip and palate have been carried out which show there are significant differences from normal facial growth. Reduced midface development and increased compensatory growth of the lower face being reported by (Graber 1954, Ross 1987). Semb (1991) studied the soft tissues and the hard tissues of patients born with cleft lip and palate with a non-cleft group. She concluded that the UCLP face was characterised by a short retrusive maxilla and elongation of the anterior face (even thought the upper face is shorter) and a retrusive mandible, the nose was flatter. These differences are believed to be associated with intrinsic developmental deficiencies, functional distortions due to anatomical disruption, and iatrogenic (glossary) factors, including surgery and the environment (Bishara 1985, Ross 1987).

Some authors reported that lack of growth in the naso-maxillary complex and the mandible was evident in subjects with isolated cleft palate and that this was due to intrinsic growth impairment (Graber 1949; Dahl *et al.* 1982; Smahel 1984). According to the researches of Krogman *et al.* (1975); Jain and Krogman (1980); Goto (1993) craniofacial growth differences in cleft subjects are dependent on the extent of clefting. These studies suggest that the difference in facial morphology of cleft subjects and subsequent growth pattern after surgery reflects both the intrinsic growth patterns related to the cleft and the effects of surgery.

It has been possible to conduct research on adults with unoperated clefts of the lip and palate, (Ortiz-Monasterio *et al.* 1959; Mestre *et al.* 1960; Bishara *et al.* 1976; Katsuki *et al.* 1976; Sakuda *et al.* 1983; Mars and Houston 1990; Mars 1993). It was found that the face shape differences detected were within the deviations of a normal population, lending support to the idea that the differences in facial growth and morphology within a cleft population is largely related to surgical repair of the hard palate.

Mars (1993) who studied facial growth in Sri Lankans with cleft lip and palate found that lip closure without palate closure was not associated with reduced maxillary growth. He further states that lip surgery without palate surgery almost restores appearance and facial morphology to normal, and that subjects who have had lip repair only have the greatest potential for facial growth.

As surgeons became more aware of the lack of facial growth in the naso-maxillary complex experienced by their patients, a trend towards delaying the closure of the hard palate, was undertaken. In 1944 Schweckendiek (1951) undertook early closure of the soft palate, but left the hard palate open in the belief that this procedure would allow normal maxillary growth and good speech development. The work of Schweckendiek, who delayed palatal closure until twelve to 15 years of age, was examined by (Bardach *et al.* 1984). They reported excellent facial growth and dental occlusion but found eighty one percent of patients had some degree of velopharyngeal incompetence and eighty six percent had glottal and pharyngeal articulation.

The facial growth and morphology of three groups of Sri Lankan males with unilateral cleft lip and palate, who were over thirteen years of age at the time of the study, was investigated by Mars and Houston (1990). The results of this study showed that the subjects who had no surgery had a potential for normal maxillary growth, those who had lip repair in early infancy showed relatively normal maxillary growth, however the group with early lip and palate repair displayed maxillary hypoplasia.

The speech therapists working on the Sri Lankan project (Sell and Grunwell 1990) indicated that late palatal closure results in severe disruption to speech. This has been demonstrated by Schweckendiek (1978); Bardach *et al.* (1984) who state that delayed palatal closure beyond 12 years of age significantly impairs normal speech even though maxillary growth is better. According to the researches of Hotz and Gnoinski (1976, 1979) a co-ordinated timing of procedures in cleft lip and palate cases in Zurich showed beneficial results. They found that early orthopaedic treatment could only be efficient if concomitant primary surgery is adequately timed and performed and they emphasise the importance of a two-stage palatal closure (soft palate at 18 months and hard palate after 5 years of age). Comparison of these results with former treatment methods showed that the current method reduced the need for orthodontic treatment considerably, the patients showed good arch form and intermaxillary relationships in deciduous and mixed dentition, and that the procedure was beneficial to speech development.

A long-term follow up of two cleft groups was undertaken by Rohrich *et al.* (1996). One group had early palatal closure at 10.8 months and the second group the palate was closed at 48.6 months. They concluded that statistically significant speech deficiencies were noted in the group with delayed hard palate closure, especially in articulation, nasal resonance, intelligibility and substitution pattern assessment. They also found that the persistent palatal fistula rate in the late palate closure group was 35% compared with only 5% in the early palate closure group. No significant differences were found in hearing or maxillofacial growth between the groups. They concluded that the data used in this research suggests that delayed hard palate closure results in significant speech impairment without a beneficial maxillofacial growth response.

Cephalometrics have been used in many studies to assess the facial growth in cleft lip and palate patients (Ross1987, Brattstrom 1991, Mars and Houston 1990, Mackay *et al.* 1994), and also in the acquisition and assessment of normative data (Broadbent 1937, Subtelny 1959, Nanda 1990). Significant differences between UCLP and BCLP groups were found by Bishara (1985), especially in the width of the nose base and nose length. Kaplan (1978) measured the dimensions of the upper lip in patients with cleft lips and found a tissue deficiency in the transverse and vertical plane on the side of the cleft, with reduced growth potential in the vertical plane.

Smahel and Mullerova (1994a) who examined lateral skull radiographs of a group of unilateral cleft lip and palate patients showed that there was limited growth in the depth of the upper jaw and the height of the upper lip. The greatest amount of growth was seen in the nose, despite the retrusion of the maxilla. Enemark *et. al.* (1993) studied the morphology of the lip and nose in sixty patients with UCLP from four different centres. Each of the four groups had been treated with different protocols, but many similarities were found, with shorter lip heights at the cleft side and inclination of the rima oris. Asymmetry of the nose and retropositioning at the cleft side naris were generally seen.

Brattstrom (1991) studied craniofacial development in cleft lip and palate children related to different treatment regimes. She concluded that treatment regimes that did not include bone grafting seemed to be the most favourable for maxillary and mandibular development. Treatment regimes, which without bone grafting or with bone grafting after 10 years of age, seemed to be the most favourable to the vertical skeletal proportions. Soft tissue profile (assessed from lateral skull radiographs) was best after regimes that included bone grafting at 10 years of age.

Summary

In this chapter the aims of cleft lip and cleft palate repair have been discussed. A review of the literature on the case for early palate closure versus late palate closure has also been discussed.

- Ross (1987) found that timing of lip repair did not significantly affect future facial development. He did emphasise that if the alveolus was repaired at the same time then growth in the vertical dimension was less favourable.
- Some researchers believe that early palatal closure results in better speech and language development, with no appreciable difference in facial growth found between the late and early palate closure groups (Rohrich *et al.* 1996). Others advocate a co-

ordinated late palate closure as this improves maxillary growth, reduces the need for orthodontic treatment and does not interfere with speech and language development, (Hotz and Gnoinski 1979).

- (Ross 1987), concluded that variations in the timing of hard and soft palate repair within the first decade do not influence facial growth in the vertical or anteroposterior dimension. He felt that the surgeons should repair the hard and soft palate when it is in the best interests of the child.
- Enemark *et. al.*(1993) found shorter lip heights at the cleft side and inclination of the rima oris, asymmetry of the nose and retropositioning at the cleft side naris in 60 cleft lip and palate patients treated with different treatment protocols.
- Brattstron (1991) found soft tissue profile was best after regimes that included bone grafting at 10 years of age.
- Semb (1991) studied the soft tissues and the hard tissues of patients born with cleft lip and palate with a non-cleft group. She concluded that the UCLP face was characterised by a short retrusive maxilla and elongation of the anterior face (even thought the upper face is shorter) and a retrusive mandible, the nose was flatter.

Chapter Five
Facial Measurement

---

5. Introduction

This chapter charts the development of techniques by artists, sculptors and scientists to quantify face shape and proportion. The study of the face is important to many different medical and scientific disciplines because changes in facial appearance due to normal growth, abnormal growth, facial injury or the result of surgical procedures, can deeply effect the individual. Two- dimensional methods such as photography and cephalometrics will be discussed together with their impact on present day development of three-dimensional methods of data collection and the development of computer graphics.

5.1 History of Facial Measurement

The limitations of two-dimensional representations of human anatomy have been recognised for many years. The human body is an object comprised of irregular geometric structures and no obvious internal co-ordinate system. There is no easy way of applying an external reference system. The face in particular, because of the vital importance of appearance, illustrates the need for accurate measurement.

Interest in facial shape pre-dates the ancient Greeks, who were fascinated by beauty, proportion and harmony, leading many to investigate methods of dividing the face in order to develop their ideas more fully.

Not surprisingly, the quest to make good measurements of the three-dimensional surface anatomy of the face spans many centuries. More than 1000 years BC ancient Greek sculptors designed frames for recording facial shape in order to faithfully produce likenesses in stone and to contemplate the aesthetic significance of various proportionate measures. Greek philosophers and mathematicians attempted to interpret beauty in terms of "divine proportions" (Huntley, 1970). The Greeks were impressed with the idea of balance and symmetry. Plato defined beauty in what he termed the "golden section", which is a method of subdividing an object into thirds. The brow would be one third of the way down from the hairline, the mouth would be situated one third of the way up from the point of the chin and the width of the face would be two thirds of its height. According to Liggett (1974), Mediaeval artists believed a perfect face was divisible by sevenths. Further philosophical and analytical inquiries have been made in more recent times.

In the 15th century Leonardo da Vinci recorded many faces and attempted to understand them in mathematical terms (Clark, 1968). In the 16th century Dürer (1528) produced a work which included facial analysis in three-dimensions. In 1888 the geneticist Francis Galton (1888) described a device for recording facial profiles as a series of measurements and used these measurements over many years to produce morphological classifications (Galton 1910).

The development of orthodontics in the nineteenth century created an upsurge of interest in facial growth and development as successful outcome depends on careful and accurate measurement. Many ingenious mechanical devices were proposed to record the geometry and growth of the face, such as the prosthometer (glossary), which was designed for the measurement of head size and the relationship of the teeth relative to the head, (figure 1).

Figure 1: A Prosthometer which measures head size and the position of the teeth relative to the head

With the discovery of x-rays by Roentgen in 1895 it became possible to obtain detailed information on the internal anatomy. Although the x-ray images themselves were planar projections it was quickly realised that 3D information could be derived from them. The first attempt of deriving 3D information from planar x-rays was carried out by Davidson (1898). The concept of combining data from a set of x-rays taken from orthogonal viewpoints to produce key anatomical landmarks within the skull was introduced by Broadbent (1931).

In today's society facial aesthetics has attained immense standing. This has led many people to seek the skills of plastic surgeons, so that they may conform to an idealised sense of beauty. Many scientific groups, such as anthropologists, medical scientists, forensic scientists and geneticists have also undertaken the study of the face. The interest shown by so many different professions has led to the development of many different methods for measuring facial morphology.

5.2 Computer Graphics and Visualisation

Currently, the most common methods used to predict and analyse facial growth and surgical outcome are photography, cephalometrics, direct facial measurement and stereophotogrammetry. Photography is a broadly used no-contact technique with the advantage of recording the tissues undistorted. Problems may arise due to small variations in the viewpoint from which the face is depicted and the 2D nature of the record limits its usefulness. Its 2D character, difficulty in soft tissue definition and landmarking (Cutting *et al.* 1986) limits the use of cephalometrics. As with any radiographic technique there is the additional hazard imposed by the radiation dose. However, cephalometrics have been used in several studies for assessing differences in facial growth and morphology in UCLP patients (Ross 1987; Brattstrom 1991). The 3D assessment of the face is possible using CT scans, the accuracy of which is dependent on slice thickness. The considerable radiation dosage associated with CT also restricts its usefulness. Ras *et al.* (1995) have used Stereophotogrammetry to measure in 3D the faces of children with cleft lip and palate

By the mid 1980's several groups demonstrated the effectiveness and benefits of using computer graphics in the planning of facial and craniofacial surgery (Moss, *et al.* 1989; Rabey, 1971,1977; Joffe *et al.* 1992). However, the use of graphics techniques to plan and simulate cranial and maxillofacial surgery was greeted with both scepticism and criticism from some eminent surgeons' (Savolini *et al.* 1984 Tessier and Hemmy 1986). Subsequently, a number of graphics workstations have been designed and built specifically for the production of anatomical surface images from commonly used medical imaging systems including, Computerised Tomography (CT) scanners, Nuclear Magnetic Resonance (NMR) imaging systems and Ultrasound systems which are able to provide full information on the spatial position. However as NMR has geometric distortions it is not suitable for use in facial measurement. *

Direct facial measurement of patients with UCLP was reported by (Farkas *et al.* 1993), this author has also collected direct facial measurements of control populations (Farkas *et al.* 1992). Hodgkinson and Rabey (1986), used a method of combining lateral skull radiography and photography to produce a measuring technique called three-dimensional morphanalysis.

At present no 3D method is available which provides a readily analysable global description of the face. Facial morphometry is extremely important in many clinical and research fields, and has numerous applications. Before objective mathematical methods can be applied to its morphology, sets of measurements representing the facial shape are needed. Clinically, one of the main problems in assessing the changes in the faces of those born with facial asymmetry is that 2D analysis does not give a satisfactory picture of the underlying problem. Also the qualitative and quantitative 3D changes which occur in the face during growth or as a result of surgery remain largely undetermined.

For a complete understanding of most questions involving facial morphology, three-dimensional information is essential. For reasons of cost and hazard to the subject or patient, it is desirable to avoid the use of scanners using X-rays to collect the data needed, particularly in serial studies and patient follow up. Where only surface anatomy is of importance various kinds of measuring devices have been developed. One such system of automatic optical surface scanning developed at UCL is capable of producing 60, 000 3D measurements across the entire facial surface in 7-10 seconds.

Computer graphics techniques for representing and displaying surfaces have had a profound effect when applied to the study of the human body. Modern generation medical imaging systems such as computerised tomography (CT), magnetic resonance imaging (MRI) and ultrasound produce great quantities of data on the human body. The advantage of these systems is that they produce truly three-dimensional data whereas the older x-ray systems produced only projections through anatomical volumes. Using computer graphics it is possible to show data collected by CT, MRI and ultrasound scanners as anatomical surfaces. Presentation techniques allow anatomical surfaces to be perceived as a solid three-dimensional object, albeit on a two-dimensional screen. In the

* personal communication

more advanced systems an operator may interact with these to make measurements, simulate surgery or design prostheses. Having anatomical surfaces in numerical form also allows the possibility of using mathematical tools to analyse shape change in a way that had been previously impossible. Computer graphics can be seen to be opening many new possibilities for planning surgical procedures and improving aesthetic outcome.

5.3 Photography

Photography is a commonly used technique for recording facial data undistorted. Photographs taken from anterior and lateral views of the face have been widely used for identifying, describing and measuring facial features, mainly for security and forensic purposes. The extensive use of two-dimensional data to study and measure the face is well documented. The 2D nature of the record limits its usefulness and problems can arise due to small variations in the viewpoint from which the face is depicted (Asher-McDade *et al.* 1992, Enemark *et al.* 1993, and Ras *et al.* 1995).

The Frenchman, Alphonse Bertillon (Rhodes 1956), was one of the first people to develop a method of classifying and identifying people from photographs, combined with some anthropometric measurements of the individual. The method used by Bertillon involved cutting the photographs and blending the isolated features of different individuals by mounting them side by side on pieces of cardboard.

More recently the method of computer digitisation of photographs has been used in several studies. Coghlan *et al.* (1993) used this technique to measure nasal asymmetry and Bishara *et al.* (1995a); Cummins *et al* (1995) used this method of digitisation to allow the analysis of changes in the face following orthodontic treatment. Further analysis of the changes in facial dimensions using frontal and lateral photographs has been carried out by Bishara *et al.* (1995b). They concluded that the technique was operator and technique sensitive and there were many limitations to using facial photographs, such as, positioning of the camera and subject, magnification, and lighting which are vital to accuracy and difficult to overcome. Although surface measurements can be taken from standardised photographs, these are 2D images of 3D objects and therefore provide limited information on changes in face shape.

5.4 Cephalometrics

To those involved with facial measurements the discovery of x-rays by Roentgen in 1895 was an exciting prospect. As x-ray images were planar projections it was quickly realised that three-dimensional information could be derived from them. The first attempt at deriving 3D information from planar radiographs was reported by Davidson in 1898. This coincided with an upsurge of interest arising from the development of orthodontics, the success of which depends on careful and accurate measurement.

With the arrival of medical x-ray systems, the techniques of radiographic cephalometrics developed first slowly and then rapidly over the period between 1920 and 1940. The principles of cephalometry are based closely on the science of craniometry, a method that has been used by anthropologists in the quantitative assessment of the skull.

It was Broadbent (1931) who introduced the concept of combining data from a set of x-rays taken from orthogonal viewpoints to produce the three dimensional distribution of key anatomical landmarks within the skull. Although this system was properly conceived it did not come into widespread use, as it was limited in accuracy by the contemporary technology, however Broadbent's ideas significantly influenced future developments in this field (Rabey 1971).

Rabey (1977) reported the development of a system similar in principal to Broadbent's. This system was technologically advanced and capable of producing accurate and consistent results. The key to this system was the method of fixing the pose of the head so that an external co-ordinate system could be applied. Research carried out by Mitgard (1974), and Ahlqvist (1986), showed that errors in cephalometrics could be very low when due care was given to positioning the patient in a cephalostat. Provided that the external auditory meatus could be accurately located, measurements made with this system were repeatable and a series of measurements taken over time could be validly compared.

Most of the information we now have on hard and soft tissue growth changes is derived from lateral cephalograms and it is essential that points identified on consecutive radiographs are reproducible, so that comparisons can be validated. Many studies have been undertaken on the evaluation of the errors in obtaining measurements from lateral skull radiographs and these have been well documented (Richardson 1966, Baumrind and Frantz 1966, 1971). It is virtually impossible to identify soft tissue points on an anteroposterior radiograph. Another disadvantage is that many of the landmarks are not homologous, do not lie on the skeleton and are in fact points in space (Cutting *et al.* 1986).

One of the main disadvantages of cephalometrics is that it exposes the patient to hazardous ionising radiation. However this remains the main method of assessment of changes in facial dimensions between groups (Ross 1987; Brattstrom 1991; Semb, 1991; Smahel and Mullerova 1994b). In the past researchers have been able to x-ray the general population in order to study the differences in growth within a population, with the strict ethical approval required in the present day, it would not be possible to use this method when investigating population norms. Standardisation of the technique is also necessary to minimise error such as enlargement caused by positioning the head too far from the x-ray film, the x-ray beam must be perpendicular to the subjects midsaggital plane and the film surface.

5.5 Stereophotogrammetry

The principle of stereophotogrammetry is based on viewing two photographs taken from two slightly different viewpoints, which are then viewed with each eye simultaneously. Mansbach (1922) was the first person to realise the potential of this method of recording and the use of stereophotogrammetry to record the facial surface was demonstrated by Zeller (1939). Thalmaan-Degan (1944) applied the method clinically and reported changes in facial morphology due to orthodontic treatment and illustrated and quantified them by means of contour plots.

Three-dimensional co-ordinates are obtained by identifying the same points on both images using either a pattern projected onto the surface of the object or by placing physical markers on the surface. The main advantages of stereophotogrammetry are that data collection time is fast and the system is accurate. Savara *et al* (1965) claimed an accuracy of 0.2mm for recording the facial surface. Burke and Beard (1967) found errors up to 0.8mm, studies carried out by Burke (1971,1972) suggest that the standard deviation error to be 0.69, while Farkas *et al.* (1992) found that linear measurements obtained using this technique were comparable to direct anthropometric measurement.

This method of data collection has been widely used to study facial growth and change (Burke and Beard 1979; Burke and Hughes Lawson 1989; Burke *et al.* 1983; Ayoub *et al.* 1996, Ayoub *et al.* 1997, Ayoub *et al.*1998). Stereophotogrammetry has been used to measure the soft tissues of the face in 3D (Ras *et al.* 1994) and in a later study the system was used to analyse a group of 16 patients with UCLP (Ras *et al.* 1995). Ras and his co-workers identified eight pairs of surface landmarks and used a reference plane to measure asymmetries. They demonstrated that this produces a reproducible index to assess facial asymmetry and may be used to distinguish between the control and UCLP group. They showed that in the unilateral cleft lip and palate patients the nose was significantly wider above the alar base, and that overall the cleft nose was larger than the controls.

The main disadvantages of stereophotogrammetry are that the optical systems are expensive to buy, are complicated to use, requiring a skilled operator and complex computations to yield accurate and consistently good results. According to Chadwick (1992) most work using stereophotogrammetry should be carried out in specialist cartographic units.

5.6 Moiré Topography

Takasaki (1970) described the technique of Moiré Topography. This technique uses a light source projected through a grid, casting a shadow onto the surface of the object to be measured. This shadow is then viewed through another grid and a set of fringe patterns is seen. These are called Moiré fringes and they correspond to contours on the surface being investigated. A permanent record of Moiré fringe patterns can be provided by photography.

Several authors have used Moiré fringes to measure the face (Xenofos and Jones 1979). More recently moiré topography has been used to map the in-plane distribution in slices from human tooth crowns under compression Wang and Weiner (1998) and in the evaluation of facial palsy Yuen *et al.* (1997).

The fringe patterns are dependent on the position and orientation of the patient and considerable skill is needed to interpret them (Turner-Smith, 1988). The surface can only be measured from one viewpoint using this method; for 360-degree measurements separate photographs taken from different viewpoints would be necessary as well as a means of connecting them together. Topographic information can be extracted from these fringes but this is difficult and time consuming

Although the fringe patterns are difficult to analyse, (Elad and Einav 1990), some advances have been made towards automatic analysis (Boehnlein and Harding, 1986, Kawai *et al.* 1990).

The complex patterns, which are formed by Moiré fringes, especially on the face and body surfaces, are not well suited to automatic conversion to 3D co-ordinates (Arridge *et al.* 1985). Head position is critical as small changes in head position produce large changes in the fringe patterns (Kanazwa and Kamiishi, 1978).

5.7 Fourier Transform Method

Takeda and Mutoh (1983) proposed this method of data acquisition to overcome some of the difficulties associated with moiré fringe patterns. The Fourier transform was used to analyse bands of light produced when a grating pattern was projected onto an object. This process avoids the need for determining the order of fringes, locating the centre of the fringe or interpolating between fringes as it provides the distribution of the object's height across the entire image. It is also sensitive to variation in height within fringes and can automatically distinguish between depressions and elevations in the shape of an object. This method was used by Ferrario *et al* (1990) to analyse different chewing movements and Ferrario *et al* (1996) to assess the effects of growth and development on soft tissue human facial shape, and the effect of growth and development on cephalometric shapes in orthodontic patients (Ferrario *et al.* 1997a).

5.8 Facial Three-Dimensional Morphometry

This method of data collection provides three-dimensional data independent from head posture and projection errors (Ferrario *et al.* 1994a). The method uses two high-resolution infrared CCD video cameras, coupled with a video processor. The landmarks are identified either by careful inspection or palpation of the subjects' face and reflective markers are then placed on the centre of each point, usually sixteen landmarks are identified. The infrared cameras illuminate the markers and views are obtained of the left and right profiles. The computer then produces the metric three-dimensional co-ordinates of the centre of gravity of the landmarks.

This method of data collection has been used in the assessment of human facial volume (Ferrario *et al.* 1995a) and used in the comparison of the facial morphology of television actresses with normal women (Ferrario *et al.* 1995b). It has also been used to compare the soft tissue facial morphology of children with Class I and Class II occlusions (Ferrario *et al* 1994b) and in the study of the growth and development of the nose (Ferrario *et al.* 1997b).

The main disadvantages of this method of data collection are the time taken to place the markers and the lack of computer software to visualise the differences between faces, only the production of figures.

5.9 Direct Facial Measurement

Direct facial measurement, anthropometrics, has been used primarily by anthropologists, to study changing dimensions of the human body. Direct facial measurement is carried out using callipers, protractors and measuring tapes (Farkas 1994). Normal growth of the face in Caucasians has been monitored using direct clinical measurement Farkas *et al.* (1992). Lindsay and Farkas (1972) reported the direct measurement of the cleft nose using a landmarking technique. They found that cleft noses were significantly wider than comparable controls. In a later study, Farkas *et al.* (1993) examined patients with unilateral cleft lip and palate and bilateral cleft lip and palate, both before and after surgery, using direct anthropometric measurements. They showed a decrease in the frequency of noses that were disproportionately wide following surgery, they also demonstrated that unilateral cleft lip and palate patients had nostril floor width asymmetry, columella length asymmetry and a unilateral flat alar. This technique is limited by difficulties in landmark identification and reproducibility, compression of the soft tissues when taking the measurements and the time taken to record the data. The number of 3D co-ordinates is small.

5.10 Computerised Tomography

The 3D assessment of the face is possible using x-ray computerised tomography (CT), the accuracy of which depends on slice thickness. This method of 3D data collection involves the collection of tightly collimated x-ray beams that are received by a series of detectors. The detectors convert the information into electrical impulses proportionate to the amount of radiation received. A CT scan can provide information on both hard and soft tissues the data may be displayed and manipulated on the computer screen. CT scanning can be used in surgical planning as various parts of the anatomy which have been scanned can be separated and bone thickness can be measured, it is also possible to mirror image the data to produce a template for missing or damaged bone tissue. The major disadvantage of CT scanning is that large doses of radiation are required for accurate data collection, therefore its use for collection of normative data for comparative studies is unlikely (Arridge *et al.* 1985, Grayson *et al.* 1988).*

5.11 Optical Surface Scanning

The technique of optical surface scanning has been described by Moss *et al* (1987, 1988). The system consists of an optical bench incorporating the camera, laser and mirrors, a rotating chair and a PC compatible computer. A concentrated monochromatic low power

* C.T is also unsuitable for repeat scans which may be needed for longitudinal studies.

(1 milliwatt) Helium-Neon laser beam produces a red light that strikes a small cylindrical lens and fans out to a vertical line 0.7mm wide. This line runs vertically down the subject's face to illuminate the profile. The red line is viewed from either side by a pair of large mirrors that are in turn viewed obliquely by a video camera.

This system of data collection is non-hazardous, non-invasive, non-contact and quick. The system is capable of recording and measuring 60,000 3D points over the facial surface with a data collection time under 10 seconds. The data recorded is processed automatically by computer providing almost instantaneous images, which can be edited and manipulated on the computer screen. The system is easy to use, exact positioning of the head is not necessary for the comparison of scans, and landmarking is comparatively easy. Although the system is initially costly to set up, data capture is very cost effective.

Summary

Chapter five has covered the history of facial measurement from Ancient Greece until the present day. The advantages and disadvantages of two-dimensional imaging techniques have been discussed. The development of computer graphics has been discussed and the advantages and disadvantages of 2D and 3D data collection methods have been assessed:

- The quest to make measurements of the 3D surface anatomy spans many centuries, Plato defined beauty in terms of the golden section.
- Leonardo da Vinci recorded many faces and tried to understand them in mathematical terms.
- Francis Galton described a device for recording facial profiles as a series of measurements that he used over many years to produce morphological classifications.
- Computer graphics techniques for representing and displaying surfaces have had a profound effect when applied to the human body and were seen to open up new possibilities for planning surgical procedures and improving aesthetic outcome.
- Photography is a commonly used method of collecting facial data but is limited by its 2D nature, camera positioning, magnification and lighting.
- The use of Cephalometrics for assessing changes in the hard and soft tissues of the face. The disadvantages of this technique include ionising radiation, standardisation of the technique is required to minimise enlargement error.

- Stereophotogrammetry has been used clinically to study facial growth and change. Data collection time is fast and the system accurate, the main disadvantages of this system are expense, complex computations are required to give consistently good and accurate results.

- Moiré Topography has been used to measure the face. Automatic interpretation of the fringe patterns is difficult. Head position is critical as small changes in head position produce large changes in the fringe patterns.

- The Fourier Transform Method was developed to provide analysis of Moiré fringes.

- Facial three-dimensional morphometry has been used to study facial morphology of different groups.

- Direct Facial Measurement has been used to monitor normal facial growth and also the growth of the cleft nose. Limitations of this technique include difficulties with landmark identification and reproducibility, compression of the soft tissues and the time taken to record the data.

- Optical Surface Scanning is a no-contact, non-hazardous and quick method of collecting three-dimensional data. The system is easy to use, exact positioning of the head is not necessary for comparison of the data and landmarking is comparatively easy. Data capture is very cost effective. In-house software developed alongside the system allows visualisation and comparison of facial data.

Chapter Six
Material and Methods

6. Introduction

The facial data used for analyses in this thesis were taken from a database of three-dimensional facial data comprised of cleft lip and palate patients and a control group. The data were collected using the optical surface scanner developed at UCL and the methods used are described in full in this chapter. Two methods of analysis were used for the groups under investigation, registration and distance measurement, both of which are discussed in detail in this chapter.

The three-dimensional optical surface scanner used for this work is a no contact, non-invasive, quick and accurate method of recording faces in 3D. Computer software developed alongside this system allows the comparison and analysis of data with a normal population.

6.1 Material

In order to investigate the facial morphology of patients with unilateral cleft lip and palate and to ascertain any differences in facial morphology the cleft group was compared with a control group. Both groups were divided into males and females and grouped according to age, 4-8 years, 9-12 years and 13-16 years. The facial morphology of male clefts compared with female clefts was also studied within each age group.

The age ranges for the groups were chosen on the basis that at 4-8 years of age the sample within the UCLP group had all had the lip and palate repaired. At age 9-12 alveolar bone grafting has been carried out, and at 13-16 no orthognathic surgery had been undertaken. The groups are as follows:

- 73 Caucasian children born with a unilateral complete cleft of the lip and palate attending our East London data collection centre, all operated on by one surgeon. All right sided unilateral clefts were mirror imaged to make them left sided clefts, and so increase the numbers within the groups.
- 245 Caucasian children with an Angle class I dental occlusion, attending either our East London centre or our Central London centre. No history of extractions or orthodontic treatment.
- The age range for both male and female groups would be from 4 years of age to 16 years of age.

Females	No. in group	Males	No. in group
UCLP		**UCLP**	
Age 4-8	19	Age 4-8	19
Age 9-12	10	Age 9-12	12
Age 13-16	9	Age 13-16	7
Control		**Control**	
Age 4-8	39	Age 4-8	65
Age 9-12	38	Age 9-12	42
Age 13-16	23	Age 13-16	38

Table 1: Male and Female cleft and control group numbers

The data used in this study was acquired using the cross-sectional method described below. There have been many debates within the scientific community of the value of cross-sectional versus longitudinal data (Prahl-Andersen and Kowalski 1973; Farkas 1996). Farkas (1996) described the following advantages and disadvantages of both methods.

6.1.1 Longitudinal Method

In longitudinal studies the subjects are examined regularly at specific ages over a long period of time. The advantage of this method is that it offers information on the pattern, changes and acceleration of growth. Tanner (1962) held the view that longitudinal data are essential to document the variability of change from one year to the next. The disadvantages of longitudinal data collection are many. Data collection time is long, if studying changes in facial morphology from birth to 18 years of age then 20 years would be required to complete the study, it is also very difficult to maintain contact with all the subjects in the group being studied. The data may be acquired using several different investigators whereas if only one investigator is used variability with the results will be reduced.

6.1.2 Cross-Sectional Method

In a cross-sectional study, the subjects are studied at certain ages. The data is collected from samples of individuals of a similar age. There are many advantages to using the cross-sectional method. A minimal number of investigators are required, completion time for the investigation is relatively short, and costs are significantly reduced. A cross-sectional sample also provides a representative population sample, as individuals in the group are much more likely to be from different socio-economic and cultural groups.

The disadvantages of cross-sectional studies are that they are of limited value in growth studies according to Tanner (1962) who states that the magnitude of the growth spurt can be grossly underestimated. Pruzansky (1977) believed that individual growth patterns were obscured. However studies comparing head circumference obtained by longitudinal study (Kantero and Tiisala, 1971) are in agreement with cross-sectional studies by Takkunen (1962).

6.1.3 Treatment Protocol

One surgeon has operated on all 73 UCLP patients studied using the following protocol:

- **birth:** active feeding plate to help align the palatal shelves
- **3 months:** lip repair using the Millard repair
- **6 months:** closure of the palate using a modified von Langenbeck technique
- **9-12 years:** alveolar bone grafting using iliac crest
- **10-12 years:** orthodontic treatment
- **17 years:** orthognathic surgery and rhinoplasty

6.2 Methods

All the data acquisition and analyses described in the following sections were performed by the author alone.

6.2.1 Acquisition of Data

The three dimensional facial data used in this thesis was obtained by optical surface scanning of the face using a system described by Moss *et al.* (1987, 1988). This system of data collection is non-hazardous, non-invasive, no contact and quick. The system is capable of recording and measuring 60,000 points over the facial surface with a data collection time of approximately 10 seconds.

Figure 2 illustrates the scanner and its optical set-up. The system consists of an optical bench incorporating the camera, laser and mirrors, a rotating chair and a PC compatible computer containing a TV line digitizer and transputer graphics interface.

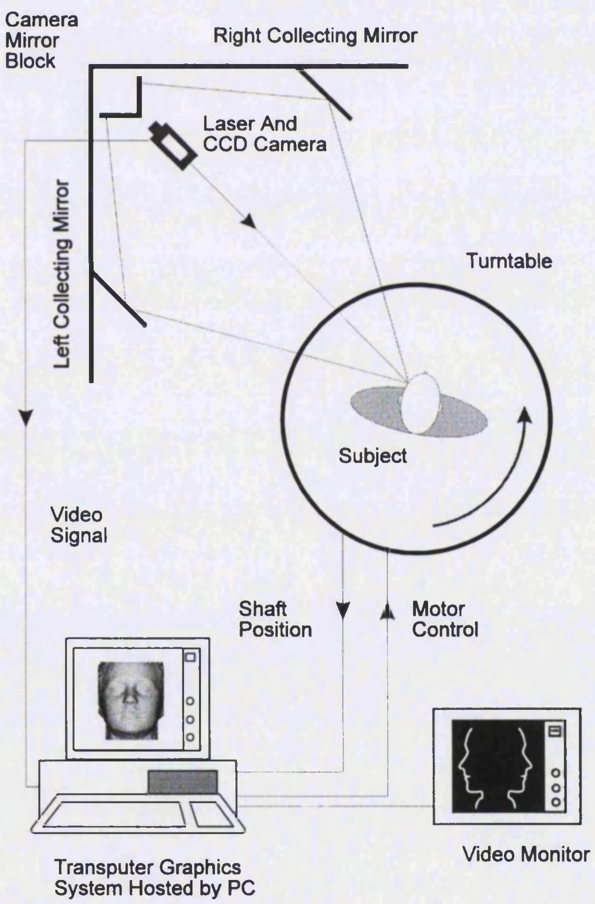


Figure 2: Optical Surface Scanner

A monochromatic Helium-Neon laser (1 milliwatt) beam produces a red light, which strikes a small cylindrical lens and fans out to a vertical line 0.7mm wide. This line runs vertically down the subject's face to illuminate a profile. The red line is viewed from either side by a pair of large mirrors, which are in turn viewed obliquely by a video camera. The subject is seated on a chair, which is fixed on a platform and is connected to a central drive and can be rotated by a stepper motor under computer control for a known time. Hair is kept clear of the forehead and ears by the use of a hairband. All the subjects were instructed to close gently on their back teeth with a relaxed lip posture for the duration of the scan. Overhead lighting in the room is reduced and any windows shaded to prevent extraneous light sources.

The subject is turned towards the laser beam, the position and height of the chair is adjusted using a worm screw height adjuster. The position and height of the subject can be viewed on the black and white monitor, and when the headrest of the chair is at the correct level and the laser beam illuminates the entire midline profile then the scanning procedure can begin

The computer system is activated and the chair manually rotated in a clockwise direction so that the laser beam illuminates the region posterior to the left ear. This is the start position for scanning, the subject is asked to keep still and the scan is initiated using the computer keyboard. As the chair rotates the video image of the line of intersection between the beam and the facial surface is pre-processed and passed via an interface to the memory of the computer. The distortion of the laser line as it illuminates the face is recorded every 2 degrees of rotation, except across the central portion of the face where it is recorded at 1 degree intervals. The operator can adjust chair speed and scanning interval.

Calibration of the system was carried out weekly, and the accuracy of the system has been investigated by Moss *et al.* (1989). Single profiles can be recorded with a radial spatial resolution better than 0.5mm and vertical resolution better than 1.0 mm. Approximately 250 facial profiles are recorded on each subject and the 300 data points within each profile are then imaged by faceting and Gouraud shading of the polygons to give a realistic picture of facial form, as seen in figure 3. Measurements made using the UCL optical scanner may be presented on the graphics screen in several ways. Raw profile data may be displayed as individual points measured along the profile. When the data are presented in this way any point on the profile may be individually edited to a new position. This method may be used to remove a rare erroneous point or for low level editing to change the shape of the anatomical surface in the neighbourhood represented by this data. The data may also be presented as the entire population of profiles in projection or as derived transverse sections.

Figure 3: An example of an optical surface scan

The method has been used to study facial form and aesthetics (Moss *et al.* 1991, Moss *et al.* 1995). It has also been used to study the effects of orthognathic surgery (McCance *et al.* 1992; McCance *et al.* 1993), the soft tissue differences between two ethnic groups (Sulaiman 1995), the growth of Caucasian children from 5-10 years of age (Nute 1997) and in the analysis of the child cleft face (Duffy 1997).

6.2.2 Averaging

To produce an average scan for comparison between groups, the individual surface measurements of each scan must first be registered, using the technique of multiple landmarking. The facial data under investigation in this study was processed to produce average facial data using the method described below.

The scaling of the scans for the creation of an average is dependent on the landmarks chosen. To allow radial data to be sampled from the whole facial surface and to give equal weighting to all parts of the scan, fifteen landmarks are required. These are ten interactively inserted landmarks and five automatically generated forehead points.

After registration and scaling the surfaces are resampled on a regular cylindrical grid in the common co-ordinate system. The new radial measurements of the surfaces are used to produce an average face as seen in figure 4.

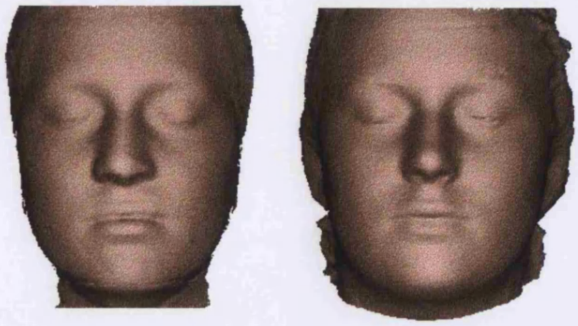


Figure 4: An example of two average faces for comparison

6.2.3 Landmarks

Each point on a dataset has an arbitrary position, in that it does not necessarily correspond to any known feature on the head. However if we wish to describe or locate the head in space, the positions of a number of landmarks are required.

Fifteen landmarks were identified on each optical surface scan and marked with a mouse driven cursor. The identification of landmarks is greatly assisted by the displaying of both horizontal and vertical profiles over the surface of the scan at each chosen point, an example of which can be seen in figure 5. This allows the maxima and minima curvatures associated with landmarks to be accurately located.

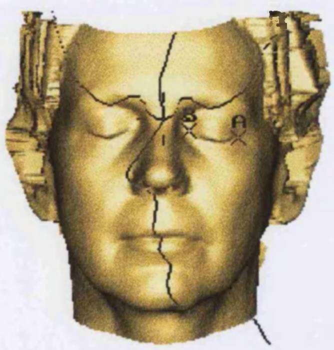


Figure 5: Illustration of horizontal and vertical profiles

Ten landmarks are interactively marked using a mouse driven cursor these are:

- **Exocanthion:** the depth of the concavity in the vertical and horizontal planes at the outer commisure of the right and left eye fissure.
- **Endocanthion:** the depth of the concavity in the vertical and horizontal planes at the inner commisure of the right and left eye fissure.
- **Soft tissue nasion:** the depth of the concavity of the soft tissue in the vertical plane and the maximum convexity in the horizontal plane at the base of the brow ridges.
- **Subnasale:** the midpoint of the angle at the columella base where the lower border of the nasal septum and the upper lip meet.
- **Alar Base:** the most lateral point of the curved right and left alar base indicating the facial insertion of the nasal wings.
- **Upper Lip:** vermilion border in the midline.
- **Lower Lip:** vermilion border in the midline.

An additional five points are mathematically constructed across the forehead.

6.2.4 Construction of Forehead Points

The five points across the eyes and nasion are joined to form a constructed line. The face is then orientated with the midsaggital plane at 90 degrees to this line. Five additional landmarks, which are arbitrary points, are then automatically constructed on the forehead. The first point is a perpendicular projection from the canthal-constructed line at a distance of 30mm up from soft tissue nasion. The next two pairs of points are constructed at 15mm intervals across the forehead, perpendicular to the midsaggital plane.

6.2.5 Registration

In order to visualise the differences, compare shapes and quantify changes between scans of an individual or groups of individuals taken at different times, and allow the quantitative assessment of the effects of growth or surgery, the facial surfaces must be transformed to a common co-ordinate system. This process is called "registration". In-house software was developed which allows the registration of surfaces in 3D. Using the University College workstation the two anatomical surfaces to be compared are displayed side by side on the graphics screen and a set of homologous landmarks are placed using the PC mouse directed cursor. Landmark location is greatly assisted by a simultaneous display of the vertical and horizontal sections of the facial surface through the point at which the cursor is located. Ten landmarks, five across the eyes and five across the forehead, above the brow ridges, were used to register the optical surface scans for the comparison of the two groups in this project.

For registration purposes only parts of the face which have not changed are used. Once appropriate landmarks have been located and selected, registration is achieved by a least squares iterative procedure, which takes advantage of Newton's least squares method of fitting the radial distances between a set of points (Fright and Linney 1993).

6.2.6 Visualisation and Display Data

The differences in the registered surfaces are colour coded and displayed, these differences are the radial distances from a computed common axis of the two surfaces. The colour coding is in 2mm steps with cold colours (green to purple) representing negative surface displacement and the warm colours (yellow to red) representing positive displacement. The brown areas represent surfaces that have not changed.

6.3 Errors in the Methods

6.3.1 Errors in data acquisition

Movement of the object during scanning can be detected immediately by viewing the scan on the monitor, a re-scan will then be undertaken. The system is calibrated on a weekly basis so that any errors in the geometry of the system are minimised.

6.3.2 Posing Errors

A protocol for positioning of the patient was adhered to. The patients were asked to gently close on their back teeth with the lips gently touching.

6.3.3 Errors in landmark identification

Reproducibility of landmarks have been investigated by Baumrind and Frantz (1971) who stated that the most reproducible were those around the eyes and the tip of the nose. Moss *et al.* (1989) and McCance *et al.* (1992) have used similar landmarks to those used in this study. The repeatability of landmark placement can be investigated by one person repeating measurements several times on the same scan, or two people may mark the same point on the same scan. The siting of landmarks by a single operator or by two different operators has been shown by Coward *et al.* (1997) to be highly repeatable.

6.3.4 Error Study of Reproducibility of Landmarks for Registration

One patient was scanned twice, one week apart, and the facial scans were landmarked by the author on two separate occasions to check the accuracy of the system and precision of intra-operator landmarking. The registered image of the error study is shown in figure 6, the image on the left represents the subtraction of surface A from surface B and the image on the right represents the subtraction of surface B from surface A. Visual inspection indicates that the registration between the two surfaces is very good, that landmark placement is accurate, as no significant differences between the faces can be seen. The root mean square error of the two datasets was 4.23mm. and 4.32mm. respectively indicating good registration of the data. Table 2 shows the *x, y* and *z* co-ordinates of the scans and confirms an accurate correlation in landmark placement. Aung *et al.* (1995) compared laser scan measurements with direct facial measurement and found that these were highly reliable especially across the nose and circumoral region. They do not state whether the landmarks were placed by one operator or several, although they do mention that accurate location of landmarks and operator skill are important factors to achieve accurate results. Coward *et al.* (1997) tested the accuracy of landmark identification of the ears using two operators and concluded that landmarks of the ears and face can be sited consistently by two assessors who jointly agreed the landmark position.

Figure 6: Error study of two registered images.

Landmark	X	Y	Z
1	45.00	16.100	52.835
2	17.500	21.700	61.771
3	3.500	24.500	72.313
4	-11.200	21.700	61.390
5	-37.800	16.100	56.240

Landmark	X	Y	Z
1	46.200	16.000	51.883
2	17.500	21.000	61.788
3	3.500	23.800	72.345
4	-11.200	21.700	61.390
5	-37.800	16.100	55.726

Table 2: the *x, y, and z* co-ordinates of landmarks for registration error study

6.4 Mark and Measure

Our software programme allows distances between a set of landmarks on the average images to be carried out. The operator may place an unlimited number of homologous landmarks on the facial surfaces as required using a mouse directed cursor. As previously mentioned, landmark placement is assisted by an on screen display of both horizontal and vertical profiles over the surface of the scan at each chosen point. Since there is a numerical representation of the facial surface in the computer, any point on the surface and the *x y z* values can be found by the computer. It is also possible to calculate the distances between the 3D co-ordinate points.

6.4.1 Facial Landmarks

For this analysis thirteen facial landmarks were used and are listed below.

- **Exocanthion:** the depth of the concavity in the vertical and horizontal planes at the outer commisure of the eye fissure
- **Endocanthion:** the depth of the concavity in the vertical and horizontal planes at the inner commisure of the eye fissure
- **Soft tissue nasion:** the depth of the concavity of the soft tissue in the vertical plane and the maximum convexity in the horizontal plane at the base of the brow ridges
- **Pronasale:** was the most prominent point on the vertical profile of the nose
- **Subnasale:** the midpoint of the angle at the columella base where the lower border of the nasal septum and the upper lip meet
- **Alar Base:** the most lateral point of the curved alar base indicating the facial insertion of the nasal wings
- **Upper Lip:** vermilion border in the midline
- **Lower Lip:** vermilion border in the midline
- **Sublabiale:** the point in the midline of the labial mental sulcus
- **Pogonion:** the most anterior midpoint of the chin

6.4.2 Definition of Linear Facial Measurements

For the purpose of this study the measurements have been defined as follows:

- **Nose length:** soft tissue nasion to pronasale
- **Nasal tip protrusion**: subnasale to pronasale
- **Alar base width**: the distance between the most lateral aspect of the left and right alar contour
- **Upper face height**: soft tissue nasion to subnasale
- **Lower face distance**: subnasale to pogonion
- **Upper lip length**: subnasale to the most prominent point on the midline of the upper lip
- **Lower lip length:** the most prominent point on the midline of the lower lip to the labial mental fold which is the depth of the concavity above the prominence of the chin at the level of the apices of the lower incisor teeth
- **Chin Height:** the concavity of the labial mental fold in the midline to pogonion

The mark and measure programme allows points to be inserted on the facial surface as shown in figure 7, the distances between these points can then be measured. Asymmetry of the nose is one of the most common problems the surgeon must deal with when treating children with UCLP therefore nasal angles were also investigated as they provide information on shape. Six nasal angles were identified and are also illustrated in figure 7.

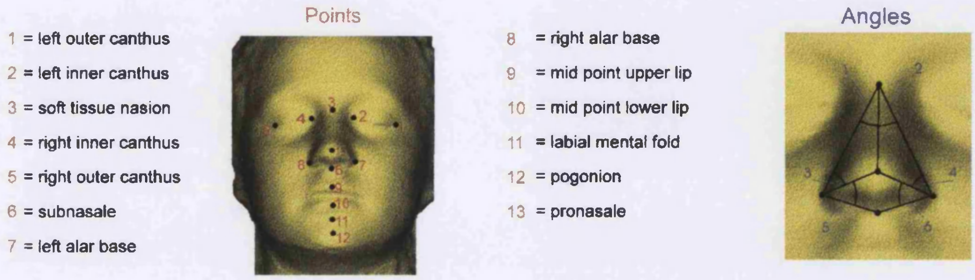


Figure 7: Linear points identified on the face and nasal angles

6.4.3 Statistical Analysis

The linear distance measurements and angular measurements were loaded into a standard spreadsheet. This programme has the facility to calculate averages and standard deviations of datasets. A standard paired *t* test was carried out on the average distances for all groups within this study using the same software. The programme also provides a measure of the probability of the value of *t* calculated, therefore the significance of any difference is found. Nasal angles were also analysed as they give an indication of nasal symmetry.

The results of this analysis are given in detail in chapter 8.

6.4.4 Error study of reproducibility of landmarks for mark and measure

One dataset was landmarked on ten separate occasions by one person and the measurements loaded into a Microsoft Excel programme and average and standard deviations created. Table 3 shows the standard errors in mm for distances and, degrees for angles measured.

Distances Measured	Standard Error in mm
1-2	0.50
2-3	0.15
3-4	0.03
4-5	0.31
1-5	0.47
3-6	0.24
6-7	0.07
6-8	0.05
7-8	0.01
6-9	0.17
9-10	0.19
9-11	0.13
10-11	0.15
11-12	0.12
6-12	0.20
3-13	0.28
6-13	0.32
3-8	0.30
3-7	0.36
Angle Measured	**Standard Error in degrees**
1	0.40
2	0.35
3	0.51
4	0.44
5	0.90
6	0.62

Table 3: Standard errors of measured distances and angles

Summary

In chapter six a discussion of the materials and methods has been given.

- 73 patients between the ages of four and 16 years with cleft lip and palate had their faces scanned using the method known as optical surface scanning. One surgeon using the same protocol operated on this group.

- 245 children with normal facial growth of the same age were also scanned and formed a control group.
- The cleft group and the control group were subdivided by age and sex so that comparisons of the soft tissue morphology of the groups could be undertaken.
- The method of optical surface scanning was discussed in detail. Averaging and landmarking of data was also discussed. Error studies for both methods of analyses have been given.
- Two methods of analyses were introduced and discussed, registration and measurement. A definition of the landmarks and measurements used in both methods of analyses was given.
- Results of the registration analysis are presented in chapter 7.
- Results of the measurement analysis are presented in chapter 8.

Chapter Seven

Registration Results

---

7. Introduction

In this chapter a detailed discussion of the results is given for each of the groups analysed in this thesis using the registration software package. The groups are discussed with regard to age, sex, cleft or control. The male and female cleft groups are compared with each other and also with their equivalent control groups. A discussion of the standard deviations between the groups is also given in this chapter. Colour illustrations are included which have been created from our visualisation software. Figure 8 is an illustrated a guide, the cold colours blue to purple represent negative differences, while the warm colours, yellow to red represent positive differences, the colour brown means there are no differences between the surfaces being compared.

Figure 8: Colour code in steps of 2mm

For the purpose of this study the following areas have been examined:

- **nose length:** soft tissue nasion to pronasale
- **alar base position:** the distance between the most lateral aspect of the left and right alar contour
- **nasal tip protrusion:** subnasale to pronasale
- **total face height:** soft tissue nasion to menton
- **prominence of the chin:** distance between the centre of rotation and the most prominent point on the surface of the chin
- **upper lip position**: subnasale to the most prominent point on the upper lip in the midline
- **lower lip position:** the most prominent point on the lower lip in the midline to the labial mental fold which is the depth of the concavity above the prominence of the chin at the level of the apices of the lower incisor teeth
- **right cheek**
- **left cheek**
- **right infra-orbital region**
- **left infra-orbital region**

7.1 Comparison of Average Male and Female Cleft Groups

7.1.1 Female cleft compared with male cleft age 4-8 (Fig. 9)

The comparison between the female cleft group age 4-8 and the male cleft group age 4-8 shows that the female group has a shorter nose by approximately 1-3mm, the right alar bases of the female group is narrower by 1-3mm. In the right and left infra-orbital region the female group is more protrusive than the male group by 1-3mm. The upper and lower lip position of the female group is less protrusive than that of the equivalent male group by 3-5mm. Total face height is greater in the male cleft group by 3-7mm. The facial width of the male cleft group is greater than that of the females by 1-3mm on the right and left sides. The prominence of the chin is greater in the male cleft group by 3-5mm.

7.1.2 Female cleft compared with male cleft age 9-12 (Fig. 10)

Figure 10 shows the comparison between the female cleft group and male cleft group age 9-12. Registration between these groups shows that in the infra-orbital region the female group is more protrusive than the male group by 1-3mm. The female cleft nose is longer than that of the equivalent males by 1-3mm and the alar base position is wider by 1-3mm. The upper lip position is slightly more protrusive in the female group by 1-3mm and the lower lip position is also more protrusive in the female group by 1-3mm. Total face height is greater in the female group by 5-7mm. The width of the face is the same for females and males. The increased nose length, face height and chin prominence seen in the female group can be explained by the earlier onset of pubertal growth.

7.1.3 Female cleft compared with male cleft age 13-16 (Fig. 11)

In this comparison the total face height of the male group age 13-16 was greater than that of the female group by 5-9mm. The width of the male face is greater than its female counterpart by 1-3mm on the left side and 3-5mm on the right side. The length of the female nose is greater than that of the males by 1-3mm. Left alar base width is greater in the female group by 1-3mm, however right alar base width is greater in the male group by 3-5mm. The infra-orbital regions are similar but the cheeks, on either side of the nose is 1-3mm more protrusive in the female group when compared with that of the male group.

7.1.4 Summary of Comparison of Male and Female Clefts

At the age of 4-8 years the facial dimensions of the male cleft group differ from those of the equivalent female. The male nose is longer and wider at the alar bases than the female. Total face height was greater in the male group by 1-7mm. Chin prominence was also greater in the male group by 3-5mm. Growth of the soft tissues at this age appears to be symmetrical.

At age 9-12 years the female face has surpassed the growth of the equivalent male face. The female nose is longer by 3-7mm and the alar bases are wider by 1-3mm. Total face height was 5-7mm greater in the female group when compared with equivalent males. Chin prominence is also greater in the female group by 1-3mm. This difference can be explained by earlier female pubertal growth.

In the 13-16 year age group growth of the face in the male group is greater than that of the female group by 7-9mm. The female nose is still marginally longer than the males, by 1-3mm. Right alar base width is greater in the male cleft group by 1-3mm, the left alar base is wider in the female group by 1-3mm. The male face is wider on the right side by 3-5mm and on the left side by 1-3mm. The chin is more prominent in the male cleft group by 3-5mm. There is some asymmetry of the nose and the left side of the face.

Figure 9:Average 4-8 years Female Cleft (left) compared with Male Cleft (right). Anterior and right and left 75 degree registered views.

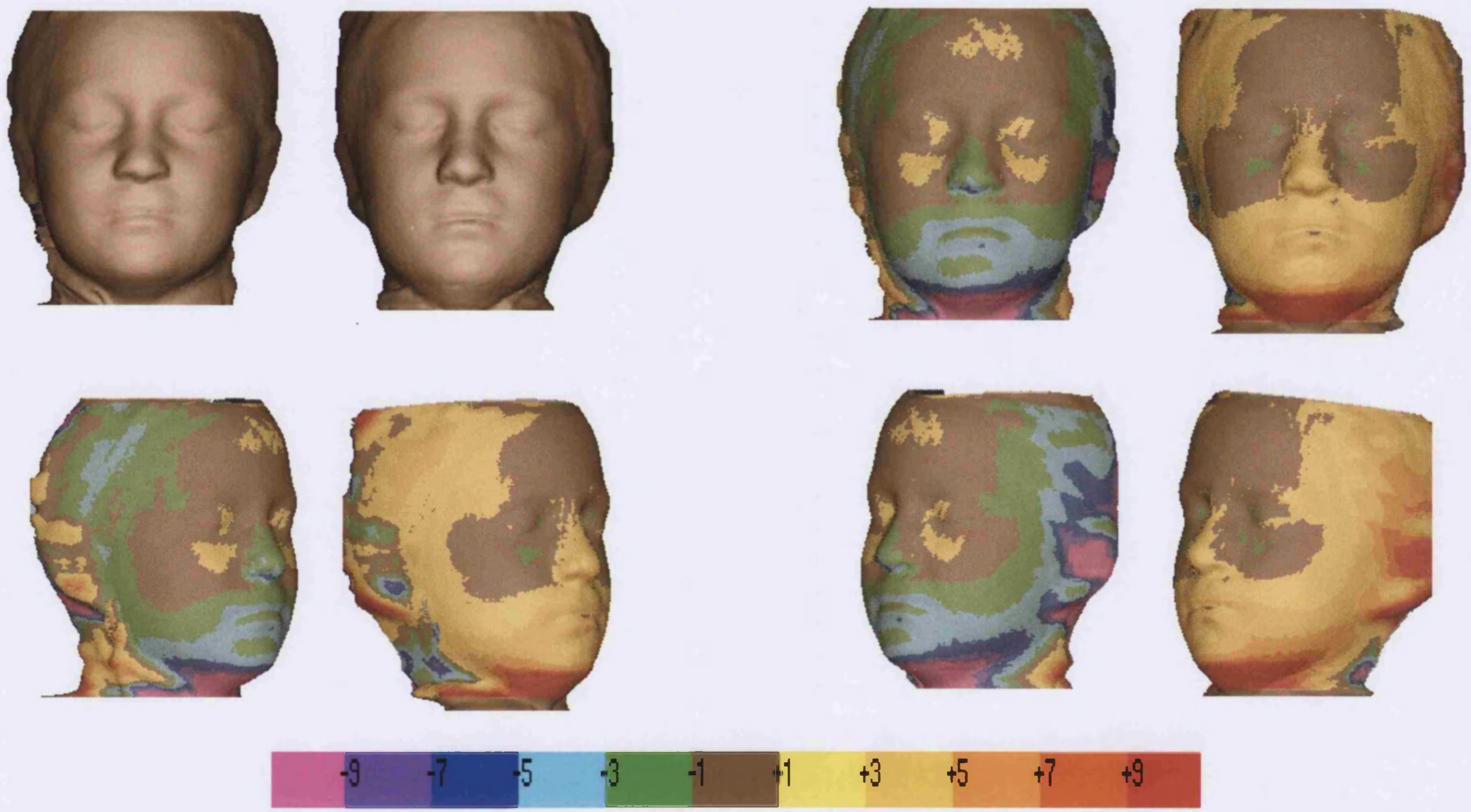


Figure 10: Average 9-12 years Female Cleft (left) compared with Male Cleft (right). Anterior and right and left 75 degree registered views.

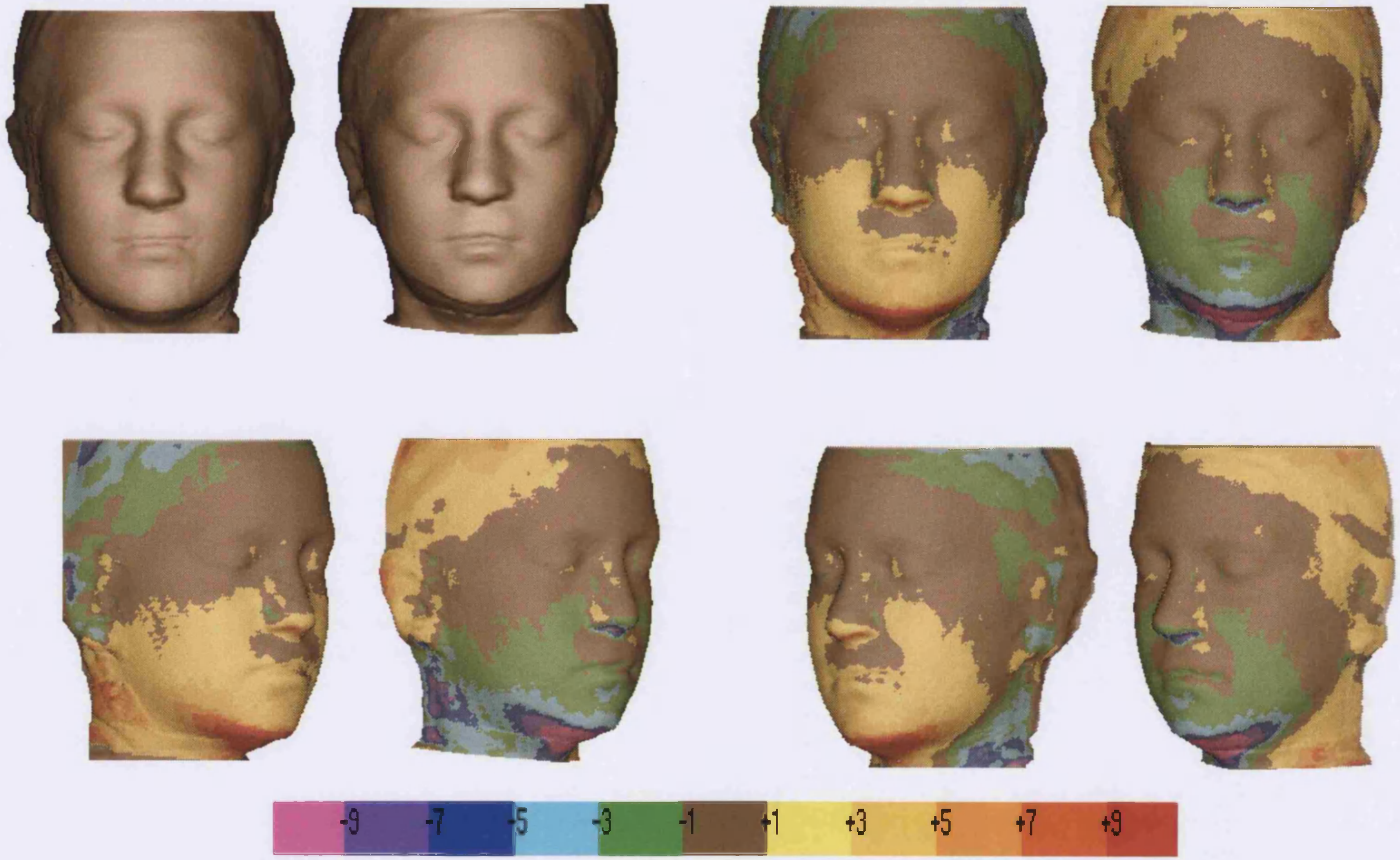
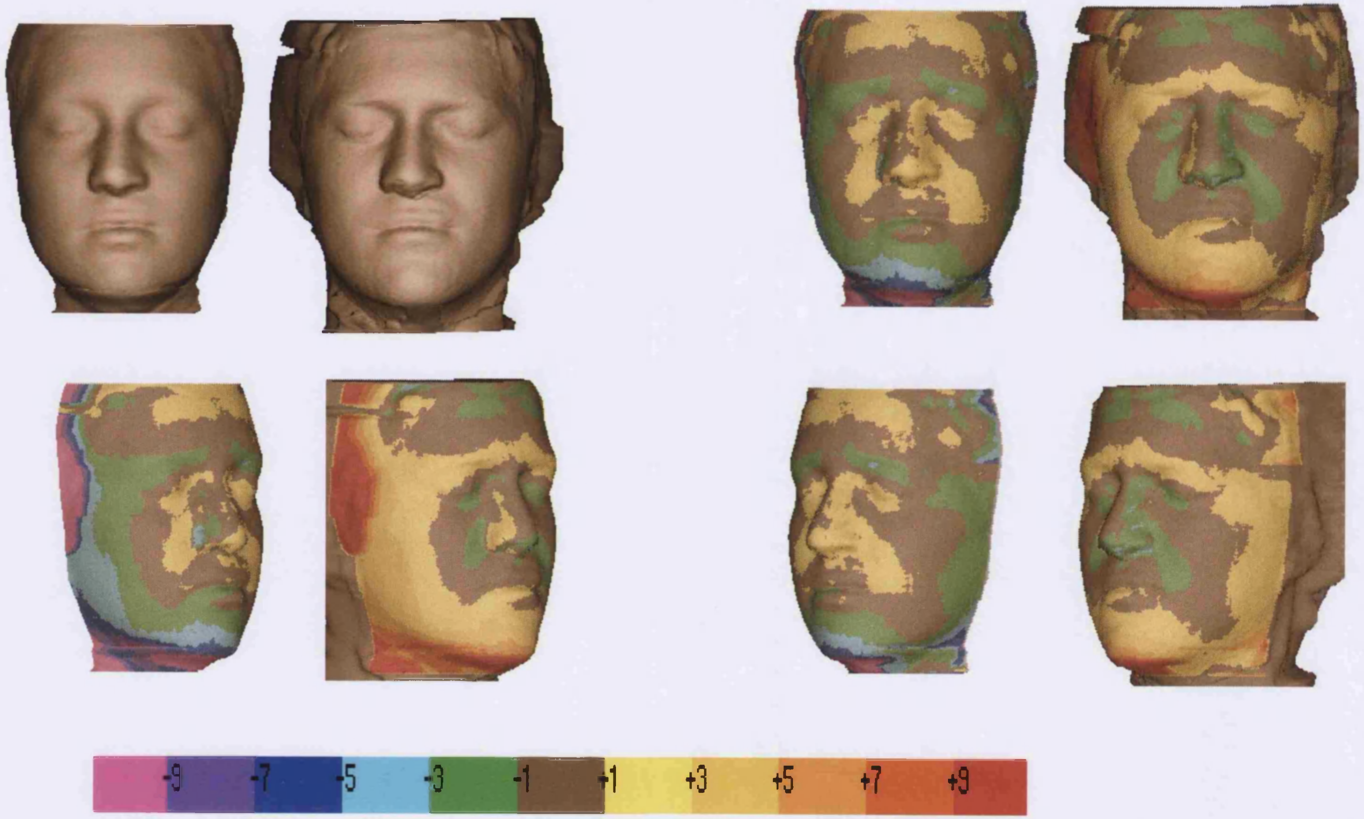


Figure 11: Average 13-16 years Female Cleft (left) compared with Male Cleft (right). Anterior and right and left 75 degree registered views.



7.2 Comparison of Average Female Cleft with Female Control

7.2.1 Female cleft compared with female control age 4-8 (Fig.12)

This comparison shows that the length of the nose in the female cleft group is shorter relative to that of the controls by 3-5mm. The alar base of the cleft group is wider on the right side by 1-3mm but narrower on the left-cleft side by 1-3mm. Nasal tip protrusion is less in the cleft group than that of the control group by 3-5mm, indicating that the tip of the nose in female clefts is flatter than that of the equivalent control group.

The upper lip of the cleft group is less protrusive than that of the control group by 3-5mm, increasing to 5-7mm in the region of the cleft. The lower lip of the cleft group is also less protrusive than that of the control group by 1-3mm. On the left-cleft side there is a soft tissue deficit in the female cleft group of 5-7mm. This indicates a marked degree of asymmetry on the cleft side of the group. Total face height is less in the female cleft group by 3-7mm.

7.2.2 Female cleft compared with female control age 9-12 (Fig. 13)

At age 9-12 years the nose of the female cleft group is longer than that of the equivalent control group by 1-3mm. The alar base width of the female cleft group on the left cleft side is wider by 1-3mm, whilst the right alar base width is greater in the female control group by 3-5mm. Nasal tip protrusion in the cleft group is less than that of the control group by 3-5mm, indicating a flatter nasal tip.

The position of the upper and lower lips of the female cleft group is less protrusive by 5-7mm on the right side when compared with the equivalent control group.

Total face height in the cleft group is greater by 7-9mm when compared with the equivalent control group. Chin prominence in the cleft group is less than that of the controls by 1-3mm, especially towards the right side. There is a marked soft tissue facial asymmetry within this group, especially on the right side, which is rather unexpected as the groups are all left-sided clefts.

7.2.3 Female cleft compared with female control age 13-16 (Fig. 14)

The length of the nose in the cleft group is shorter than that of the control group by 1-3mm. Alar base width on the left cleft side is increased by 1-3mm whilst the right alar base width of the cleft group is the same as the control group. Nasal tip protrusion in the cleft group is less than that of the controls by 3-9mm.

The infra-orbital region the female cleft group is more posteriorly positioned than the control group by 1-3mm. The upper lip is less protrusive in the cleft group by 3-9mm. The lower lip is less protrusive than that of the control group by 3-9 mm, especially on the right side. Chin prominence in the female cleft group is less than that of the equivalent control group by 5-7mm. The right cheek of the female cleft group is retrusive by 3-5mm, the left cheek is retrusive by 1-3mm. There is a marked soft tissue asymmetry in the region of the right mandible, lower and upper lip, which show a soft tissue deficiency of 7-9mm.

7.2.4 Summary of Comparison of Female Clefts compared with Controls

Comparison of the female cleft and female control groups age 4-8 years shows that overall the soft tissues of the female cleft group are deficient, especially on the left cleft side. The length of the nose is shorter and nasal tip protrusion is flatter in the female cleft group age 4-8 years. Total face height is less in the female cleft group by 3-7mm and chin prominence less by 3-5mm. There is asymmetry of the soft tissues on the left side of the face.

However, at age 9-12 years, comparison of the female cleft and female control groups show that the total height of the face in the female cleft group is greater than that of the control group. At this age the nose of the female cleft group is longer than that of the control, left alar base width is greater in the cleft group by 1-3mm, whilst the right alar base width is less than that of the control group by 3-5mm. The nose of the female cleft group is flatter than that of the equivalent control group by 3-5mm. Also, at age 9-12 there is a marked soft tissue deficiency of 5-7mm on the right side of the face in the female cleft group.

At the age of 13-16 years a marked deficiency can be seen in the facial soft tissues of the female cleft group when compared with the equivalent female control group. The length of the nose is shorter in the female cleft group and the left alar base is slightly wider than that of the control group. Total face height is less in the female cleft group by 5-7mm. The chin prominence in the cleft group is less than that of the control group by 5-7mm, increasing to 7-9mm on the right side.

The female cleft groups show variability in nose length and alar base width. They have flatter noses, reduced chin prominence and reduced face height, except at age 9-12.

Figure 12: Average 4-8 years Female Cleft (left) compared with Female Control (right). Anterior and right and left 75 degree registered views.

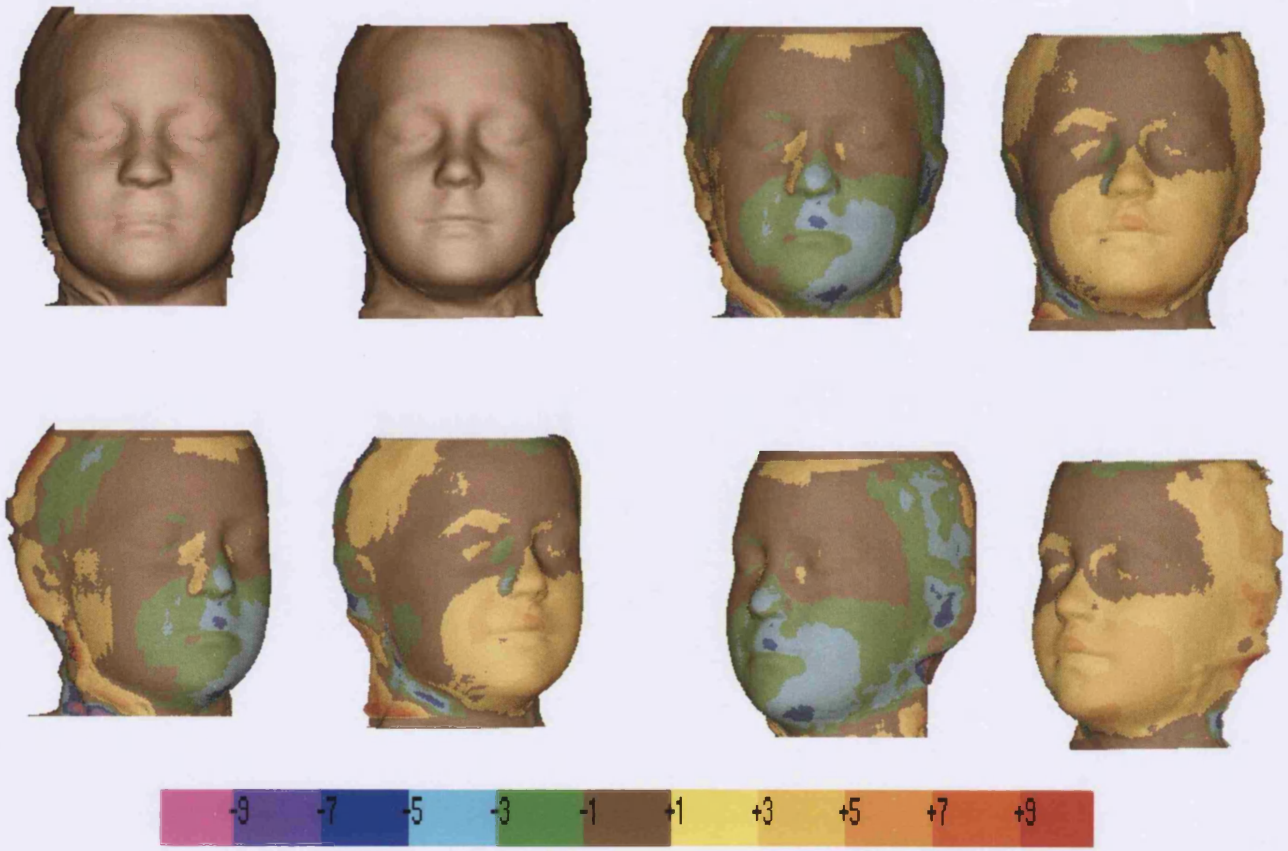


Figure 13: Average 9-12 years Female Cleft (left) compared with Female Control (right). Anterior and right and left 75 degree registered views.

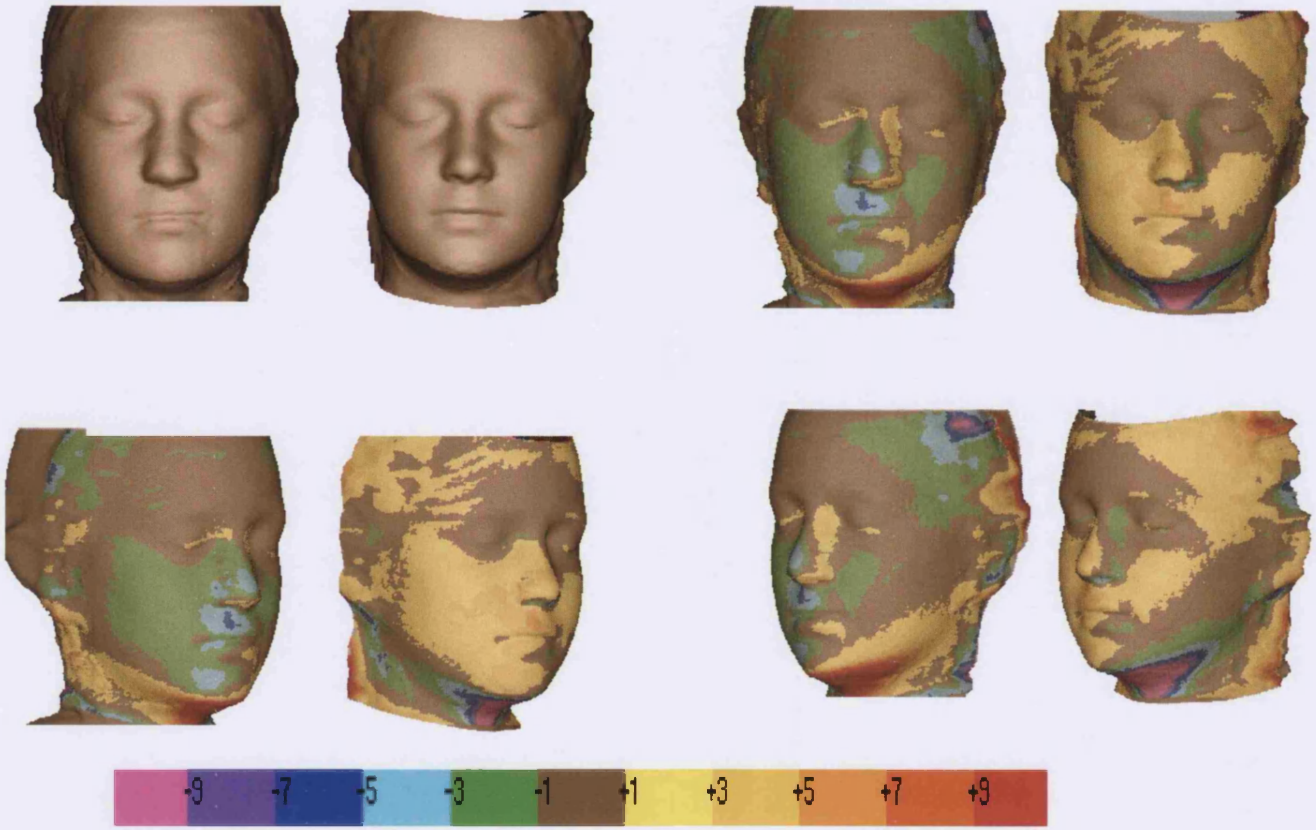
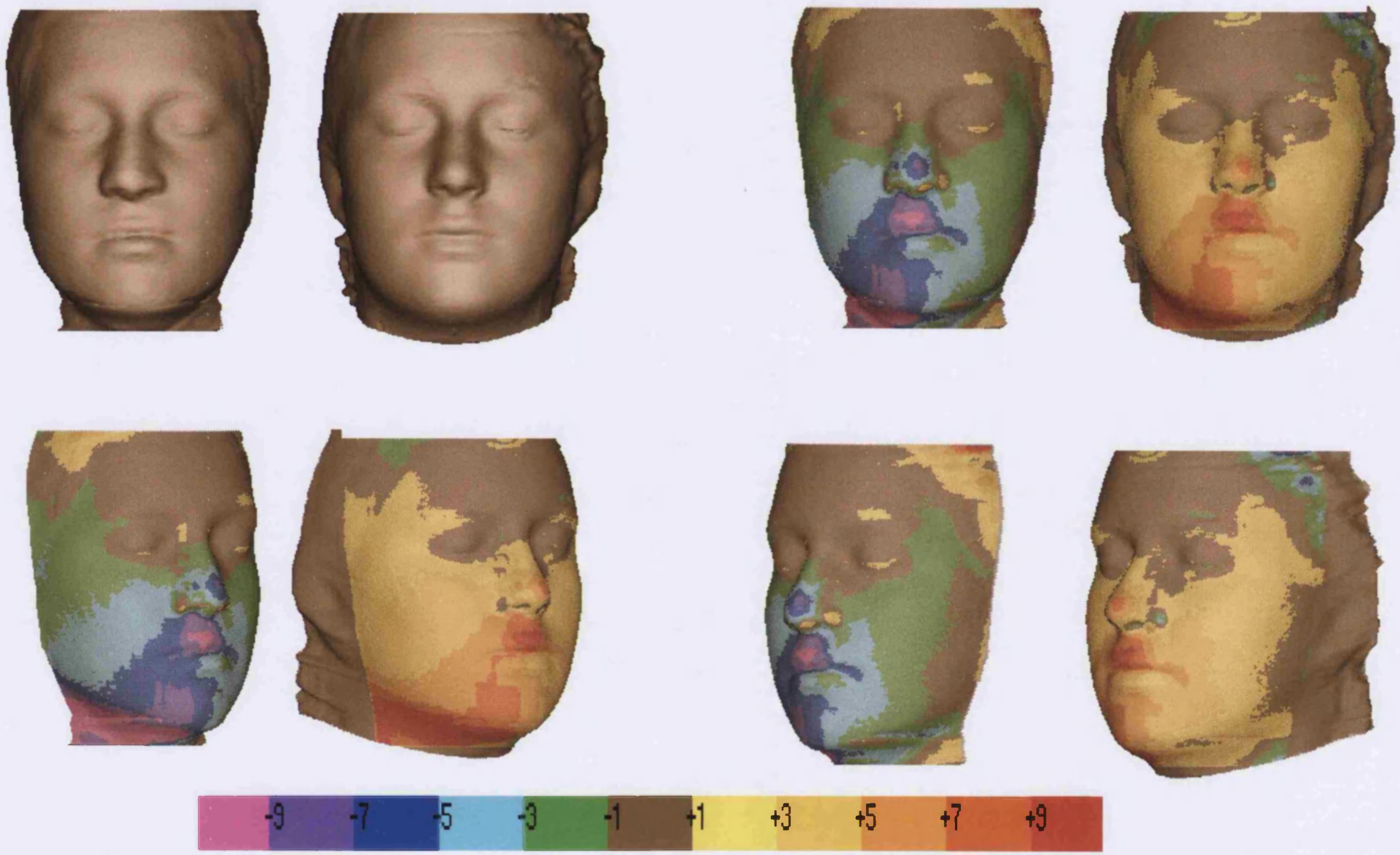


Figure 14: Average 13-16 years Female Cleft (left) compared with Female Control (right). Anterior and right and left 75 degree registered views.



7.3 Comparison of Average Male Cleft and Male Control

7.3.1 Male cleft compared with male control age 4-8 (Fig. 15)

The male cleft nose at age 4-8 years is longer by 1-3mm relative to the control group. The alar base is wider on the right side by 1-3mm in the cleft group, but there is no difference in left alar base width between the groups.

The upper lip is less protrusive in the cleft group by 3-7mm the lower lip is also less protrusive by 3-5mm when compared with the equivalent controls. The chin is less prominent in the cleft group by 3-5mm. Total face height in the male cleft group age 4-8 years is greater than that of the control group by 3-5mm. There is soft tissue asymmetry within this group, especially on the left, cleft side, and the male cleft group shows a greater degree of soft tissue asymmetry than the female cleft group of the same age, compared with the controls.

7.3.2 Male cleft compared with male control age 9-12 (Fig. 16)

The nose in the male cleft group age 9-12 years is longer than that of the controls by 1-3mm. The left alar base is wider in the cleft group by 1-3mm, whilst the right alar base width is the same for both groups. Nasal tip protrusion in the cleft group is less than that of the control group by 3-5mm. The upper and lower lips are less protrusive in the cleft group than that of the controls by 3-7mm. Total face height is greater in the control group by 5-9mm. Chin prominence is less in the cleft group by 3-5mm. Face width on the right side is less in the male cleft group by 1-3mm, but the same on the left side. There is asymmetry of the soft tissues in the cleft group particularly on the right side of the face.

7.3.3 Male cleft compared with male control age 13-16 (Fig.17)

The nose of the male cleft group age 13-16 years is shorter, flatter and narrower than the control group by 5-9mm, with exception of the right alar base where it is wider than the control group by 1-3mm. The nose of the cleft group shows a marked degree of asymmetry on the left affected side.

The upper lip is less protrusive in the cleft group by 5-9mm, the lower lip is 3-7mm less protrusive but the chin prominence is the same in both groups. The nose, upper and lower lips are more posteriorly placed in the male cleft group age 13-16.

7.3.4 Summary of Comparison of Male Clefts compared with Controls

In the 4-8 year age group we can observe that the cleft group has a soft tissue deficiency over the cheeks, lips and chin point of 3-5mm when compared with the equivalent control group. The male cleft group age 4-8 years has a longer nose than the control group, however nasal tip protrusion in the cleft group is less than that of the control group, indicating a flatter nasal tip. Chin prominence is less in the cleft group by 3-5mm. Total face height is greater in the cleft group by 5-7mm. The soft tissues of the face of the male cleft age 4-8 years are more posteriorly positioned by 3-5mm when compared with the control group.

At 9-12 years the comparison shows that the soft tissues of the male cleft face are deficient when compared with the equivalent control. Nasal tip protrusion is reduced by 3-5mm in the cleft group this was also seen in the male cleft group age 4-8 years. The length of the nose in the male cleft group at 9-12 years is slightly longer than the control group, the left alar base is also wider in the cleft group. The upper and lower lip position is less protrusive by 3-7mm in the cleft group. Total face height and chin prominence is less in the cleft group. The soft tissues of the face in the male cleft group age 9-12 years are posterior to those of the male control group. The soft tissue deficiency of the male cleft group age 9-12 was more severe on the right side of the face a phenomenon also seen in the female cleft group age 9-12.

In the 13-16 year age group we can see that there is a continuing deficiency in the facial soft tissues of the male cleft group. The length of the male cleft nose is 5-9mm shorter than that of the male control group, especially on the left side. Nasal tip protrusion is less in the male cleft group. The upper lip is less protrusive by 5-9mm than the male control and this deficiency extends across the cheeks, lower lip and labio-mental fold. Chin prominence is the same for both groups. The male cleft nose is flatter in all age groups when compared with the control groups. There is variability in the length and width of the cleft nose. The maxilla and mandible of all the male groups are posteriorly positioned when compared with the control groups.

Figure 15: Average 4-8 years Male Cleft (left) compared with Male Control (right). Anterior and right and left 75 degree registered views.

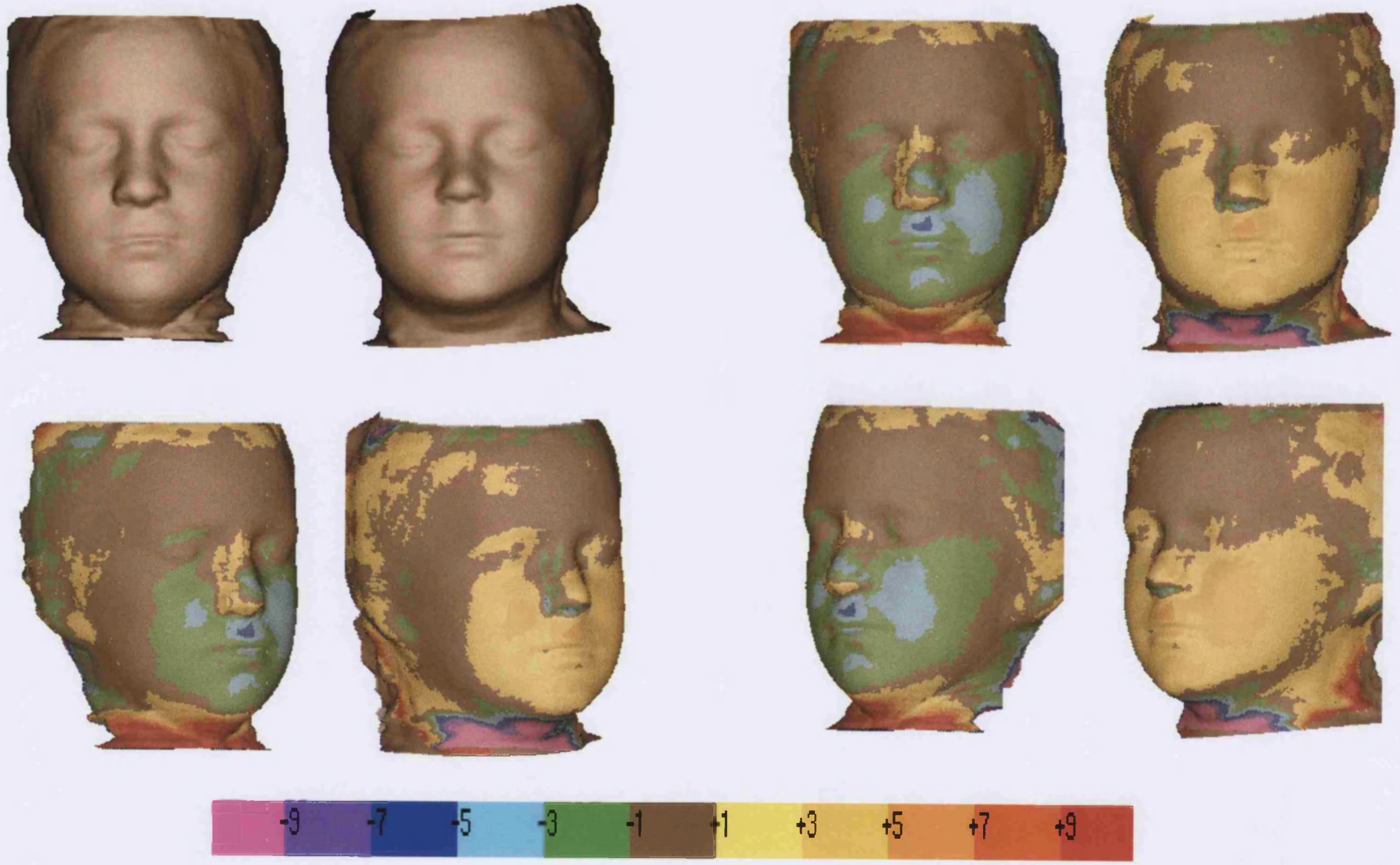


Figure 16: Average 9-12 years Male Cleft (left) compared with Male Control (right). Anterior and right and left 75 degree registered views

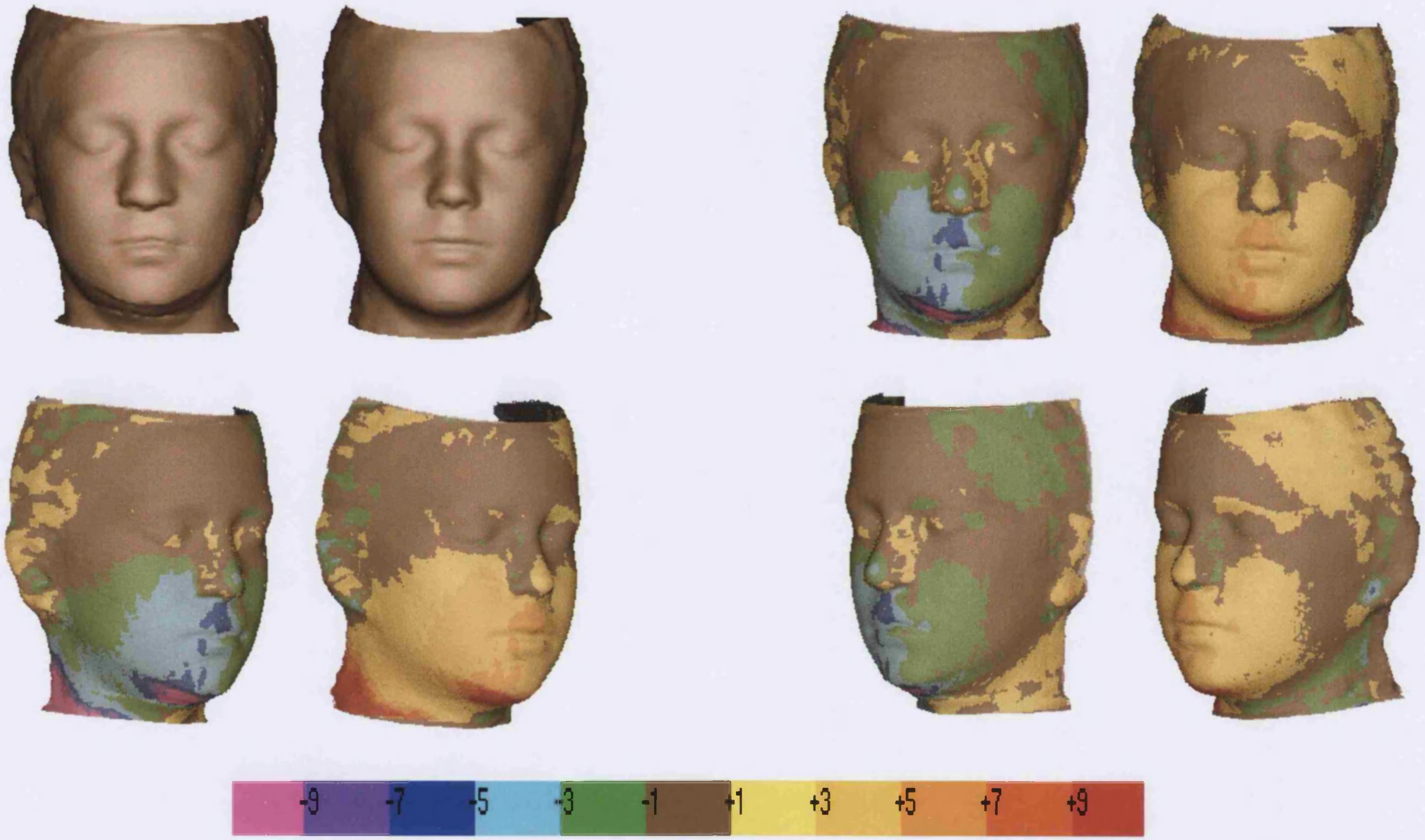
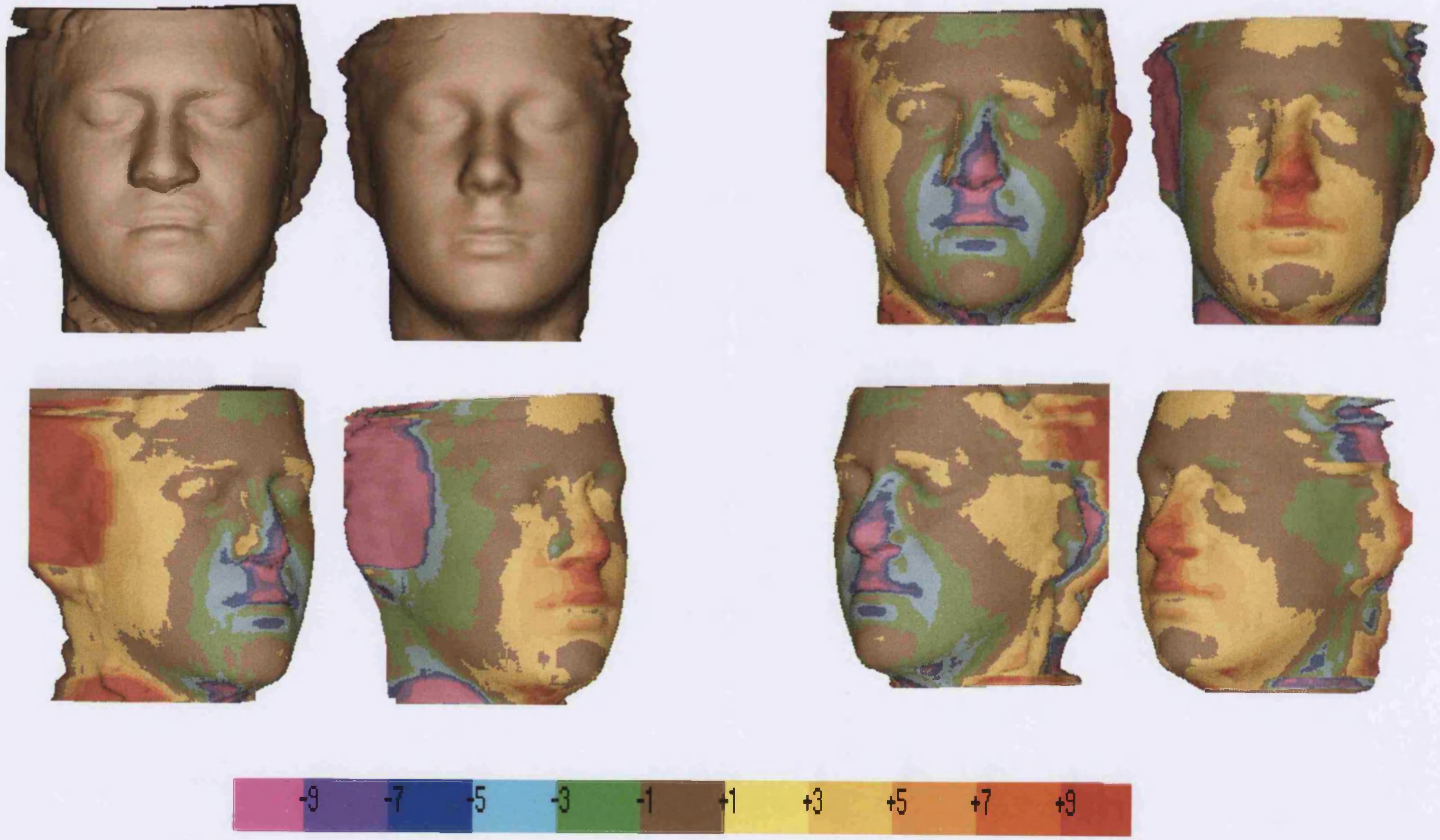


Figure 17 Average 13-16 years Male Cleft (left) compared with Male Control (right). Anterior and right and left 75 degree registered views.



7.4 Standard Deviations

Standard deviations (SD) of the averaged groups are presented as these give an indication of the variability of the entire facial surface within the groups. However as the faces are registered across the forehead and eyes, the greatest variability from the average will be seen in the lower part of the face. Nonetheless it is possible to compare the variability of the normal subjects with that of the clefts in this region of the face.

Figure 18: Colour code ranging from 0-10mm

The colour code ranges from 0 to +10mm. Zero is identified as the blue colour and red as + 10mm.

7.4.1 Female Cleft and one standard deviation

7.4.2 Average Female Cleft compared with 1 SD age 4-8 (Fig. 19)

This figure shows there was very little variation within the group. The colour code indicates that the majority of the face was between 0 and 2mm. The greatest amount of variation was in the area of the chin and lower border of the mandible indicating variability in face height. There is no significant difference between the female cleft and control groups at this age.

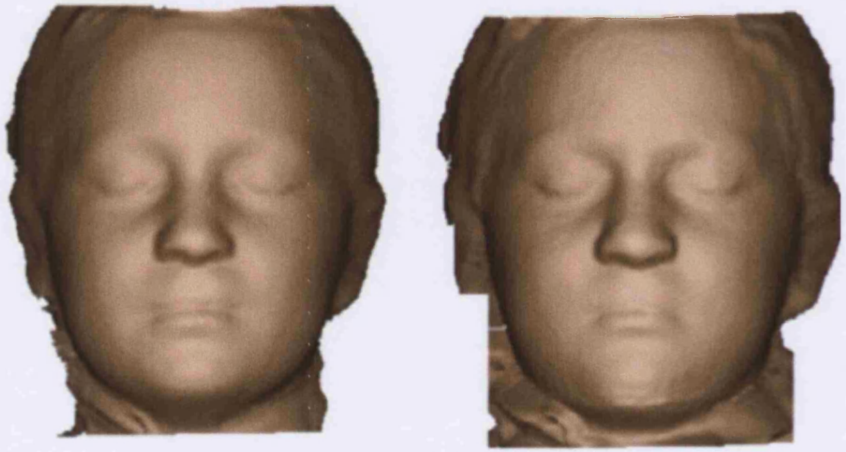
7.4.3 Average Female Cleft compared with 1 SD age 9-12 (Fig 20)

There was greater variability in this group over the mandible, lower border of the mandible and chin when compared with the equivalent control group. There was also an increase in variability in the region above the right ala.

7.4.4 Average Female Cleft compared with 1 SD age 13-16 (Fig 21)

At the age of 13-16 years the pattern of variation between the female cleft group and control group appears to be very similar and of the same magnitude.

Figure 19: Average Female Cleft 4-8 years (left) and 1 SD (right)



Registered image of average Female Cleft 4-8 years and 1 SD (below)

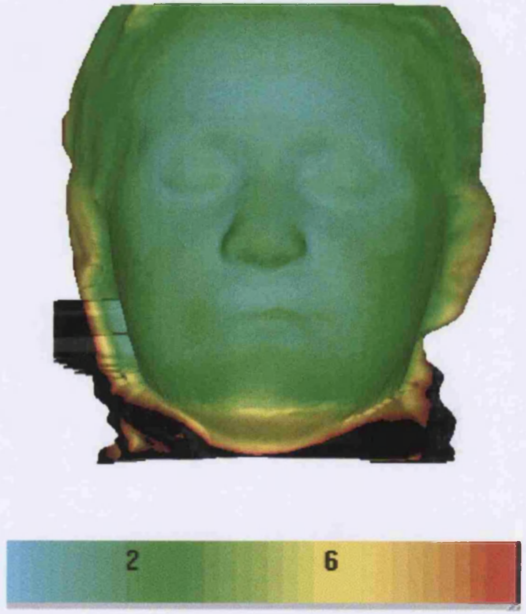
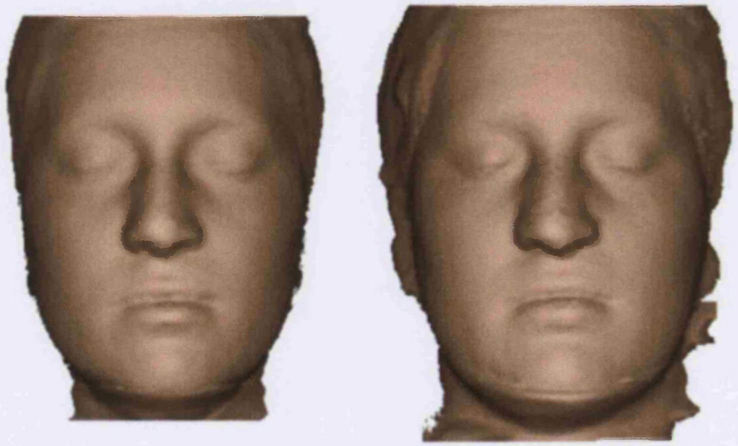


Figure 20: Average Female Cleft 13-16 years (left) and 1 SD (right)



Registered image of average Female Cleft 13-16 years and 1 SD (below)

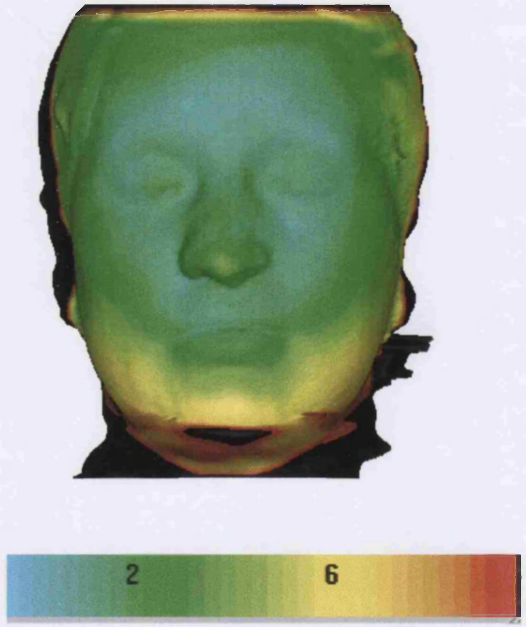
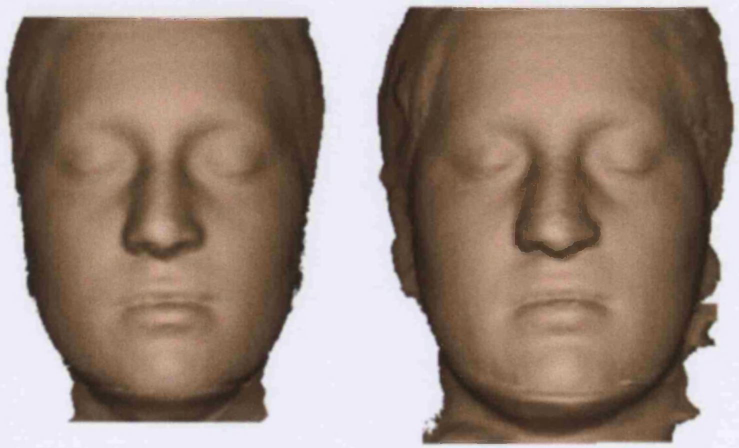
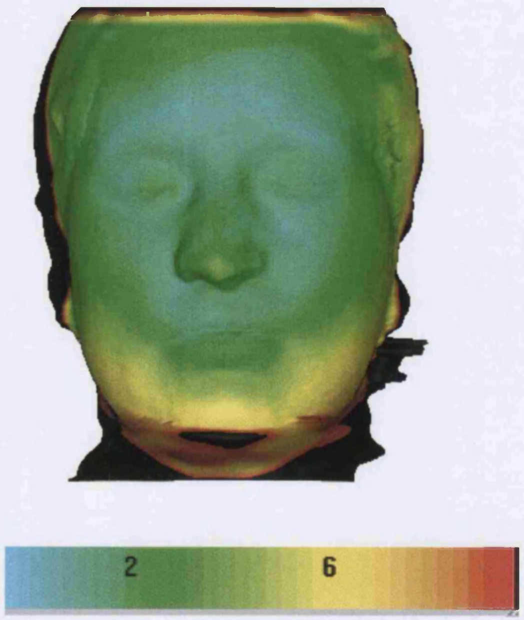


Figure 21: Average Female Cleft 13-16 years (left) and 1 SD (right)



Registered image of average Female Cleft 13-16 years and 1 SD (below)



7.5 Female Control and one Standard Deviation

7.5.1 Average Female Control compared with 1 SD age 4-8 (Fig 22)

The female control group age 4-8 showed the greatest degree of variability in the chin and lower border of the mandible, which was similar to the results found in the equivalent female cleft group. However in this group there was also a greater degree of variability in the left cheek region.

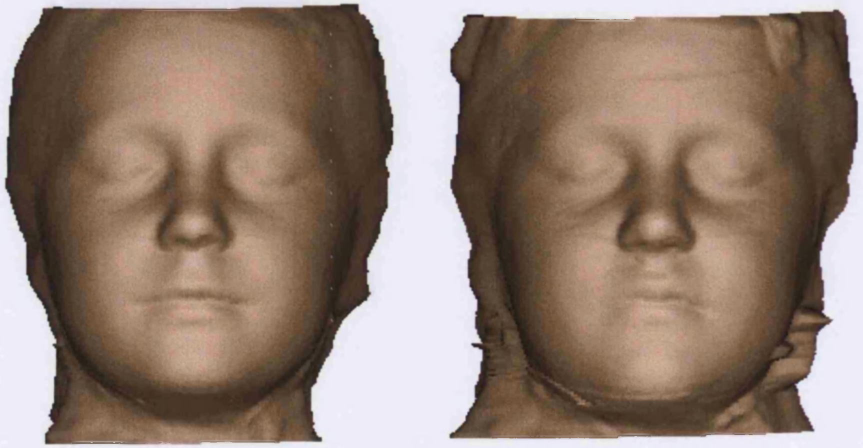
7.5.2 Average Female Control compared with 1 SD age 9-12 (Fig 23)

Once again the variability within this group was seen particularly in the region of the lower border of the mandible, and in the left and right horizontal ramus.

7.5.3 Average Female Control compared with 1 SD age 13-16 (Fig 24)

At age 13-16 years the variability in the region of the chin and lower border of the mandible was greater in this group when compared to the younger control groups. When comparing this control group with the equivalent cleft group, we can observe a greater degree of variability in the nose and mandible of the cleft group.

Figure 22: Average Female Control 4-8years (left) and 1 SD (right)



Registered image of average Female Control and 1 SD (below)

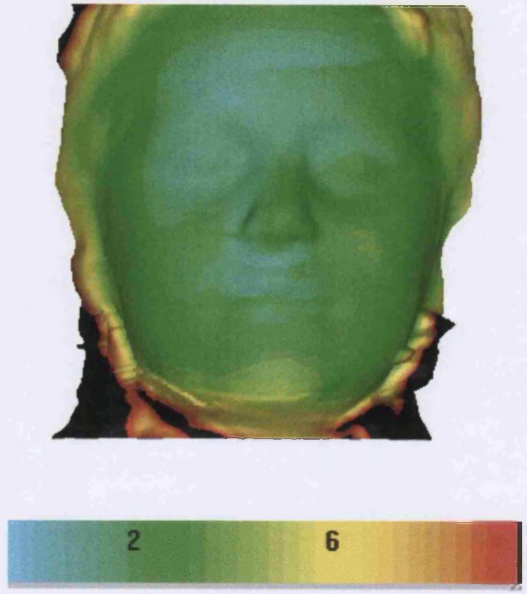
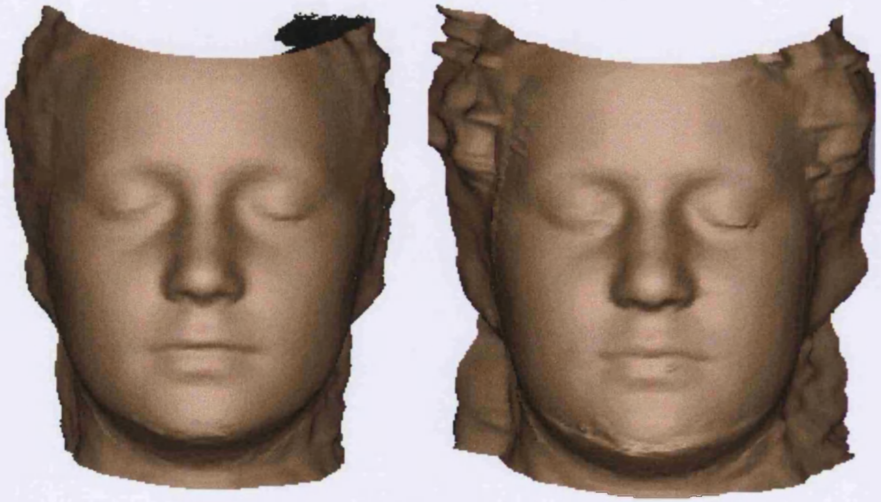


Figure 23: Average Female Control 9-12 years (left) and 1 SD (right)



Registered image of Average Female Control 9-12 years and 1 SD (below)

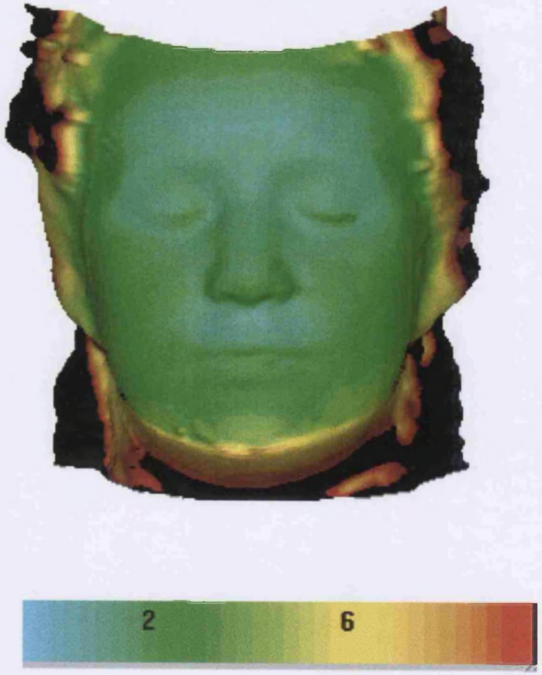
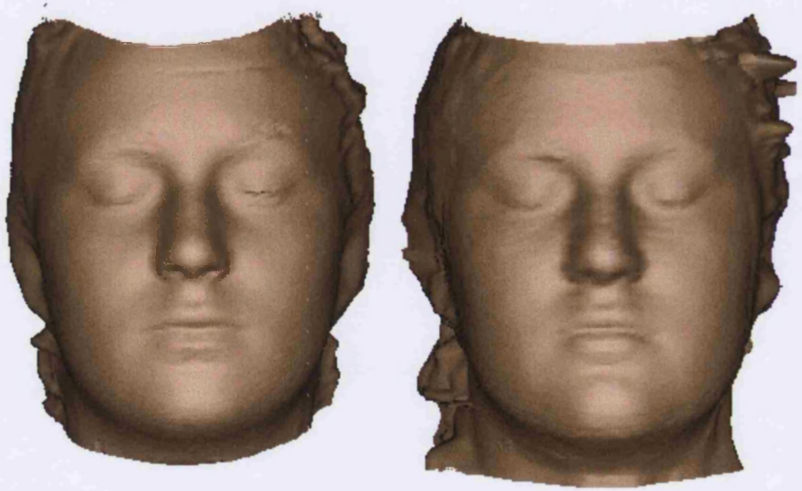
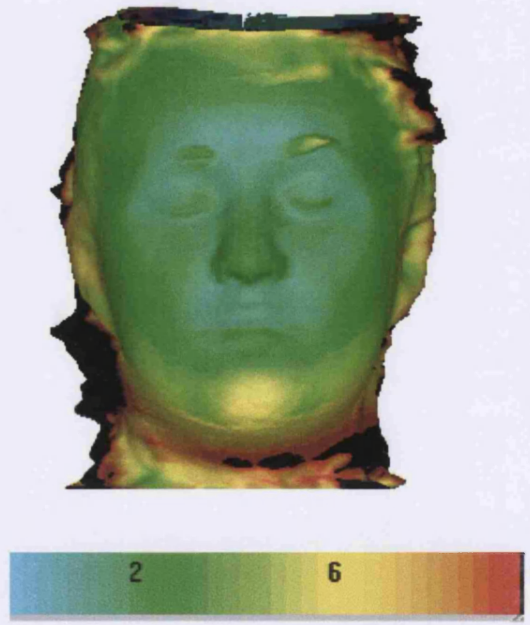


Figure 24: Average Female Control 13-16 years (left) and 1 SD (right)



Registered image of average Female Control 13-16 years and 1 SD (below)



7.6 Male Cleft and one Standard Deviation

7.6.1 Average Male Cleft compared with 1 SD age 4-8 (Fig 25)

The male cleft group age 4-8 years shows a similar degree of variability but more symmetry than that of the equivalent controls. However there is slightly greater variability of the horizontal ramus and chin on the right side of the face of the cleft group.

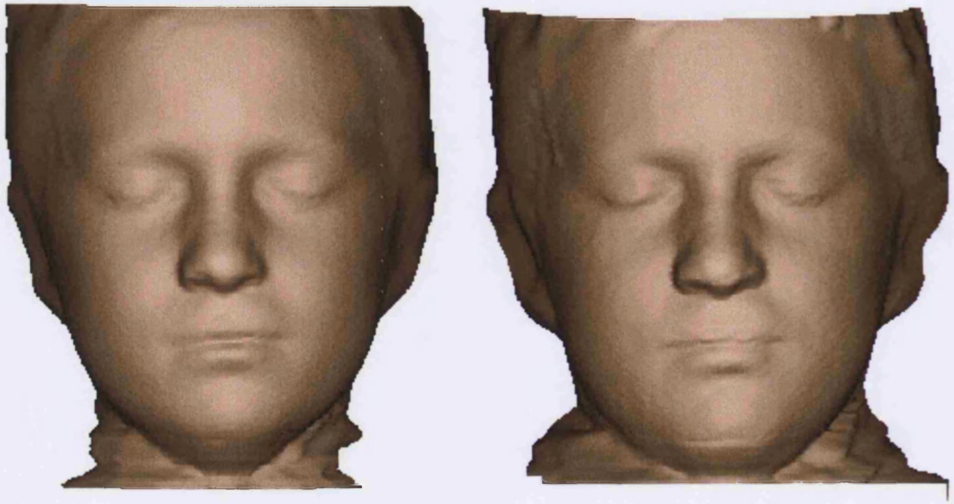
7.6.2 Average Male Cleft compared with 1 SD age 9-12 (Fig 26)

At age 9-12 the male cleft and control groups show a very similar variability across the facial surface with that of the equivalent control group.

7.6.3 Average Male Cleft compared with 1 SD age 13-16 (Fig 27)

At age 13-16 the variability was similar between the male cleft and male controls, however there was greater variability in the tip of the nose in the cleft group.

Figure 25: Average Male Cleft 4-8 years (left) and 1 SD (right)



Registered image of average Male Cleft 4-8 years and 1 SD (below)

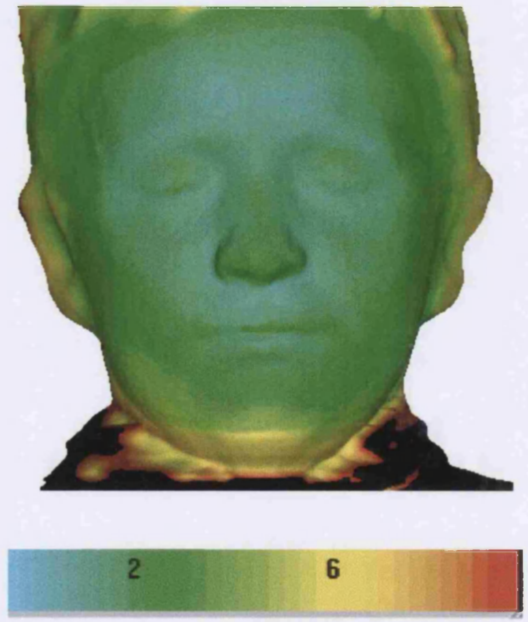
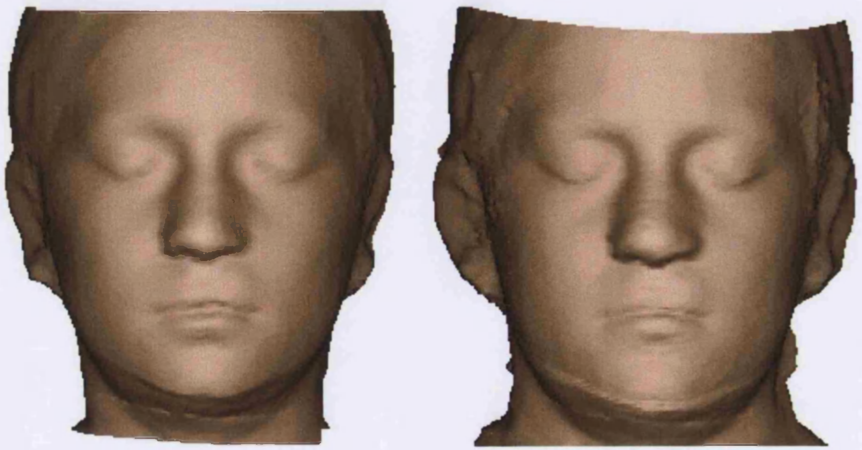


Figure 26: Average Male Cleft 9-12 years (left) and 1 SD (right)



Registered image of average Male Cleft 9-12 years and 1 SD (below)

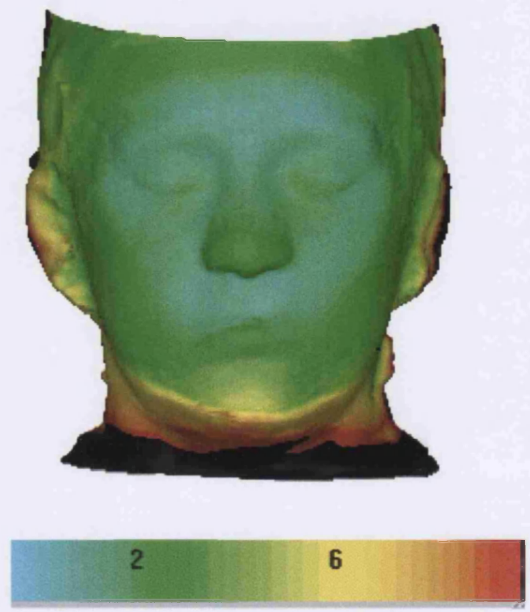
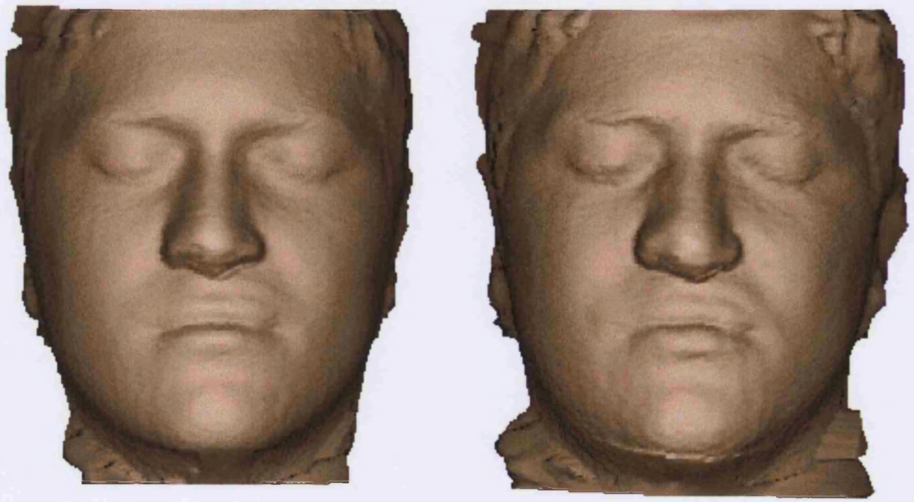
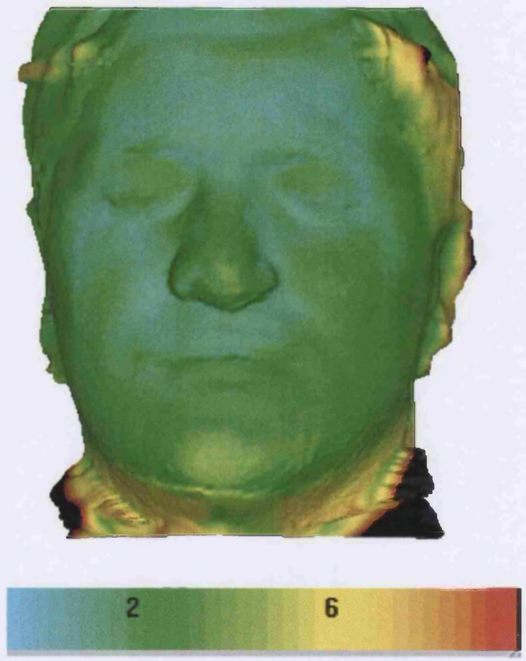


Figure 27: Average Male Cleft 13-16 years (left) and 1 SD (right)

Registered image of average Male Cleft 13-16 years and 1 SD (below)





7.7 Male Control and one Standard Deviation

7.7.1 Average Male Control compared with 1 SD age 4-8 (Fig 28)

In the male control group age 4-8 years we can see that the greatest degree of variability is in the region of the mandible and tip of the nose. There is also greater variability over the left cheek region, whilst in the equivalent male cleft group there was greater variability of the horizontal ramus and chin on the right side.

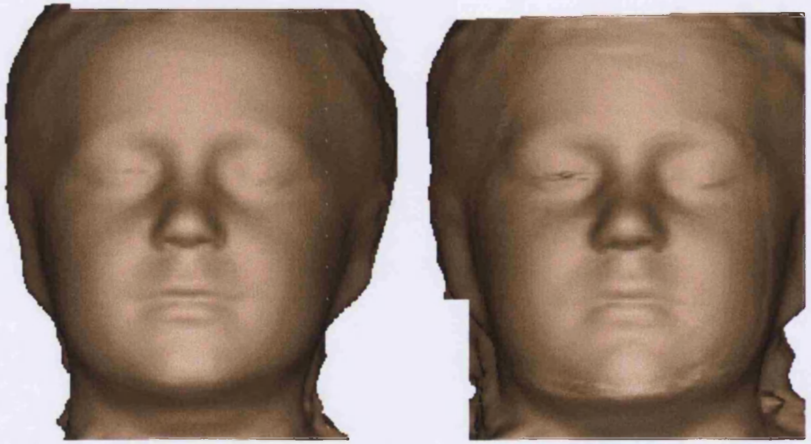
7.7.2 Average Male Control compared with 1 SD age 9-12 (Fig 29)

At age 9-12 years the degree of variability in the mandible is less than that found in the males age 4-8 years. The greatest variability is in the chin horizontal ramus and the lower border of the mandible, however the majority of the face falls within the range of 0-2mm.

7.7.3 Average Male Control compared with 1 SD age 13-16 (Fig 30)

At age 13-16 years the greatest variability is in the chin and the lower border of the mandible. The control group displays a greater degree of variability in the chin and mandible than the male cleft group age 13-16, while the male cleft group age 13-16 shows greater variability in the tip of the nose.

Figure 28: Average Male Control 4-8 years (left) and 1 SD (right)



Registered image of average Male Control 4-8 years and 1 SD (below)

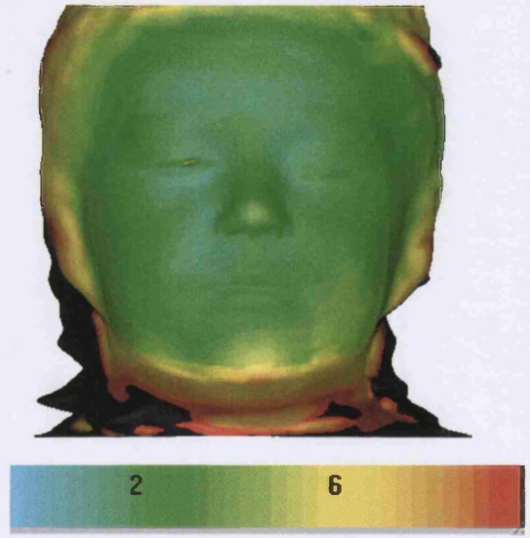
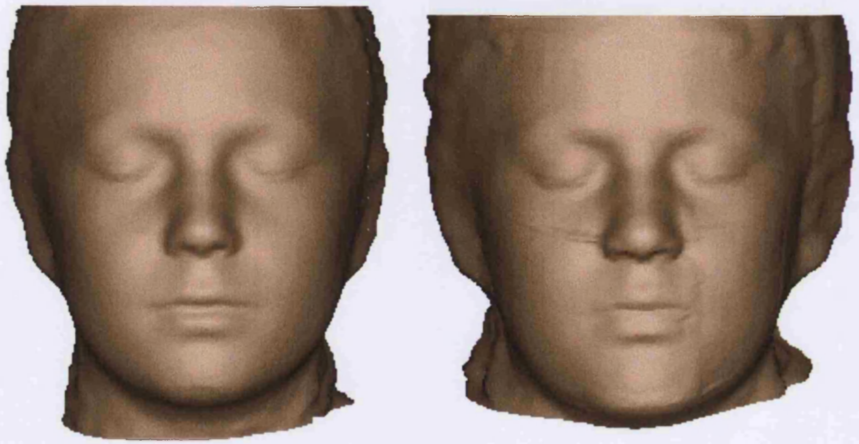


Figure 29: Average Male Control 9-12 years (left) and 1 SD (right)



Registered image of average Male Control 9-12 years and 1 SD (below)

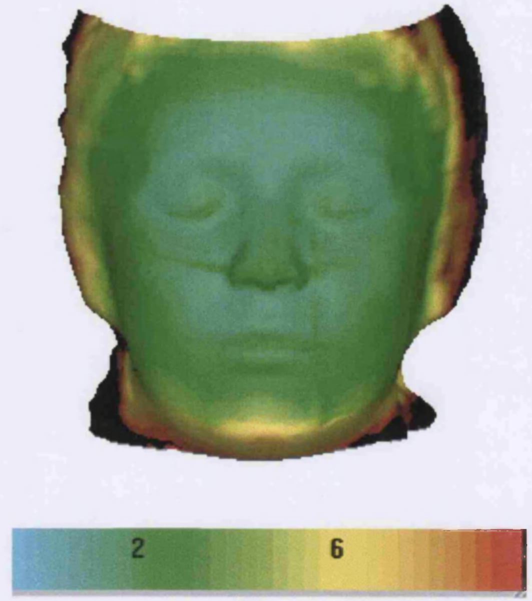
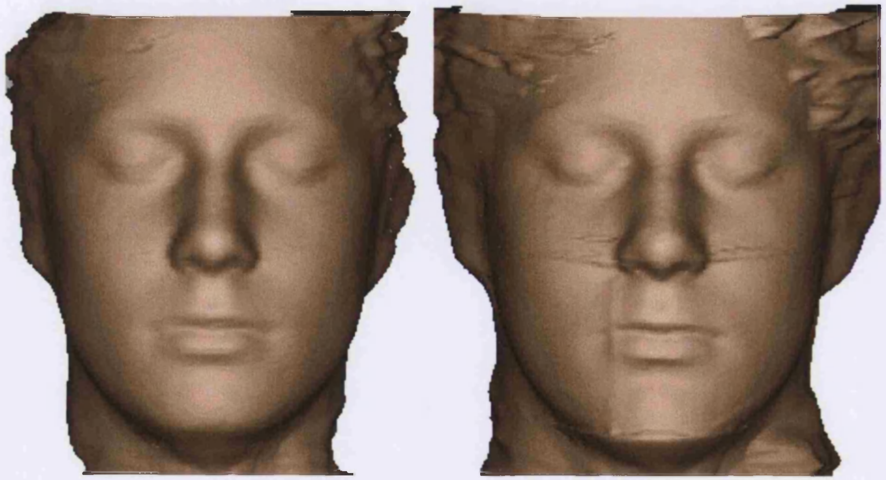
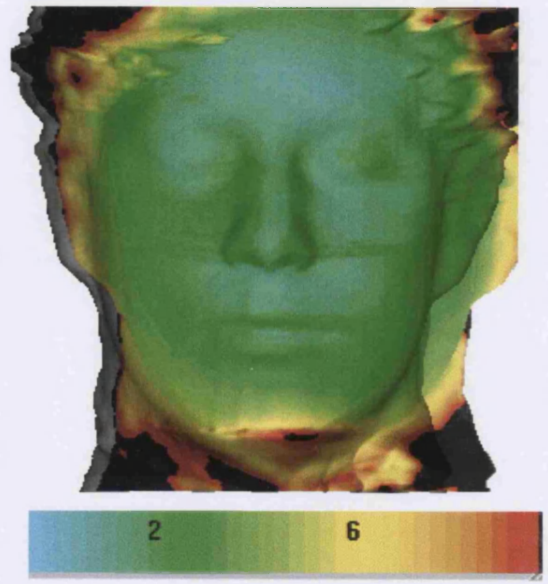


Figure 30: Average Male Control 13-16 years (left) and 1 SD (right)



Registered image of average Male Control 13-16 years and 1 SD (below)



7.8 Summary of Standard Deviations

7.8.1 Female Cleft Groups

At the age of 4-8 years there was very little variation within the group. The colour code indicates that the majority of the face was within the range of 0-2mm. The greatest amount of variation was in the area of the chin and lower border of the mandible indicating variability in face height.

At age 9-12 years the majority of the face was within the range of 0-2mm, however there was greater variability in this group over the mandible, lower border of the mandible and chin. Greater variability in the region above the right ala was also seen.

At 13-16 years the variation from the mean was more extensive, especially over the area of the mandible. The greatest variation is over the lower border of the mandible, especially near the chin where the SD is in excess of 10mm.

7.8.2 Male Cleft Groups

The male cleft group age 4-8 years shows a similar degree of variability 0-2mm as the female cleft group age 4-8 years. However there was slightly greater variability of the horizontal ramus and chin on the right side of the face of the male cleft group.

At age 9-12 variability was more extensive and can be seen particularly in the chin and lower border of the mandible. As with the female UCLP group of the same age this variability was most likely due to the effects of surgery and the pubertal growth spurt.

At age 13-16 the variability had decreased. The variability over the entire face, except the chin, was within 0-2mm, showing that there was very little variability within this group. When comparing this group with the equivalent female cleft group we can observe that there was a greater degree of variability in the region of the mandible in the female group.

7.8.3 Female Control Groups

The female control group age 4-8 showed the greatest degree of variability in the chin and lower border of the mandible, which was similar to the results found in the equivalent female cleft group. However in this group there was also a greater degree of variability in the left cheek region.

At the age of 9-12 the variability within this group was seen particularly in the region of the lower border of the mandible, and in the left and right horizontal ramus.

At age 13-16 years the variability in the region of the chin and lower border of the mandible was greater in this group when compared to the younger control groups. When comparing this control group with the equivalent cleft group, we can observe a greater degree of variability in the nose of the cleft group.

7.8.4 Male Control Groups

In the male control group age 4-8 years the greatest degree of variability was within the region of the mandible and tip of the nose, this was not seen in the male cleft group age 4-8. There was also greater variability over the left cheek region; due possibly to the asymmetric growth of the males at this age, but the variability across the majority of the face was within 0-2mm.

At age 9-12 years the degree of variability in the mandible is less than that found in the male control group age 4-8 years. The greatest variability is in the chin horizontal ramus and the lower border of the mandible, however the majority of the face falls within the range of 0-2mm.

At age 13-16 years the greatest variability is in the chin and the lower border of the mandible in the chin region. The control group displays a greater degree of variability in the chin and mandible than the male cleft group age 13-16. However the variability over the majority of the face is 0-2mm.

Chapter Eight

Distance Measurement Results

8. Introduction

An explicit list of the 3D points measured using the mark and measure programme is given in table 4. A detailed comparison of the cleft male and female groups with each other and a comparison of the cleft male and female groups with their equivalent control groups follow this. A comparison of the nasal angles for the groups is also discussed. The distances and angles measured are the averaged measurements for each group. Colour graphs of the distances and angles measured are also included in this chapter, the measurements that are statistically significant are indicated.

8.1 Statistical Evaluation of 3D Linear and Angular Measurements

8.1.1 Facial Landmarks

- **Exocanthion:** the depth of the concavity in the vertical and horizontal planes at the outer commisure of the eye fissure (left and right)
- **Endocanthion:** the depth of the concavity in the vertical and horizontal planes at the inner commisure of the eye fissure (left and right)
- **Soft tissue nasion:** the depth of the concavity of the soft tissue in the vertical plane and the maximum convexity in the horizontal plane at the base of the brow ridges
- **Pronasale:** was the most prominent point on the vertical profile of the nose
- **Subnasale:** the midpoint of the angle at the columella base where the lower border of the nasal septum and the upper lip meet
- **Alar Base:** the most lateral point of the curved alar base indicating the facial insertion of the nasal wings

- **Upper Lip:** most prominent point of the lip in the midline
- **Lower Lip:** most prominent point of the lip in the midline
- **Sublabiale:** the point in the midline of the labial mental sulcus
- **Pogonion:** the most anterior midpoint of the chin

8.1.2 Definition of Linear Facial Measurements

For the purpose of this study the measurements have been defined as follows:

- **Nasal bridge length:** soft tissue nasion to pronasale
- **Nasal tip protrusion**: subnasale to pronasale
- **Left alar base width**: subnasale to the most lateral aspect of the left alar contour
- **Right alar base width:** subnasale to the most lateral aspect of the right alar contour
- **Width of the nose**: the distance between the most lateral aspect of the left and right alar contour
- **Nose length** soft tissue nasion to subnasale
- **Lower face distance**: subnasale to pogonion
- **Upper lip length**: subnasale to the most prominent point on the midline of the upper lip
- **Lower lip length:** the most prominent point on the midline of the lower lip to the labial mental fold which is the depth of the concavity above the prominence of the chin at the level of the apices of the lower incisor teeth
- **Chin Height:** the concavity of the labial mental fold in the midline to pogonion

Distances Measured	Homologous Landmarks
1-2	Length of left eye fissure (left outer canthus to left inner canthus)
2-3	Left facial midline distance (left inner canthus to soft tissue nasion)
3-4	Right facial midline distance (right inner canthus to soft tissue nasion)
4-5	Length of right eye fissure (right inner canthus to right outer canthus)
1-5	Outer canthal distance (left outer canthus to right outer canthus)
3-6	Nasal length (soft tissue nasion to subnasale)
6-7	Left alar base width (left alar base to subnasale)
6-8	Right alar base width (right alar base to subnasale)
7-8	Width of the nose (left alar base to right alar base)
6-9	Height of upper lip (subnasale to vermilion border of the upper lip)
9-10	Vermilion width (vermilion border of upper lip to vermilion border of the lower lip)
9-11	Width of mouth and lower lip (vermilion border of upper lip to labial mental fold)
10-11	Height of lower lip (vermilion border of the lower lip to labial mental fold)
11-12	Chin height (labial mental fold to pogonion)
6-12	Lower face distance (subnasale to pogonion)
3-13	Nasal bridge length (nasion to prn)
6-13	Nasal tip protrusion (subnasale to prn)
3-8	Right lateral nose dimension (soft tissue nasion to right alar base)
3-7	Left lateral nose dimension (soft tissue nasion to left alar base)

Table 4: Homologous landmarks with distances measured

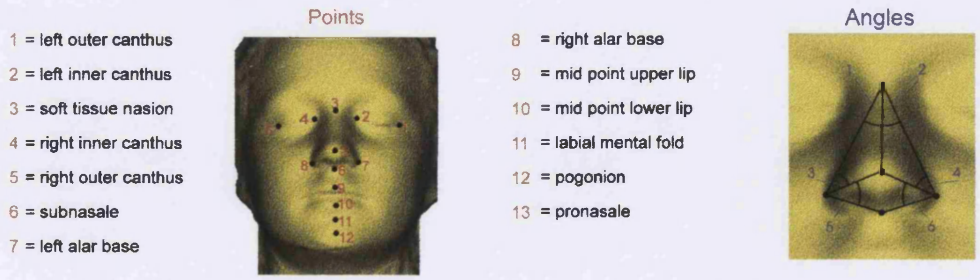


Figure 31: Linear points identified on the face and nasal angles

8.2 Comparison of measurements of male and female clefts

8.2.1 Comparison of measurements of male and female clefts age 4-8 (Graph 1a)

The comparison of these two groups of male and female clefts at the age of 4-8 years shows that the left facial midline distance (2-3) is greater in the male cleft group than that of the female cleft group. This measurement is statistically significant when a standard *t* test is applied $p < 0.001$

Nasal bridge length (3-13) is greater in the male cleft group at age 4-8 years when compared with equivalent females. This was statistically significant when a standard *t* test was applied $p < 0.001$.

Observation of the dimensions of the upper lip and lower lip reveal that the vermilion width of the upper lip (9-10) was greater in the male cleft group, this measurement was statistically significant $p < 0.05$, as was the height of the lower lip (10-11) $p< 0.05$.

Distances Measured	Statistically Significant
2-3	*** $p < 0.001$
9-10	* $p < 0.05$
10-11	* $p < 0.05$
3-13	*** $p < 0.001$

Table 5: Summary of graph 1a

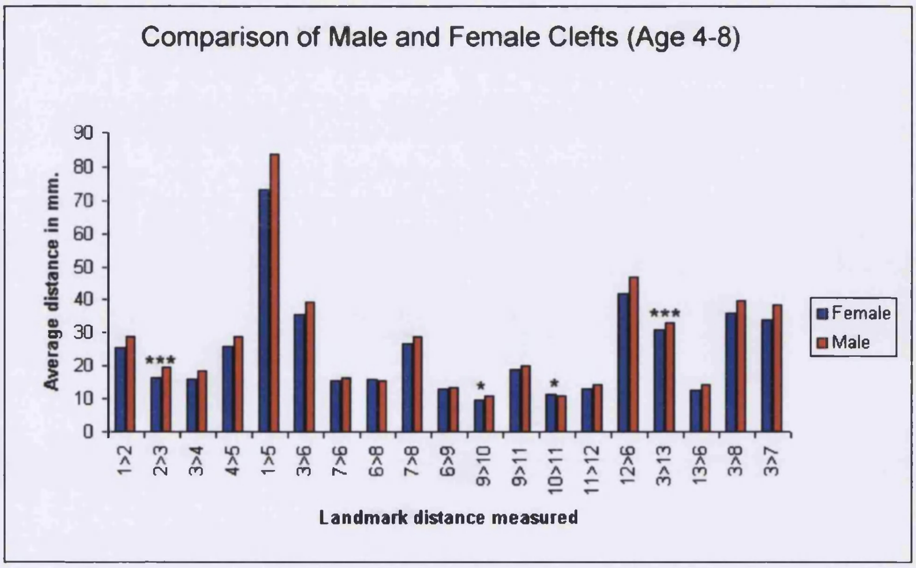
8.2.2 Comparison of nasal angles of male and female clefts age 4-8 years (Graph 1b)

At the age of 4-8 years there were statistically significant differences in the angles of the nose (6,2,4) between male and female clefts This would indicate that the alar base in males is displaced away from the midline more than the female group. The angles on 1,3 and 5 show no significant difference, indicating that the right side of the nose is similar in males and females.

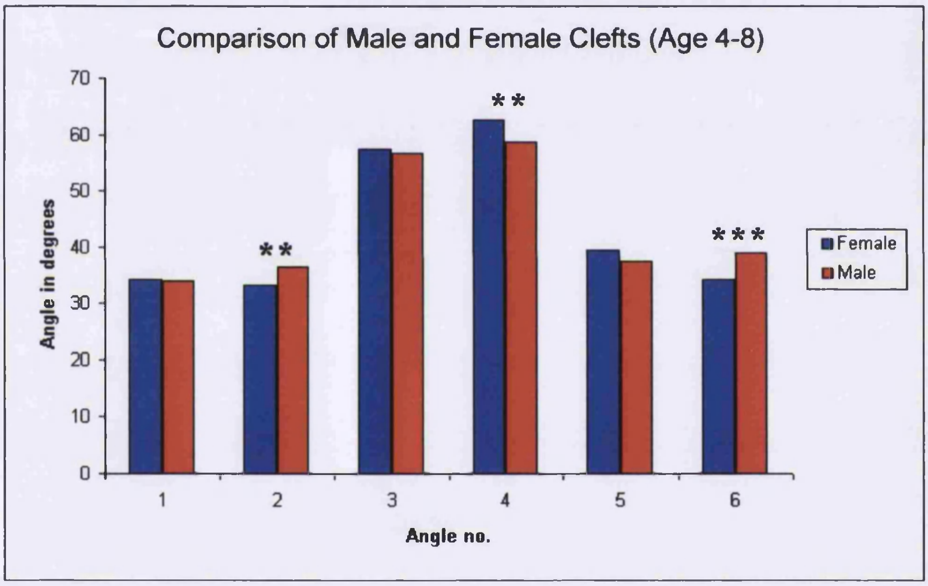
Angles Measured	Statistically Significant
Angle 2	** $p < 0.01$
Angle 4	** $p < 0.01$
Angle 6	***$P < 0.001$

Table 6: Summary of graph 1b

Graph 1a: Average Distance Measurements of Male and Female Clefts Age 4-8 years.

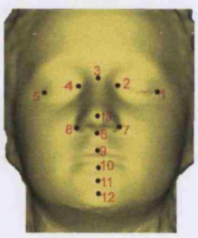


Graph 1b: Average Nasal Angles of Male and Female Clefts Age 4-8 years.



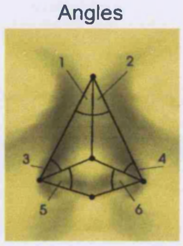
1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base

Points



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale

Angles



8.2.3 Comparison of measurements of male and female clefts age 9-12 (Graph 2a)

At the age of 9-12 years the differences between the males and females is less significant. The nasal bridge length (3-13), of the female cleft group age 9-12 is greater than that of the male cleft group ($p< 0.05$) this is probably due to the earlier pubertal growth of the females.

The right lateral nose dimension (3-8) is wider and the nasal length (3-6) longer in the female than the male ($p< 0.05$).

Distances Measured	Statistically Significant
3-6	* $p < 0.05$
3-13	* $p < 0.05$
3-8	* $p < 0.05$

Table 7: Summary of graph 2a

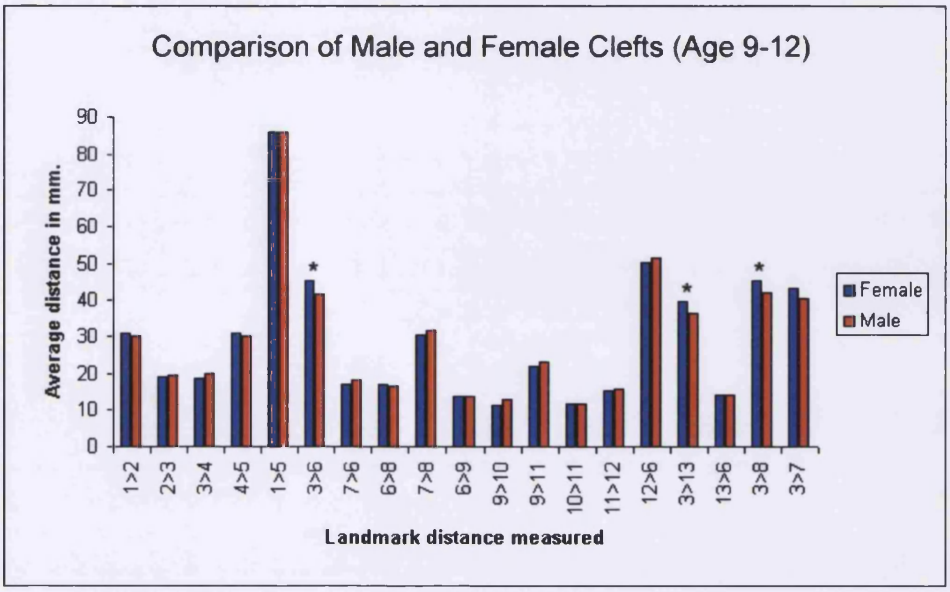
8.2.4 Comparison of nasal angles of male and female clefts Age 9-12 years (Graph 2b)

At the age of 9-12 years angle 2 was significantly greater in the male cleft group ($p<0.001$) indicating a significant difference in the shape of the nose on the left-cleft side between the male and female groups. Although angles 4 and 6 showed similar differences to those seen in the groups age 4-8, the differences were not significant.

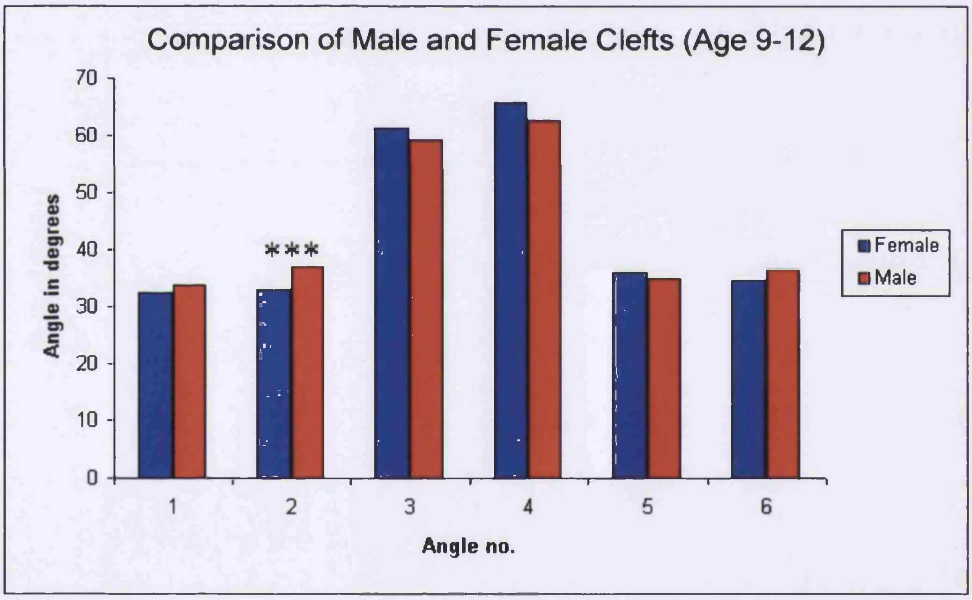
Angles Measured	Statistically Significant
Angle 2	*** $p < 0.001$

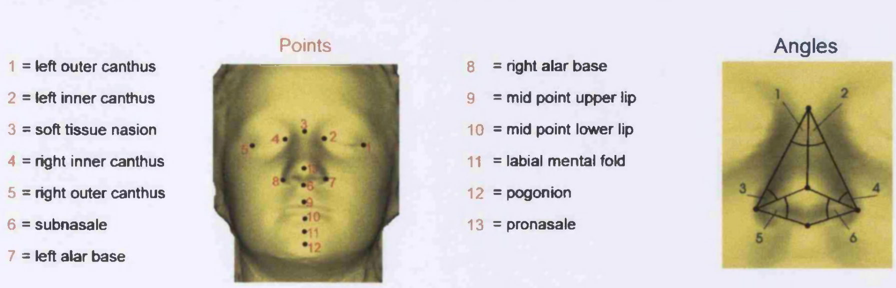
Table 8: Summary of graph 2b

Graph 2a: Average Distance Measurements of Male and Female Clefts Age 9-12 years.



Graph 2b: Average Nasal Angles of Male and Female Clefts Age 9-12 years.





8.2.5 Comparison of measurements of male and female clefts age 13-16 (Graph 3a)

At 13-16 years the most significant differences between the groups is seen in the lower part of the face. There is a very significant difference ($p<0.001$) of the chin height (11-12) the males being larger than the females. There is also a significant difference in the height of the lower lip (10-11) ($p< 0.001$), and the lower face distance (6-12) in males at this age ($p<0.05$). There is no significant difference in the nasal length (3-6) or the nasal width (7-8) or in the right and left lateral nose dimensions (3-8 and 7-8).

Distances Measured	Statistically Significant
10-11	** $p < 0.001$
11-12	*** $p < 0.001$
6-12	* $p < 0.05$

Table 9: Summary of graph 3a

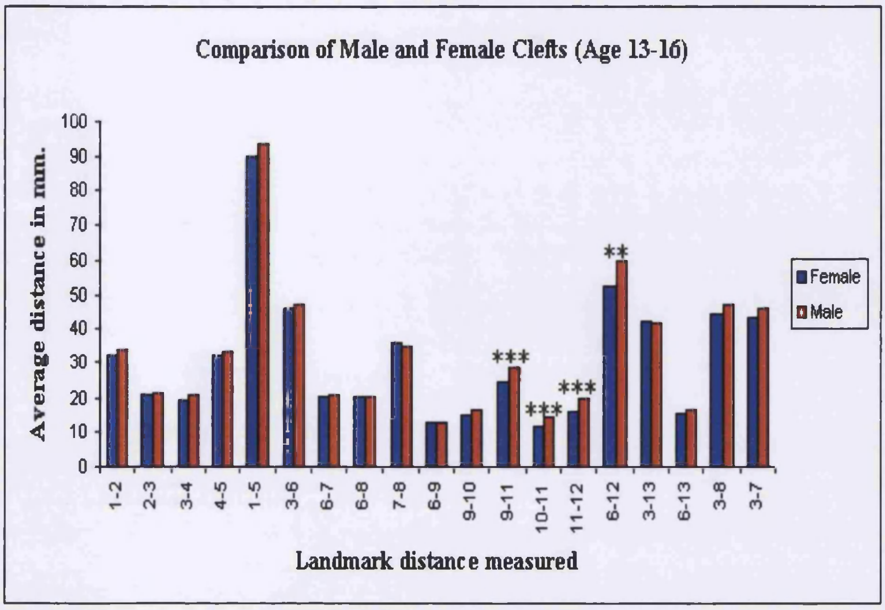
8.2.6 Comparison of nasal angles of male and female clefts age 13-16 years (Graph 3b)

At the age of 13-16 years angles 3 and 4 were significantly different ($p<0.001$) for both angles. Angle 3 was greater in the female group and angle 4 was greater in the male group.

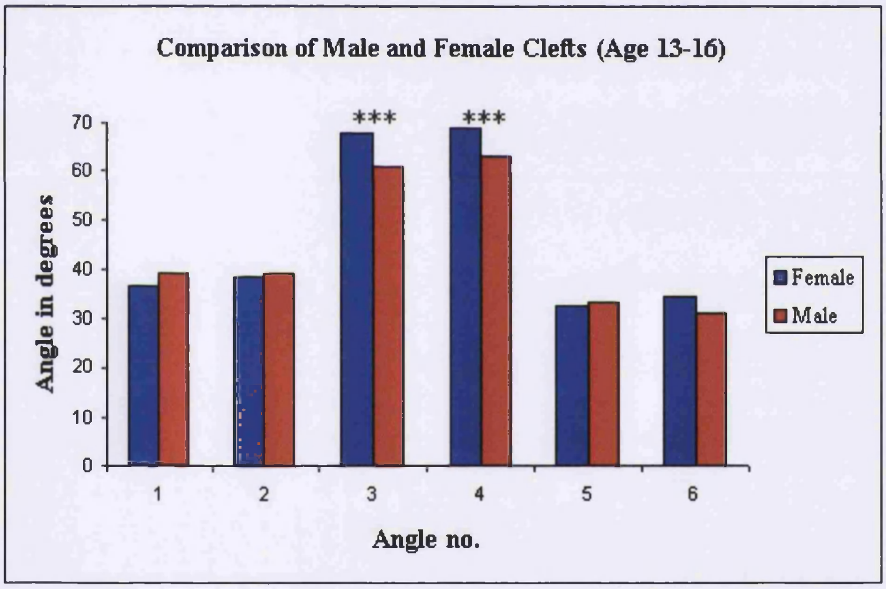
Angles Measured	Statistically Significant
Angle 3	$P<0.001$
Angle 4	$P<0.001$

Table 10: Summary of graph 3b

Graph 3a: Average Distance Measurements of Male and Female Clefts Age 13-16 years.

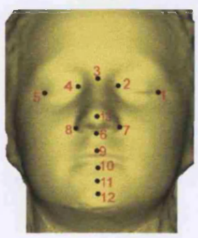


Graph 3b: Average Nasal Angles of Male and Female Clefts Age 13-16 years.



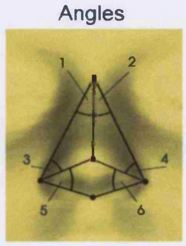
1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base

Points



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale

Angles



8.3 Comparison of measurements of female clefts with female controls

8.3.1 Comparison of measurements of female clefts with female controls age 4-8 (Graph 4a)

Comparison of the female clefts with the control group of the same age show that there are considerable differences in the nasal tip protrusion (6-13) and the left lateral nose dimension (3-7) these were significant at ($p<0.05$) and $p<0.001$) respectively. The height of the upper lip (6-9) in controls was significantly longer ($p<0.001$), and the lower lip (10-11)), in clefts was significantly longer ($p<0.001$), but the vermilion width (9-10) was greater in the controls than in the clefts ($p<0.05$).

Distances Measured	Statistically Significant
6-9	*** $p < 0.001$
9-10	* $p < 0.05$
10-11	*** $p < 0.001$
6-13	* $p < 0.05$
3-7	*** $p < 0.001$

Table 11: Summary of graph 4a

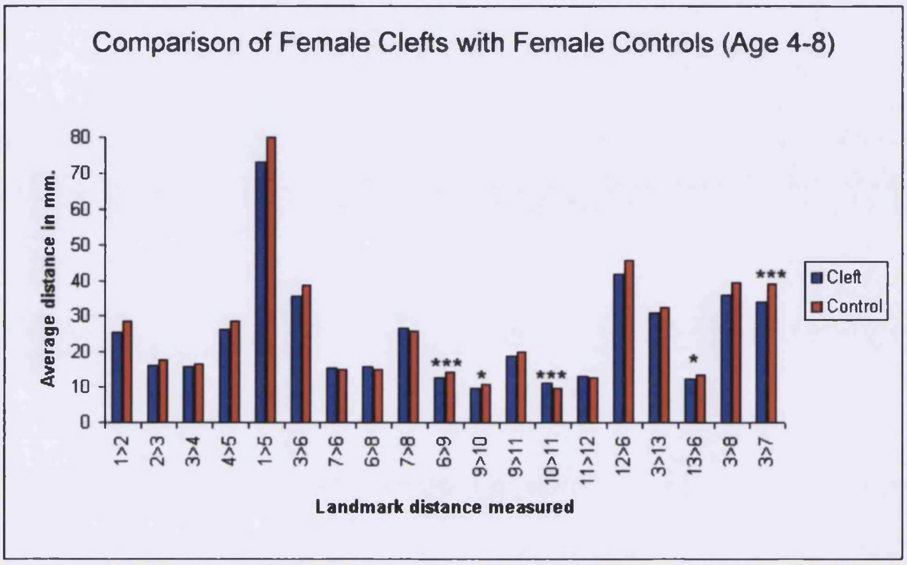
8.3.2 Comparison of nasal angles of female cleft compared with female control age 4-8 (Graph 4b)

At the age of 4-8 years there were statistically significant differences at angles 2 and 4. Angle 2 ($p<0.001$) was greater in the female control group compared with the cleft group. Angle 4 ($p<0.001$) was significantly greater in the cleft group. This indicates that the alar base in the cleft group age 4-8 is nearer the mid-line and that the nose is flatter.

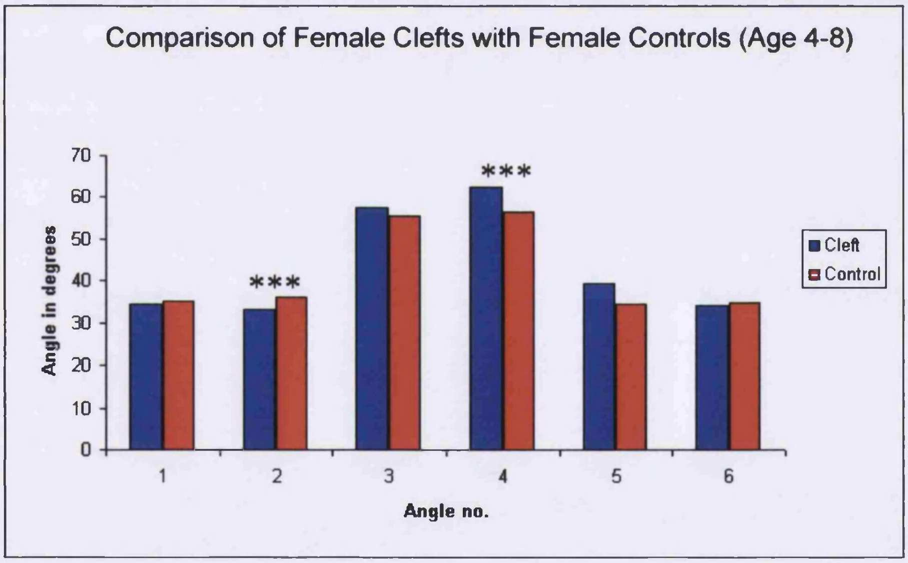
Angles Measured	Statistically Significant
Angle 2	** $p <0.01$
Angle 4	*** $p <0.001$

Table 12: Summary of graph 4b

Graph 4a: Average Distance Measurements of Female Clefts and Female Controls Age 4-8years.

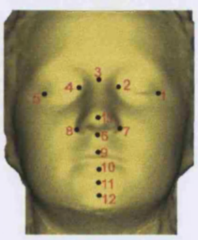


Graph 4b: Average Nasal angles of Female Celts and Female Controls Age 4-8 years.



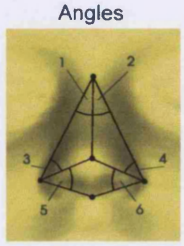
Points

1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale

Angles



8.3.3 Comparison of female clefts with female controls Age 9-12 (Graph 5a)

At the age of 9-12 the height of the lower lip (10-11) and chin height (11-12) are significantly greater in the cleft group ($p < 0.001$). There was also a significant difference ($p<0.01$) in the nasal bridge length (3-13) which was longer in the cleft group. The right lateral nose dimension (3-8) was also significantly greater in the cleft group ($p<0.05$). Although the width of the nose was greater in the cleft group this was not significant. It was interesting that there was no difference in the lateral nose dimension on the side of the cleft.

Distances Measured	Statistically Significant
10-11	*** p < 0.001
11-12	*** p < 0.001
3-13	** p < 0.01
3-8	* p < 0.05

Table 13: Summary of graph 5a

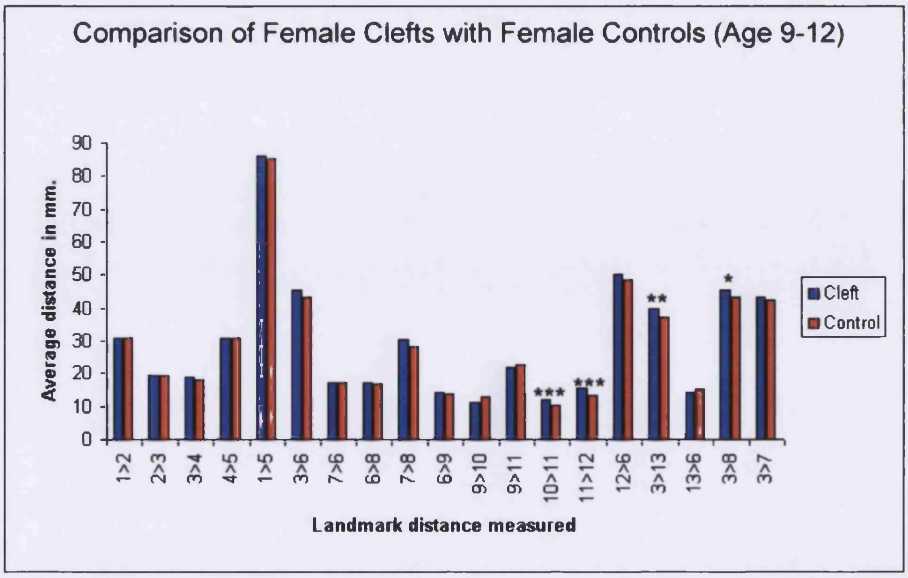
8.3.4 Comparison of nasal angles of female cleft compared with female control age 9-12 (Graph 5b)

At the age of 9-12 more statistically significant differences are found between the female clefts and female controls at angle 1,2 and 4 ($p< 0.001$). This would indicate the effect of the cleft on the left side and that the tip of the nose is displaced to that side

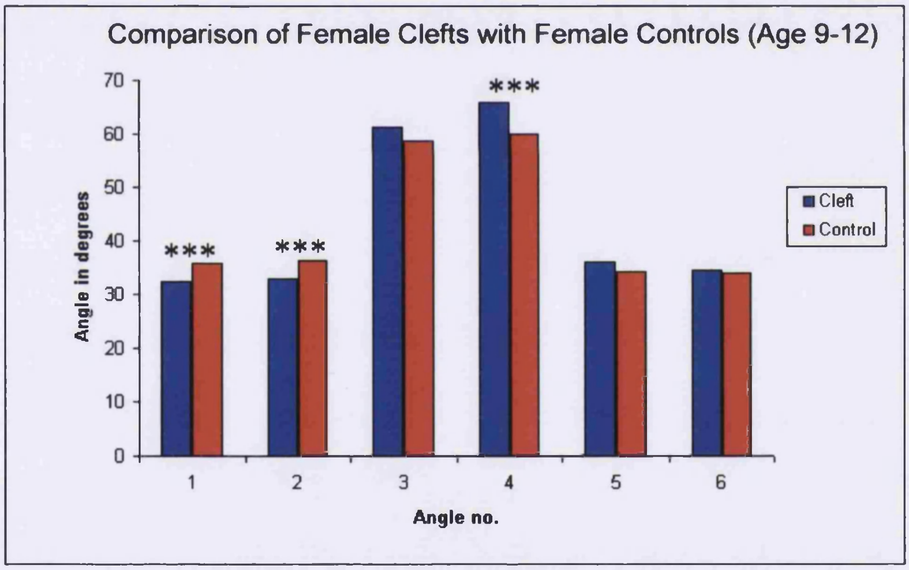
Angles Measured	Statistically Significant
Angle 1	*** p <0.001
Angle 2	*** p <0.001
Angle 4	*** p <0.001

Table 14: Summary of graph 5b

Graph 5a: Average Distance Measurements of Female Clefts and Female Controls Age 9-12 years.

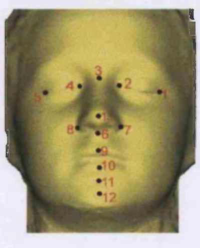


Graph 5b: Average Nasal Angles of Female Clefts and Female Controls Age 9-12 years



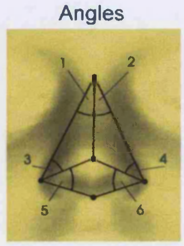
Points

1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale

Angles



8.3.5 Comparison of measurements of female clefts with female controls age 13-16 (Graph 6a)

Comparison of the female cleft and control groups at age 13-16 when most of the pubertal growth spurt is over, shows the width of the nose (7-8) is significantly wider in female controls compared to female clefts ($p<0.001$). It was interesting that although the left alar base width was larger in clefts this was not significant when compared to controls. However the right alar base width (6-8) was significantly wider ($p<0.001$) in the control group. Right (3-8) and left (3-7) lateral nasal distance was significantly greater in the control group with values of ($p< 0.001$) and ($p<0.01$) respectively. The height of the upper lip (6-9) in the cleft group was significantly shorter than the controls ($p<0.05$).

Distances Measured	Statistically Significant
6-8	*** $p < 0.001$
7-8	*** $p < 0.001$
6-9	* $p < 0.05$
3-8	*** $p < 0.001$
3-7	** $p < 0.01$

Table 15: Summary of graph 6a

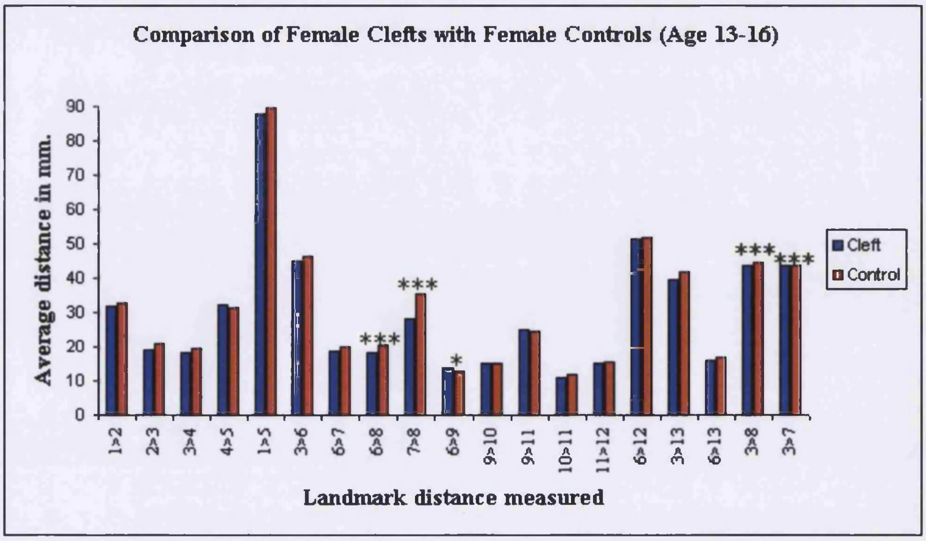
8.3.6 Comparison of nasal angles of female cleft with female control age 13-16 (Graph 6b)

Of all the angles measured angle 3 and angle 4 were the only ones to be statistically significant ($p<0.001$). These angles were greater in the cleft group indicating that the tip of the nose is more inferiorly placed in the cleft group or that the alar bases have not descended inferiorly as much as the controls.

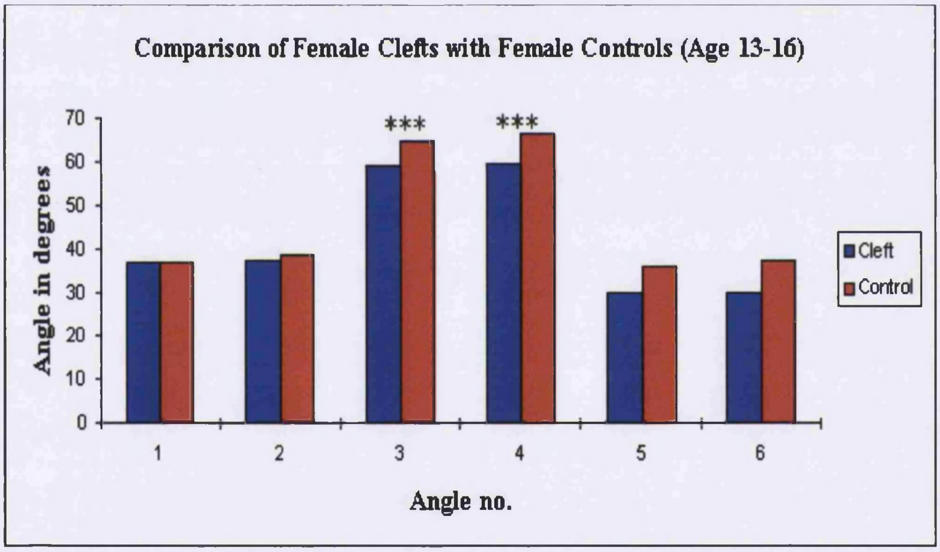
Angles Measured	Statistically Significant
Angle 3	*** $p <0.001$
Angle 4	*** $p <0.001$

Table 16: Summary of graph 6b

Graph 6a: Average Distance Measurements of Female Clefts and Female Controls Age 13-16 years.

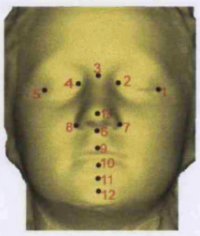


Graph 6b: Average Nasal Angles of Female Clefts and Female Controls Age 13-16 years.



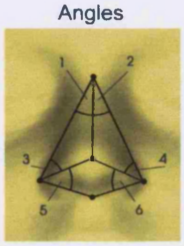
Points

1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale

Angles



8.4 Comparison of measurements of male clefts with male controls

8.4.1 Comparison of measurements of male clefts with male controls age 4-8 (Graph 7a)

The comparison of the male cleft group with the controls age 4-8 years showed a large number of statistically significant differences.

The nasal length (3-6), the width of the nose (7-8), the right and left lateral nose dimension (3-8 and 3-7)) were greater in the cleft group when compared with the equivalent control ($p<0.001$). Nasal tip protrusion (6-13) was greater in the male cleft group at 4-8 years of age ($p<0.001$).

The height of the upper lip (6-9) was greater in the control group than the cleft group ($p<0.001$). Vermilion width (9-10) was greater in the control group ($p<0.05$). However, the lower lip height (10-11) ($p<0.01$) and the chin height (11-12) ($p<0.001$) was greater in the cleft group.

Nasal bridge length (3-13) was longer in the male cleft group when compared with the equivalent control group ($p<0.05$). Left facial midline distance (2-3) and the outer- canthal distance (1-5) were greater in the male cleft group ($p<0.05$).

Distances Measured	Statistically Significant
2-3	* $p < 0.05$
1-5	* $p < 0.05$
3-6	*** $p < 0.001$
7-8	*** $p < 0.001$
6-9	*** $p < 0.001$
9-10	* $p < 0.05$
10-11	** $p < 0.01$
11-12	*** $p < 0.001$
3-13	* $p < 0.05$
6-13	*** $p < 0.001$
3-8	*** $p < 0.001$
3-7	** $p < 0.01$

Table 17: Summary of graph 7a

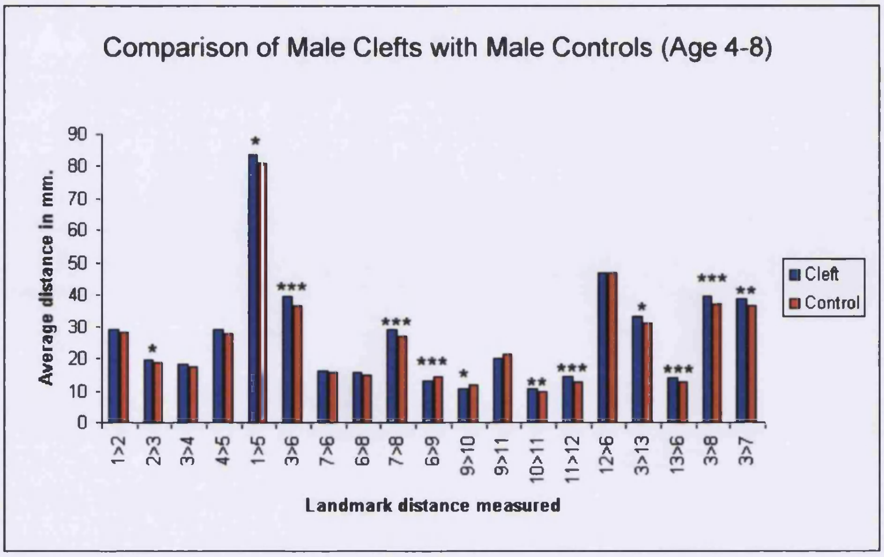
8.4.2 Comparison of nasal angles of male clefts with male controls age 4-8 (Graph 7b)

A comparison of nasal angles at age 4-8 shows a significant difference at angles 5 and 6 ($p<0.001$). These angles are greater in the cleft group suggesting differences in either the left or right alar bases relative to subnasale, or the nasal tip.

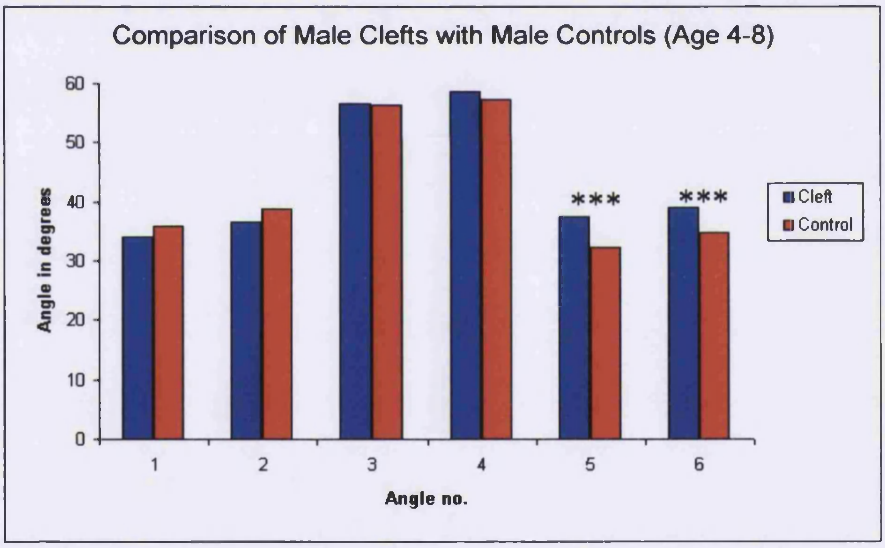
Angles Measured	Statistically Significant
Angle 5	*** $p <0.001$
Angle 6	*** $p <0.001$

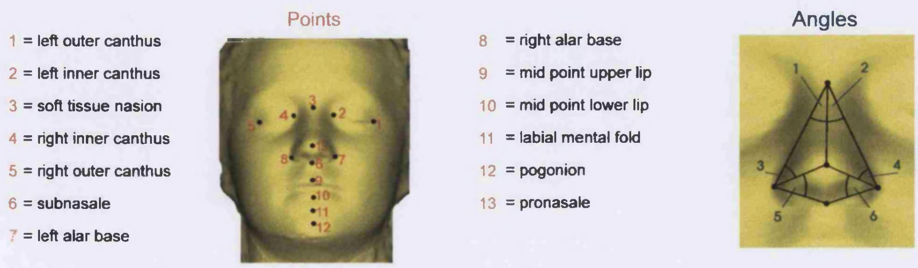
Table 18: Summary of graph 7b

Graph 7a: Average Distance Measurements of Male Clefts and Male Controls Age 4-8 years.



Graph 7b: Average Nasal angles of Male Clefts and Male Controls Age 4-8 years.





8.4.3 Comparison of measurements of male clefts with male controls age 9-12 (Graph 8a)

At the age of 9-12 years statistically significant differences can also be seen, although not as many as seen in the 4-8 year old male groups.

Left alar base width (6-7) and the width of the nose (7-8) were greater in the male cleft group (p<0.001).

The height of the upper lip (6-9) was significantly greater in the male control group (p<0.01), but the height of the lower lip (10-11) and the height of the chin (11-12) were greater in the male cleft group (p<0.05).

Distances Measured	Statistically Significant
6-7	*** p < 0.001
7-8	*** p < 0.001
6-9	** p < 0.01
10-11	* p < 0.05
11-12	** p < 0.01

Table 19: Summary of graph 8a

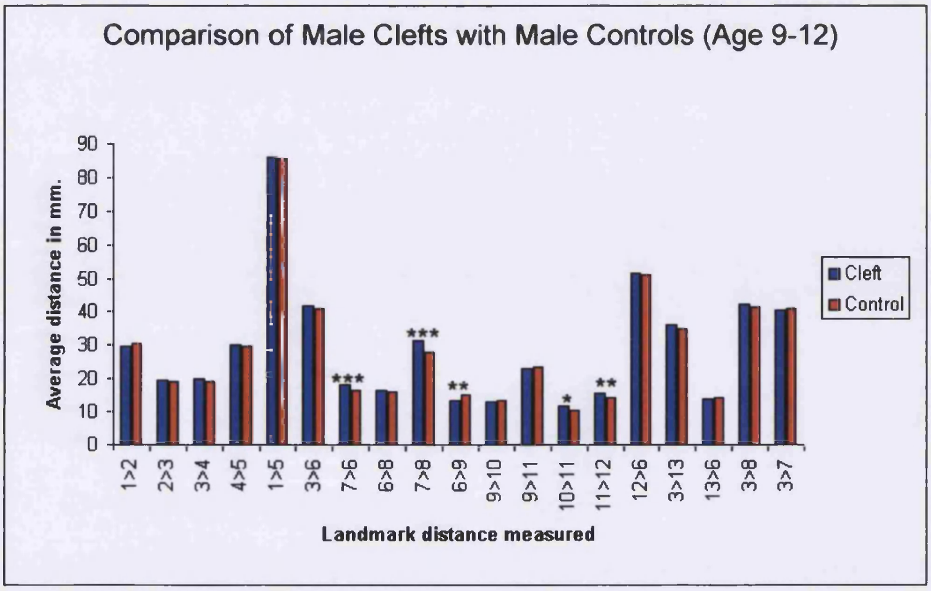
8.4.4 Comparison of nasal angles of male clefts with male controls age 9-12 (Graph 8b)

A comparison of the nasal angles of the male cleft and male controls age 9-12 shows that angle 1 is significantly greater in the control group (p<0.05). Angle 4 is significantly greater (p<0.001) in the cleft group. This indicates that the left alar base is flatter and the tip of the nose is displaced to the side of the cleft.

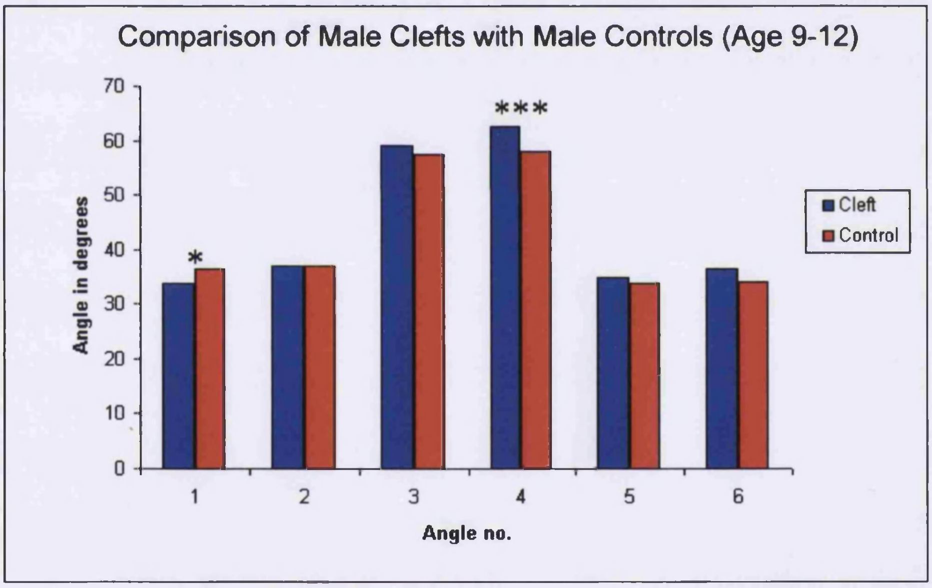
Angles Measured	Statistically Significant
Angle 1	* p <0.05
Angle 4	*** p <0.001

Table 20: Summary of graph 8b

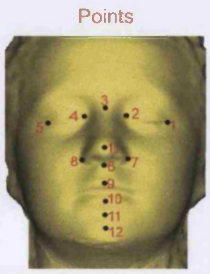
Graph 8a: Average Distance Measurements of Male clefts and Male Controls Age 9-12 years.



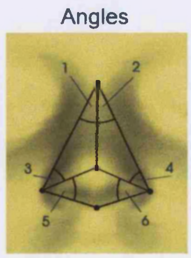
Graph 8b: Average Nasal Angles of Male Clefts and Male Controls Age 9-12 years.



1 = left outer canthus
2 = left inner canthus
3 = soft tissue nasion
4 = right inner canthus
5 = right outer canthus
6 = subnasale
7 = left alar base



8 = right alar base
9 = mid point upper lip
10 = mid point lower lip
11 = labial mental fold
12 = pogonion
13 = pronasale



8.4.5 Comparison of measurements of male clefts with male controls age 13-16 (Graph 9a)

At the age of 13-16 years there were increasingly significant differences between the cleft and the control groups.

Left and right eye fissure length (1-2 and 4-5) was significantly greater in the male cleft group age 13-16 years ($p<0.001$), but the left and right facial midline distances were greater in the male control group with ($p<0.001$). Outer canthal width (1-5) was also greater in the cleft group when compared with the equivalent control ($p<0.001$).

The width of the nose (7-8) was greater in the male cleft group ($p<0.001$). The height of the lower lip (10-11) was greater in the male cleft group ($p<0.001$). The right lateral nose dimension (3-8) of the control group was greater than that of the cleft group ($p<0.001$), and the left lateral nose dimension (3-7) was also greater in the control group ($p<0.01$). Chin height (11-12) was greater in the male cleft group ($p<0.001$) as was the lower face distance (6-12) ($p<0.001$).

Distances Measured	Statistically Significant
1-2	*** $p < 0.001$
2-3	*** $p < 0.001$
3-4	*** $p < 0.001$
1-5	*** $p < 0.001$
7-8	*** $p < 0.001$
10-11	*** $p < 0.001$
11-12	*** $p < 0.001$
6-12	*** $p < 0.001$
3-8	*** $p < 0.001$
3-7	** $p < 0.01$

Table 21: Summary of graph 9a

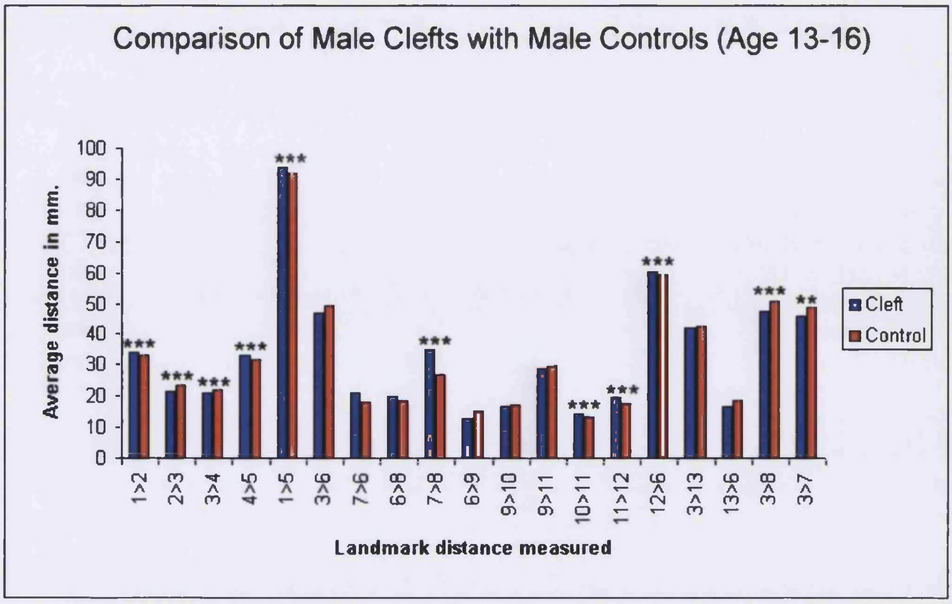
8.4.6 Comparison of nasal angles of male cleft with male control age 13-16 (Graph 9b)

No significant differences were found.

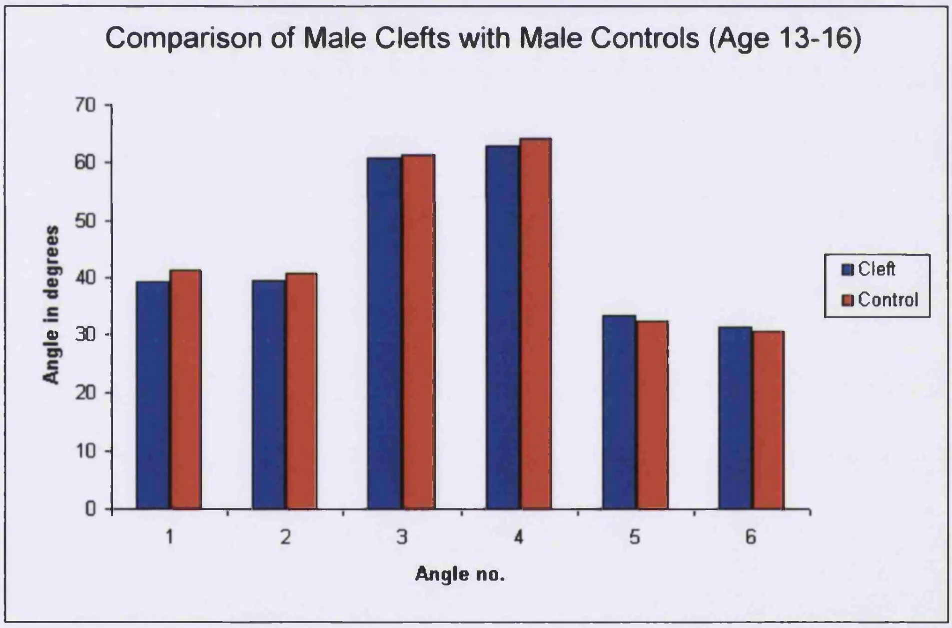
Angles Measured	Statistically Significant
All angles	None

Table 22: Summary of graph 9b

Graph 9a: Average Distance Measurements of Male Clefts and Male Controls Age 13-16 years.



Graph 9b: Average Nasal Angles of Male Clefts and Male Controls Age 13-16 years.



Points

1 = left outer canthus

2 = left inner canthus

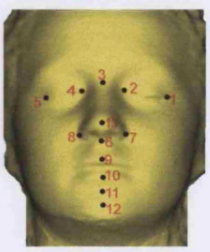
3 = soft tissue nasion

4 = right inner canthus

5 = right outer canthus

6 = subnasale

7 = left alar base



8 = right alar base

9 = mid point upper lip

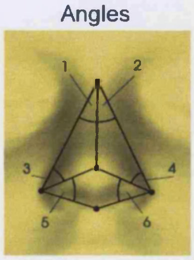
10 = mid point lower lip

11 = labial mental fold

12 = pogonion

13 = pronasale

Angles



Summary

In this chapter a detailed discussion of the statistically significant differences found in facial measurement and nasal angles between the groups has been given. The results indicate that:

- Female cleft faces are smaller than male cleft faces, except at age 9-12 where the female nose is significantly longer and wider than that of the equivalent male, this is probably due to the earlier pubertal growth in females.
- The faces of females with unilateral cleft lip and palate are smaller than those of their equivalent control groups, with the exception of the female cleft age 9-12, who have a longer face and nose than the control group. There was variability in upper and lower lip lengths.
- In the male groups at age 4-8 years the width and length of the nose in the unilateral cleft lip and palate group were significantly greater than that of the equivalent control group. Nasal tip protrusion was significantly greater in the cleft group.
- At age 9-12 significant differences were found in the left alar base width and the width of the nose, these being wider in the male cleft group. Upper lip height was significantly greater in the control group, whilst the lower lip height and the chin height were significantly greater in the cleft group.
- At age 13-16 significant differences were found in the orbital region. The total distance between the left exocanthion and right exocanthion was significantly greater in the male cleft group and this was the only group where this significant difference was found. The left exocanthion to right endocanthion, right endocanthion to left exocanthion were also significantly greater in the cleft group. Lower face distance was also significantly greater in the male cleft group. The length of the nose is greater in the control group, but not significantly whilst the width of the nose is significantly greater in the cleft group.
- A comparison of the nasal angles between each of the groups shows that significant shape differences were present, especially in the region of the alar bases and tip of the

nose. The only groups, which did not show any significant differences in nasal angles, were the male clefts and controls age 13-16 years.

Chapter Nine

Discussion and Conclusions

In this thesis the method of optical surface scanning has been used to collect, in three dimensions, the facial soft tissue morphology of a group of children with UCLP and a comparable control population. Two methods of analysis have been used to test the hypothesis that there is no difference in the soft tissue facial morphology of UCLP patients who have been carefully operated on by one surgeon, compared with a control group.

The UCL optical surface scanner is a method of quantifying objectively facial soft tissues in 3D. It is a no-contact, non-invasive method of data collection, which allows comparison with normative data. The system is capable of collecting 60,000 3D points across the facial surface in under 10 seconds. The accuracy of the system has been shown by Moss *et al.* (1989) to be better than 0.5mm across the surface of the face.

The majority of studies that have investigated the growth of the face in unilateral cleft lip and palate subjects (Ross 1987; Brattstrom 1991; Semb 1991) and control subjects, (Subtelny 1959, Nanda *et al.* 1990, Prahl-Andersen *et al.* 1995) have used cephalometrics. This method of data analysis limited by its two-dimensional nature and confined to analysis of the profile. Lindsay and Farkas (1972), Farkas *et al* (1991) have used 3D anthropological techniques to measure changes before and after surgery in cleft groups, which although accurate is time consuming thereby limiting the number of three-dimensional points collected. Mishima *et al.* (1996) used a three-dimensional digitiser to create a 3D dataset from a facial plaster model of children with unilateral cleft lip-nose. Ras *et al.* (1995) used stereophotogrammetry to assess the three-dimensional changes of facial asymmetry in children with UCLP.

Prahl-Andersen *et al.* (1995) who studied adolescent growth changes in soft tissue profile states that an understanding of the soft tissue changes during growth is important for the orthodontist and overall facial aesthetics. Nanda *et al.* (1990) stated that it was imperative that clinical cephalometric analyses include a consideration of soft tissue measurements.

In her extensive study Semb (1991) studied the soft tissues and the hard tissues of patients born with cleft lip and palate with a non-cleft group. She concluded that the UCLP face was characterised by a short retrusive maxilla and elongation of the anterior face (even thought the upper face is shorter) and a retrusive mandible, the nose was flatter.

Duffy (1997) used the optical surface scanner to study the child cleft face of 39 cleft children and 25 unaffected children age 8-11 years. He does not state whether the groups were comprised of male and female, but in view of the fact that the sample size was small it can be presumed that this was so. No information was given as to the numbers, which made up each cleft subgroup. He concluded that significant differences between the control group and the cleft subgroups were found in interocular widths, nose base widths, lateral lip lengths, vermilion thickness, mouth width and nose/mouth width ratios. Alar base width in the UCLP group was found to be broader than that of the control group, but not significantly so. He also found intercanthal width to be narrower in the cleft groups when compared with the control group. Orbital differences were found in this study at age 4-8 years and 13-16 years when the male cleft groups were compared with their equivalent controls. Intercanthal distance was found to be significantly greater in the male cleft groups, which is contrary to the findings of Duffy, (1997), and Han *et al.* (1995).

9. Male UCLP compared with Female UCLP (Registration)

9.1 Age 4-8

At the age of 4-8 years differences in the soft tissue morphology between the male and female face can be seen. The male nose is longer and wider at the alar bases than the female nose. Total face height was greater in the male cleft group by 3-7mm. Chin prominence was also greater in the male group by 3-5mm. These differences are seen in normal males and females, the female group being smaller than the male (Nute 1997). The soft tissues of both groups at this age appear to be symmetrical.

9.1.1 Age 9-12

At age 9-12 years the female face is larger than the male face, this is also found in normal children at this age. The female nose is longer by 1-3mm and the alar bases are wider by 1-3mm. Total face height was 5-7mm greater in the female group when compared with equivalent males. Chin prominence was also greater in the female group by 1-3mm. This difference can be explained by earlier female pubertal growth.

9.1.2 Age 13-16

In the 13-16 year age group total face height in the male group was greater than that of the female group by 5-9mm. Chin prominence was also greater in the male group by 3-5mm. The female nose was still marginally longer than the males, by 1-3mm. There was some asymmetry of the nose and the left side of the face.

Differences in the facial soft tissue morphology exist between male and female children with unilateral cleft lip and palate.

9.2 Female UCLP compared with Female Control (Registration)

9.2.1 Age 4-8

The comparison of the female cleft and female control groups age 4-8 years shows that overall the soft tissues of the female cleft group are deficient, especially on the left cleft side. The length of the nose was shorter and nasal tip protrusion flatter in the female cleft group age 4-8 years. Total face height was less in the female UCLP group by 3-7mm and chin prominence was also less by 3-5mm. There was asymmetry of the soft tissues on the left side of the face, due to the effect of the cleft.

9.2.2 Age 9-12

A comparison of the female cleft and female control groups at age 9-12 years, show that the total height of the face in the female cleft group was greater than that of the control group, which was the opposite of that seen at 4-8 years. At this age the nose of the female cleft group was longer than that of the control, alar base width was greater on the side of the cleft, whilst on the right side the alar width was less than that of the controls by 3-5mm. This was the opposite finding seen in the female cleft nose age 4-8 years and may be caused by the bone grafting of the alveolus. The nose of the female cleft group was flatter than that of the female control group by 3-5mm. Also at this age there was a deficiency of 1-3mm in the soft tissues on the right side of the face of the female cleft group. The area of the cleft was almost normal when compared to the control. This is probably due to the effect of the bone graft, which had been undertaken at this age. The stretch of the soft tissue over the bone graft could account for the deficiency of tissue seen in the right side of the lip, which was not present at 4-8 years.

9.2.3 Age 13-16

At the age of 13-16 years a marked deficiency can be seen in the facial soft tissues of the female cleft group. The length of the nose was less in the female cleft group and the left alar base was slightly wider than that of the control group. Total face height was now less in the female cleft group by 5-9mm. Chin prominence was greater in the female control group at this age, 5-7mm, this difference increasing to 7-9mm on the right side of the chin, lower lip and cheek.

The female cleft groups show variability in nose length and alar base width, due to the variability of the growth changes. They have flatter noses, reduced face height and reduced chin prominence when compared with the female control groups, except at age 9-12.

9.3 Male UCLP compared with Male Control (Registration)

9.3.1 Age 4-8

In the 4-8 year age group the cleft group has a soft tissue deficiency over the cheeks, lips and chin point of 3-7mm when compared with the equivalent control group. This indicates that the soft tissues of the male cleft face age 4-8 years were more posteriorly positioned by 3-7mm. This was most marked on the side of the cleft, and might be due to the contraction of the scar tissue on that side. The male cleft group age 4-8 years has a longer nose than the control group, however nasal tip protrusion in the cleft group was less than that of the control group, a similar finding to that seen in the female group. Total face height is greater in the cleft group by 3-5mm.

9.3.2 Age 9-12

At 9-12 years the comparison shows that the soft tissues of the male cleft face are more deficient when compared with the equivalent control group. Nasal tip protrusion was 3-5mm less in the cleft group this was also seen in the male cleft group age 4-8 years, showing that despite the bone grafting the position of the tip of the nose has not improved. The length of the nose in the male cleft group at 9-12 years was slightly longer than the control group; the left alar base was also wider in the cleft group. The upper and lower lip was less protrusive by 3-7mm in the cleft group. Total face height was less in the cleft group and chin prominence was also less. The soft tissues of the face in the male cleft group age 9-12 years are posterior to those of the male control group. The soft tissue deficiency of the male cleft group age 9-12 was more severe on the right side of the face. This phenomenon was also seen in the female cleft group age 9-12, and this may be due to the stretching of the soft tissue caused by the bone graft which had been placed at this age. It was also interesting that the position of the left alar base was similar to that of the controls.

9.3.3 Age 13-16

In the 13-16 year age group we can see that there was a continuing deficiency in the soft tissues of the male cleft group. The length of the male cleft nose was 5-9mm less than that of the male control group, especially on the left side. Nasal tip protrusion is also less in the male cleft group. Total face height in the male cleft group is less by 5-9mm when compared with the male control group and this deficiency extends across the cheeks, especially on the left side, and also across the lower lip and labio-mental fold. The chin prominence is the same for both groups, this finding was different to that of the female cleft groups whose chin prominence was less than that of the female controls.

Female UCLP compared with Male UCLP (Measured Distances)

9.3.4 Age 4-8

There was a significant difference in nasal bridge length (3-13) between male and female clefts at the age of 4-8 years ($p<0.001$), the male cleft having a longer nose than the female cleft. Ferrario *et al.* (1997b) observed a nose length of 36.19mm in control males and 34.5mm in control females this did not change at the age of 8 years. In this study the average nose length for male clefts age 4-8 years was 39.4mm, in the female cleft group at 4-8 years this measured 35.6mm, but this was not statistically significant. It was also interesting that the left facial midline distance was greater in males than females, perhaps indicating that the males were more asymmetric.

9.3.5 Age 9-12

However at 9-12 years the female nasal bridge length was significantly longer ($p<0.05$) than the male cleft. The length of the male cleft nose at the age of 9-12 had increased to 41mm and the female nose had increased in length to 44mm. This difference between the male and female cleft at age 9-12 years may be due to the earlier pubertal growth of females.

9.3.6 Age 13-16

At the age of 13-16 years there was no significant differences in the nasal measurements between the two cleft groups. However there was a significant difference in the lower face distance, the males being significantly larger than the females ($p < 0.05$). There were also significant differences in the lower lip measurements. The height of the lower lip and chin height being significantly greater in the male group ($p < 0.001$) ($p < 0.001$) respectively. This is probably due to the prominence of the chin, which is usually greater in males than females.

9.4 Female UCLP compared with Male UCLP (Nasal Angles)

9.4.1 Age 4-8

At the age of 4-8 the male cleft nose (angles 2 and 6) were significantly greater than the female cleft and angle 4 was significantly smaller. This would indicate a significant difference in the shape of the male nose and may reflect a greater degree of asymmetry in the male cleft nose at this age.

9.4.2 Age 9-12

At the age of 9-12 years only angle 2 was significantly different ($p < 0.001$), being larger in the male group

9.4.3 Age 13-16

At 13-16 years there were significant differences at angles 3 and 4 ($p < 0.001$), angle 3 being greater in the female cleft group and angle 4 greater in the male cleft group.

9.5 Female UCLP compared with Female Control (Measured Distances)

9.5.1 Age 4-8

The nasal tip protrusion of the female cleft group was significantly less than the controls ($p < 0.05$) at age 4-8. Farkas *et al.* (1993) found an optimal nasal tip protrusion in almost half his UCLP sample, but also found a borderline small or abnormally small protrusion in 27.9% of his sample.

The height of the upper lip was significantly greater in the female control group ($p< 0.01$), but the height of the lower lip was significantly greater in the female cleft group ($p<0.001$). At age 4-8 the female cleft group had a shorter upper face height when compared with the female controls. This might indicate that the lower lip was compensating for the deficiency in the upper lip.

Semb *et al.* (1991) found the lip outline worsened steadily during growth in the unilateral cleft lip and palate group, and that the upper lip receded in prominence and the soft tissue profile became straighter especially after the age of fifteen. She also found that the anterior face of the cleft lip and palate group was longer and that the mandible is more retrusive

Ross (1987) found a significant increase in lower face height in the male cleft groups he studied. Horswell and Levant (1988) found a shorter lower face height in their UCLP group when compared with normal controls. At age 4-8 the lower face distance of the female cleft group was less, but not significantly when compared with the equivalent control group.

9.5.2 Age 9-12

At age 9-12 the nasal bridge length was significantly greater in the cleft group than the controls ($p<0.01$), and the differences that were seen in the lower lip height and the chin height were significantly greater in the cleft group ($p<0.001$).

9.5.3 Age 13-16

At age 13-16 the right and left alar base width was significantly greater in the cleft group. The height of the upper lip was significantly shorter in the cleft group. However the right and left lateral nose dimensions were greater in the control group than in the cleft group, this suggests that the alar base in the cleft group was displaced laterally.

9.6 Female UCLP compared with Female Control (Nasal Angles)

9.6.1 Age 4-8

Angle 2 was significantly greater ($p<0.001$) in the control group and angle 4 was significantly greater in the cleft group ($p<0.001$).

9.6.2 Age 9-12

At age 9-12 years angle 2 was significantly greater ($p<0.001$) in the control group and angle 4 significantly greater in the cleft group ($p<0.001$). Angle 1 was also significantly greater in the control group.

9.6.3 Age 13-16

At 13-16 years angles 3 and 4 are significantly greater in the cleft group. This would indicate that the tip of nose is displaced inferiorly, and this is confirmed by the registered scans.

9.7 Male UCLP compared with Male Control (Measured Distances)

9.7.1 Age 4-8

In the male cleft group age 4-8 year the nasal tip was significantly more protrusive when compared to the controls ($p>0.001$) but this difference was not found in the older age groups. At all ages the width of the nose in the male cleft group was significantly wider than that of the equivalent control group ($p> 0.001$) but this was not so in the female group. Farkas (1994), measuring 51 normal males at the age of 8 years registered a mean width of the nose at 29.8mm and this was comparable to the measurements of this group, which are 26.9mm.

In the male cleft group at age 4-8 the nasal length was significantly greater than the equivalent control group ($p>0.01$), but the upper lip was significantly shorter in the cleft group. This combined with the fact that registration of the scans indicated that the nose and upper lip were more retrusive would indicate a failure of forward growth. The lower lip length and chin height was significantly increased in the cleft group, as was the nasal tip protrusion. There was also a significant increase in the left and right lateral nose dimensions which would indicate that the nose of the cleft group was wider than the controls and this was confirmed by the registration of the scans.

9.7.2 Age 9-12

At the age of 9-12 the nose of the cleft group was significantly wider than that of the controls, but now the left alar base width was also wider than the controls, which may be due to the bone graft building the left alar base up. The upper lip was shorter and the length of the lower lip and chin height greater than the controls. The distance between subnasale and the right alar contour was significantly greater in the male cleft group age 9-12 ($p>0.001$). These findings correspond with those of Farkas (1993), who found nose width disparity greater before surgical repair, the difference was reduced after surgery but normal proportions were not restored.

At age 9-12 nasal length was still greater in the cleft group, but not significantly so. At age 9-12 lower face distance was greater in the female cleft group

9.7.3 Age 13-16

The most significant differences at age 13-16 are still the width of the nose, the increase in the length of the lower lip and the height of the chin. However the right and left lateral nose dimensions are now significantly shorter than the controls, which indicates that the alar bases have not descended inferiorly. Kyrkanides et al (1996) measured asymmetry of the nose and noted that there was a significant difference between cleft and controls in three age groups from 6-16 years, and this asymmetry worsened progressively with age. The other interesting significant differences which were only found in this group are in the region of the orbits, where the length of the right and left eye fissure and outer canthal distance were greater in the clefts than in the controls. The right and left facial midline distance was also significantly smaller when compared with the controls; this could indicate a lack of protrusion of the nasal base relative to the eyes. The control values measured at 13-16 years are similar to those recorded in controls by Farkas (1994).

9.8 Male UCLP compared with Male Control (Nasal Angles)

9.8.1 Age 4-8

At the age of 4-8 angles 5 and 6 were significantly larger in the cleft group suggesting that subnasale was in a lower position.

9.8.2 Age 9-12

At the age of 9-12 years there was a significant difference in angle 4 between the clefts and the controls, this value being greater in the clefts, once again this may be due to the effects of the bone graft on the alar base.

9.8.3 Age 13-16

There were no significant differences in the nasal angles at this age.

9.9 Conclusions

- There is a significant difference in the facial morphology between male and female patients with unilateral cleft lip and palate.
- There are significant differences in the facial morphology between male and female patients with unilateral cleft lip and palate when compared with equivalent controls.
- The cleft nose is wider, and becomes more retrusive with age and this has been quantified. There is variability in nose length
- Lower lip height is significantly greater in the male cleft groups when compared with equivalent controls.
- The UCL optical surface scanner has proved to be an accurate and efficient method of collecting 3D facial surface data.
- The results of this study show that it is possible to make accurate, reliable measurements and comparisons between different groups.
- The visualisation software developed alongside the system allowed comparison of data and provided a simple means of interpretation and illustration of three-dimensional changes between the groups.

9.10 Further Work

To increase the sample size of the UCLP and control groups. This will reduce variability within the groups.

Set up inter-centre studies to increase the database and provide comparative data that surgeons can access and enable them to audit surgical outcome. A database of three-dimensional facial form of normally growing children will help provide normative standards for surgeons to work towards. The data collection should be extended to include different ethnic groups.

Appendices

Appendix A.

Female cleft age 4-8 years, showing average distances and SD measured and the average degrees and SD degrees

Female Cleft	**Age 4-8**	**No. in group 19**
Distance Measured	**Average in mm**	**SD in mm**
1-2	25.3	8.4
2-3	16.1	4.8
3-4	15.9	4.6
4-5	26.1	7.8
1-5	73.0	24.2
3-6	35.6	11.0
6-7	15.4	3.4
6-8	15.9	3.8
7-8	26.6	7.9
6-9	12.7	3.4
9-10	9.5	1.4
9-11	18.8	3.4
10-11	11.2	1.6
11-12	13.0	1.7
6-12	41.7	11.7
3-13	30.7	8.4
6-13	12.5	2.0
3-8	36.0	10.7
3-7	33.9	10.3
Angles	**Average in degrees**	**SD in degrees**
1	34.3	4.2
2	33.3	5.0
3	57.3	4.1
4	62.5	6.4
5	39.5	13.2
6	34.2	5.4

Appendix B

Male cleft age 4-8 years, showing average distances and SD measured and the average degrees and SD degrees

Male Cleft	**Age 4-8**	**No. in group 19**
Distance Measured	**Average in mm**	**SD in mm**
1-2	28.9	2.7
2-3	19.6	1.8
3-4	18.3	2.2
4-5	29.0	2.5
1-5	83.6	4.4
3-6	39.4	3.2
6-7	16.1	1.7
6-8	15.6	1.4
7-8	28.9	1.7
6-9	13.3	1.6
9-10	10.6	1.4
9-11	20.2	1.7
10-11	10.8	1.4
11-12	14.4	2.0
6-12	47.0	3.4
3-13	33.1	3.3
6-13	14.0	1.0
3-8	39.8	2.7
3-7	38.6	2.5
Angles	**Average in degrees**	**SD in degrees**
1	34.0	3.0
2	36.4	4.2
3	56.6	4.7
4	58.6	5.1
5	37.4	3.2
6	38.9	3.9

Appendix C

Female cleft age 9-12 years, showing average distances and SD measured and the average degrees and SD degrees

Female Cleft	Age 9-12	No. in group 10
Distance Measured	**Average in mm**	**SD in mm**
1-2	30.9	2.4
2-3	19.2	2.5
3-4	18.6	2.3
4-5	30.6	2.6
1-5	85.9	4.5
3-6	45.4	3.8
6-7	17.2	2.4
6-8	17.2	2.2
7-8	30.4	3.5
6-9	13.9	3.8
9-10	11.3	3.1
9-11	21.7	2.7
10-11	11.8	1.5
11-12	15.3	2.5
6-12	50.3	4.0
3-13	39.9	3.7
6-13	14.1	1.5
3-8	45.4	3.2
3-7	43.1	3.2
Angles	**Average in degrees**	**SD in degrees**
1	32.4	3.9
2	32.8	2.8
3	61.2	5.1
4	65.8	5.0
5	35.9	4.5
6	34.4	5.9

Appendix D

Male cleft age 9-12 years, showing average distances and SD measured and the average degrees and SD degrees

Male Cleft	Age 9-12	No. in group 12
Distance Measured	**Average in mm**	**SD in mm**
1-2	27.7	2.8
2-3	19.5	1.9
3-4	19.9	1.8
4-5	29.9	3.4
1-5	85.8	4.1
3-6	41.9	3.0
6-7	18.3	1.5
6-8	16.4	2.5
7-8	31.5	3.0
6-9	13.7	1.7
9-10	12.9	2.7
9-11	23.2	2.7
10-11	11.8	1.3
11-12	15.7	3.0
6-12	51.6	4.9
3-13	36.4	2.8
6-13	14.1	1.3
3-8	42.3	2.8
3-7	40.5	3.5
Angles	**Average in degrees**	**SD in degrees**
1	33.8	3.5
2	36.9	3.8
3	59.0	2.7
4	62.4	4.7
5	34.8	4.6
6	36.3	5.5

Appendix E

Female cleft age 13-16 years, showing average distances and SD measured and the average degrees and SD degrees

Female Cleft	Age 13-16	No. in group 9
Distance Measured	**Average in mm**	**SD in mm**
1-2	31.9	2.0
2-3	20.7	2.8
3-4	19.2	2.6
4-5	32.2	3.7
1-5	89.6	5.6
3-6	46.2	2.0
6-7	20.5	2.5
6-8	20.3	2.3
7-8	35.8	1.9
6-9	13.0	1.9
9-10	14.9	1.8
9-11	24.5	2.1
10-11	11.7	1.8
11-12	15.8	1.9
6-12	52.4	4.0
3-13	42.4	2.2
6-13	15.7	2.2
3-8	44.3	1.4
3-7	43.3	1.8
Angles	**Average in degrees**	**SD in degrees**
1	36.5	2.7
2	38.6	2.2
3	67.8	4.3
4	68.9	3.1
5	32.8	5.3
6	34.5	4.9

Appendix F

Male cleft age 13-16 years, showing average distances and SD measured and the average degrees and SD degrees

Male Cleft	**Age 13-16**	**No. in group 7**
Distance Measured	**Average in mm**	**SD in mm**
1-2	33.9	4.9
2-3	21.5	3.9
3-4	21.0	2.6
4-5	32.9	3.7
1-5	93.8	7.5
3-6	46.9	4.3
6-7	21.0	3.9
6-8	20.1	2.2
7-8	34.9	4.5
6-9	12.8	2.6
9-10	16.5	6.3
9-11	28.5	7.0
10-11	14.2	1.4
11-12	19.6	1.5
6-12	60.1	8.5
3-13	41.9	4.2
6-13	16.7	2.4
3-8	47.1	4.1
3-7	45.8	4.4
Angles	**Average in degrees**	**SD in degrees**
1	39.1	3.5
2	39.3	4.3
3	60.9	3.2
4	62.9	5.0
5	33.3	7.0
6	31.2	7.8

Appendix G

Female control age 4-8 years showing average distances and SD measured and the average degrees and SD degrees.

Female Control	Age 4-8	No. in group 39
Distance Measured	**Average in mm**	**SD in mm**
1-2	28.4	2.6
2-3	17.8	1.9
3-4	16.6	1.6
4-5	28.7	2.5
1-5	79.8	4.8
3-6	38.8	2.8
6-7	15.2	1.5
6-8	14.9	1.6
7-8	25.9	2.2
6-9	14.2	1.5
9-10	10.8	1.9
9-11	20.2	2.5
10-11	9.6	1.6
11-12	12.5	3.1
6-12	45.6	2.6
3-13	32.5	1.1
6-13	13.5	2.8
3-8	39.4	2.6
3-7	39.0	
Angles	**Average in degrees**	**SD in degrees**
1	35.1	2.5
2	36.0	2.4
3	55.5	3.3
4	56.4	3.4
5	34.6	4.6
6	34.9	4.4

Appendix H

Male control age 4-8 years showing average distances and SD measured and the average degrees and SD degrees.

Male Control	**Age 4-8**	**No. in group 65**
Distance Measured	**Average in mm**	**SD in mm**
1-2	28.2	2.3
2-3	18.6	1.6
3-4	17.5	1.9
4-5	27.7	2.4
1-5	81.1	4.4
3-6	36.5	3.5
6-7	15.9	1.9
6-8	15.0	1.7
7-8	26.9	2.1
6-9	14.6	1.5
9-10	11.8	2.1
9-11	21.1	2.9
10-11	9.7	1.5
11-12	12.6	1.8
6-12	46.9	2.9
3-13	31.0	3.7
6-13	12.6	1.1
3-8	37.1	3.0
3-7	36.6	3.1
Angles	**Average in degrees**	**SD in degrees**
1	35.8	4.1
2	38.7	4.3
3	56.3	5.0
4	57.2	4.6
5	32.1	4.2
6	34.8	6.1

Appendix I

Female control age 9-12 years showing average distances and SD measured and the average degrees and SD degrees.

Female Control	Age 9-12	No. in group 38
Distance Measured	**Average in mm**	**SD in mm**
1-2	30.6	2.5
2-3	19.2	1.8
3-4	18.1	1.6
4-5	30.9	2.5
1-5	85.2	4.6
3-6	43.4	2.7
6-7	16.9	2.6
6-8	16.9	2.1
7-8	28.2	2.9
6-9	13.8	1.4
9-10	12.9	2.4
9-11	22.8	2.3
10-11	10.3	1.2
11-12	13.4	1.7
6-12	48.4	3.4
3-13	37.1	2.7
6-13	14.8	1.2
3-8	43.3	2.1
3-7	42.5	2.5
Angles	**Average in degrees**	**SD in degrees**
1	35.8	3.0
2	36.3	3.2
3	58.4	3.3
4	59.9	3.5
5	34.2	3.6
6	33.9	4.5

Appendix J

Male control age 9-12 years showing average distances and SD measured and the average degrees and SD degrees.

Male Control	**Age 9-12**	**No. in group 42**
Distance Measured	**Average in mm**	**SD in mm**
1-2	30.6	2.0
2-3	19.4	2.0
3-4	19.2	1.8
4-5	29.6	2.4
1-5	85.6	3.5
3-6	41.0	3.4
6-7	16.6	1.9
6-8	16.2	1.5
7-8	27.9	2.8
6-9	15.1	1.7
9-10	13.6	2.2
9-11	23.4	2.9
10-11	10.5	1.7
11-12	14.4	1.5
6-12	51.2	4.1
3-13	35.0	3.6
6-13	14.3	1.0
3-8	41.4	2.7
3-7	40.9	2.8
Angles	**Average in degrees**	**SD in degrees**
1	36.3	3.2
2	37.0	3.5
3	57.4	4.6
4	58.0	4.4
5	33.8	5.0
6	34.0	3.9

Appendix K

Female control age 13-16 years showing average distances and SD measured and the average degrees and SD degrees.

Female Control	Age 13-16	No. in group 23
Distance Measured	**Average in mm**	**SD in mm**
1-2	33.1	2.1
2-3	20.0	2.0
3-4	19.2	1.6
4-5	33.4	2.9
1-5	91.0	4.0
3-6	46.7	2.3
6-7	19.0	2.2
6-8	18.5	2.2
7-8	29.3	2.5
6-9	14.5	1.8
9-10	15.5	2.7
9-11	25.9	3.7
10-11	11.3	1.7
11-12	15.2	3.1
6-12	53.8	5.3
3-13	41.3	2.3
6-13	16.3	0.8
3-8	45.7	2.8
3-7	45.5	2.5
Angles	**Average in degrees**	**SD in degrees**
1	38.0	3.8
2	38.5	3.5
3	62.4	3.6
4	62.6	3.3
5	31.5	4.8
6	31.7	4.2

Appendix L

Male control age 13-16 years showing average distances and SD measured and the average degrees and SD degrees.

Male Control	Age 13-16	No. in group 38
Distance Measured	**Average in mm**	**SD in mm**
1-2	25.0	2.6
2-3	25.2	1.7
3-4	23.7	1.7
4-5	26.6	2.2
1-5	82.0	4.4
3-6	44.2	2.6
6-7	18.9	1.9
6-8	19.9	2.1
7-8	29.6	2.9
6-9	13.5	2.1
9-10	16.6	2.2
9-11	26.1	2.4
10-11	11.5	1.3
11-12	16.3	2.3
6-12	51.9	4.4
3-13	39.3	2.6
6-13	16.0	1.5
3-8	43.8	2.7
3-7	42.2	2.8
Angles	**Average in degrees**	**SD in degrees**
1	41.3	2.7
2	40.6	2.8
3	61.2	2.8
4	64.1	2.9
5	32.3	4.6
6	30.5	4.8

References

Ahlqvist, J., Eliasson, S. and Wylander, U. (1986). "The effect of projection errors on cephalometric length measurements." *European Journal of Orthodontics* **8:** pp. 141-148.

AlEmran, S.E., Fatani, E. and Hassanain, J.E. (1999). "Craniofacial variability in parents of children with cleft lip and cleft palate." *Journal Clinical Pediatric Dentistry* **23**(4): pp. 337-341.

Arridge, S., Moss, J.P., Linney, A.D. and James, D.R. (1985). "Three dimensional digitization of the face and skull". *Journal of Maxillofacial Surgery* **13**: pp. 136-143.

Asher-McDade, C., Brattström, V., Dahl, E., McWilliam, J., Mølsted, K., Plint, D.A., Prahl-Andersen, B., Semb, G., Shaw, W.C. and Ralph, P.S. (1992). "A Six-Center International Study of Treatment Outcome in Patients with Clefts of the Lip and Palate: Part 4. Assessment of Nasolabial Appearance." *Cleft Palate-Craniofacial Journal* **29** (5): pp. 409-412.

Aung, S.C., Ngim, R.C.K., and Lee, S.T. (1995). "Evaluation of the laser scanner as a surface measuring tool and its accuracy compared with direct facial anthropometric measurements." *British. Journal. of Plastic Surgery* **48**: pp. 551-558.

Ayoub, A.F., Wray, D., Moos, K.F., Siebert, P., Jin, J., Niblett,T.B., Urquhart, C. and Mowforth, R. (1996). "Three-dimensional modelling for modern diagnosis and planning in maxillofacial surgery." *International Journal of Orthodontics and Orthognathic Surgery* **11**(3): pp. 225-233.

Ayoub,A.F., Wray, D., Moos, K.F., Siebert, J.P,.Jin, J., Niblett, T.B., Urquhart, C.W. and Mowforth, P.H. (1997). "A three-dimensional imaging system for archiving dental study model: a preliminary report." *Journal of Adult Orthognathic and Orthodontic Surgery* **12**(1): pp. 79-84.

Ayoub, A.F., Siebert, J.P., Wray, D. and Moos, K.F. (1998) "A vision-based three dimensional capture system for maxillofacial assessment and surgical planning." *British Journal of Maxillofacial Surgery* **36**(5): pp.353-357.

Bardach, J., Morris, H. and Olin, W. (1984). "Late results of primary veloplasty. The Marburg Project." *Plastic and Reconstructive Surgery* **73**: p. 207.

Baumrind, S. and Frantz, R.D. (1966). " The reliability of head film measurements. 2 Conventional angular and linear measurements." *American Journal of Orthodontics* **60:** pp. 505-517.

Baumrind, S. and Frantz, R.D. (1971). "The reliability of head film measurements. 1 Landmark Identification". *American journal of Orthodontics* **60:** pp. 111-127.

Bhishagratna, K. (1963). An English Translation of the Sushruta Samhita Based on Original Sanskrit Text. Varanassi, India, The Chowkhmba Sanskrit Series Office. II: 81, 106, 469. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In: Cleft Lip and Palate: Surgical, Dental and Speech Aspects (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch, K.R. Little Brown and Co., Boston.

Bishara, S., Krause, C., Olin, W., Weston, D., Van Ness, J. and Felling, C. (1976). "Facial and dental relationships of individuals with unoperated clefts of the lip and/or palate." *Cleft Palate Journal* **13**: pp. 238-252.

Bishara, S.E., Hession, T.J. and Peterson, L.C. (1985). " Longitudinal soft-tissue profile changes: A study of three analyses." *American Journal of Orthodontics* **88:** pp. 209-223.

Bishara, S.E., Jorgensen, G.J. and Jakobson, J.R. (1995a). "Changes in facial dimensions assessed from lateral and frontal photographs." Part 1- Methodology. *American Journal of Orthodontics and Dentofacial Orthopedics* **108:** pp. 389-393.

Bishara, S.E., Jorgensen, G.J. and Jakobson, J.R. (1995b). "Changes in facial dimensions assessed from lateral and frontal photographs." Part II Results and conclusions. *American Journal of Orthodontics and Dentofacial Orthopedics* **108:** pp. 489-499.

Blocksman, R., Leuz, C.A. and Mellerstig, K.E. (1975). "A conservative program for managing cleft palates without the use of mucoperiosteal flaps." *Plastic and Reconstructive Surgery* **55:** p. 160.

Boehnlein, A.J. and Harding, K.G. (1986). "Adaption of a parallel architecture computer to phase shifted Moiré interferometry." *Proceedings SPIE* **728:** pp. 183-194.

Boo-Chai, K. (1966). "An ancient Chinese text on cleft lip." *Plastic and Reconstructive Surgery* **38**:pp. 89-91.

Brattstrom, V. (1991). "Craniofacial development in cleft lip and palate children related to different treatment regimes." *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery Supplement* **25**: pp. 1-31.

Briggs, R. (1976). "Vitamin supplementation as a possible factor in the incidence of cleft lip/palate deformities in humans." *Clinical Plastic Surgery* **3**: pp. 647-652.

Broadbent, B. H. (1937). "The Face of the Normal Child." *Angle Orthodontist* **7**: pp. 183-208.

Broadbent, B.H. (1931). "A new x-ray technique and its application to orthodontia". *Angle Orthodontist* **1:** pp. 45-66.

Brodie, A. G. (1941) "On the Growth Pattern of the Human Head from the Third Month to the Eighth Year of Life." *American Journal of Anatomy* **68**: p. 209.

Burke, P.H. and Beard, L.F.H. (1967). "Stereophotogrammetry of the face." *American Journal of Orthodontics* **53:** pp. 769-782.

Burke, P.H. (1971). " Stereophotogrammetric measurement of normal facial asymmetry in children." *Human Biology* **42:** pp. 536-548.

Burke, P.H. (1972). " The accuracy and range of certain stereophotogrammetric measurements of facial morphology." *Transcriptions of the European Orthodontic Society* pp. 543-553.

Burke, P.H. and Beard, L.F.H. (1979). "Growth of the soft tissues of the face in adolescence." *British Dental Journal* **146:** pp. 239-246.

Burke,P.H. and Hughes-Lawson, C.A. (1989). "Sterephotogrammetric study of the growth and development of the nose." *American Journal of Orthodontics and Dentofacial Orthopedics* **96:** pp. 144-151.

Burke, P.H. (1979). "Growth of the soft tissues of the middle third of the face between 9 and 16 years." *European Journal of Orthodontics* **1:** pp. 1-13.

Burke, P.H. (1972). "The accuracy and range of certain stereophotogrammetric measurements of facial morphology". *Transactions of the European Orthodontic Society* pp. 543-553.

Burke, P.H., Banks, P., Beard, L.F.H., Tee, J.E. and Hughs, C. (1983). "Stereographic measurements of change in facial soft tissue morphology following surgery." *British Journal of Oral Surgery***21:** pp.237-245.

Butler, N.R., and Alberman, E.D. (1969). " Perinatal Mortality. The Second Report of the 1958 British Perinatal Mortality Survey." E. & S. Livingstone Ltd., Edinburgh.

Calzolari,E., Milan, M., Cavazzuti, G.B, Cocchi, C., Gandini, E., Magnani, C., Moretti, M., Garani, G.P., Salvioli, G.P. and Volpato, S. (1988). "Epidemiological and genetic study of 200 cases of oral cleft in the Emilia Romagna region of Northern Italy." *Teratology* **38:** pp. 559-564.

Carmichael, S.L. and Shaw, G.M. (2000). "Maternal life event stress and congenital anomalies." *Epidemiology* **11** (1): pp. 30-35.

Carmichael, S.L. and Shaw, G.M. (1999). "Maternal corticosteroid use and risk of selected congenital anomalies." *American Journal of Medical Genetics* **86** (3): pp. 242-244.

Carolus, J. (1854). "La Chirurgie de Maitre Jean Yperman." Gand, F. & E. Gyselynck. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co., Boston.

Cervenka, J. (1984). "African mask with cleft lip and palate." *Cleft Palate Journal* **21**: pp. 38-40.

Chadwick, R.G. (1992). "Close range photogrammetry-a clinical dental research tool." *Journal of Dentistry* **20:** pp. 235-239.

Chung, C.S., Bixler, D., Watanabe, T., Koguchi, H., and Fogh-Andersen, P. (1986). "Segregation analysis of cleft lip with or without cleft palate: A comparison of Danish and Japanese data." *American Journal Human Genetics* **39:** pp. 603-611.

Clark, K. (1968). "The Drawings of Leonardo da Vinci in the collection of Her Majesty the Queen at Windsor Castle." New York, Phaidon.

Clinical Standards Advisory Group (Cleft Lip and/or Palate). (1998). London: The Stationary Office.

Coupland, M.A. and Coupland, A.I. (1988). "Seasonality, incidence, and sex distribution of cleft lip and palate births in Trent Region, 1973-1982." *Cleft Palate Journal* **25**(1): pp. 33-37.

Coghlan, B.A., Laitung, J.K.G. and Pigott, R.W. (1993). "A computer aided method of measuring nasal symmetry in the cleft lip and nose". *British Journal of Plastic Surgery* **46:** pp. 13-17.

Cohlan, S. (1953). "Excessive Intake of Vitamin A as a Cause of Congenital Anomalies in the Rat." *Science* **117**: pp. 535-536.

Cohlan, S. (1954). "Congenital anomalies in the rat produced by excessive intake of vitamin A during pregnancy." *Pediatrics* **13**: pp. 556-557.

Coward, T.J., Watson, R.M. and Scott, B.J.J. (1997). "Laser scanning for the identification of repeatable landmarks of the ears and face." *British Journal of Plastic Surgery* **50:** pp. 308-314.

Cummins, D.M., Bishara, S.E. and Jakobsen, J.R. (1995). "A computer assisted photogrammetric analysis of soft tissue changes after orthodontic treatment. Part II: Results." *American Journal Orthdontics and Dentofacial Orthopaedics* **108**(1): pp. 38-47.

Cutting, C., Grayson, B. Bookstein, F. Fellingham, L. and McCarthy, J. (1986). "Computer-aided planning and evaluation of facial and orthognathic surgery." *Clinics in Plastic Surgery* **13**(3): pp. 449-462.

Dahl, E., Kreiborg, S., Jensen, B. and Fogh-Andersen, P. (1982). "Comparison of craniofacial morphology in infants with incomplete cleft lip and infants with isolated cleft palate." *Cleft Palate Journal* **19**: pp. 258-266.

Datubo-Brown, D.D. and Kejeh, B.M. (1989). "Cleft deformities in Rivers state of Nigeria: is there any association with environmental pollution?" *JR Coll Surg* **34:** pp. 328-331.

Davidson, J.M. (1898). "Roentgen Rays and Localisation." *British Medical Journal* Jan. **1:** pp.10-13.

Derijcke, A., Eerens, A. and Carels, C. (1996). "The incidence of oral clefts: A review." British Journal of Oral and Maxillofacial Surgery **34**(6): pp. 488-494.

Dieffenbach, J. (1828). "Beitraege zur Gaumennath." *Litt. Ann. Heilk.* **10:** p. 322. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In*:* *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co., Boston.

Duffy, S. (1997). "3-D Analysis of the Child Cleft Face." MSc. Thesis, University of London.

Dürer, A. (1528). "Bucher von menslicher Proportion." Nurenburg, J. Formschneyder.

Elad, D. and Einav, S. (1990). "Three-dimensional measurement of biological surfaces." *ISPRS Journal of Photogrammetry and Remote Sensing.* **45:** pp. 247-266.

Enemark, H., Friede, H., Paulin, G., Semb, G., Abeyholm, F., Bolund, S., Lilja, J. and Ostrup, L. (1993). "Lip and nose morphology in patients with unilateral cleft lip and palate from four Scandinavian centres." *Scandinavian Journal Plastic Reconstructive Surgery and Hand Surgery* **27**(1):pp. 41-47.

Farkas, L., Posnick, J. and Hreczko, T. (1992). "Anthropometric growth study of the head." *Cleft Palate Craniofacial Journal* **29**(4): pp. 303-8.

Farkas, L.G. (1996) "Accuracy of Anthropometric Measurements: Past, Present, and Future." *Cleft Palate-Craniofacial Journal* **33** (1): pp. 10-14.

Farkas, L.G. (1994). "Anthropometry of the Head and Face." 2nd. Edition. Raven Press. New York.

Farkas, L.G. Hajnis, K. and Posnick, J.C. (1993). "Anthropometric and anthroposcopic findings of the nasal and facial region in cleft patients before and after primary lip repair." *Cleft Palate Craniofacial Journal* **30**(1): pp. 1-12.

Fedrick, J., E. Alberman and H. Goldstein (1971). "Possible teratogenic effect of cigarette smoking." *Nature* **231**: pp. 529-530.

Ferrario, V.F., Sforza, C., Guazzi, M., Montorsi, F., and Toroni, A (1996). "Effect of growth and development on human soft tissue facial shape: a Fourier analysis." *International Journal Adult Orthodontic and Orthognathic Surgery* **11**(2): pp. 155-163.

Ferrario, V.F., Sforza, C., Gianni, A.B., Daddona, A., Deli, R. and Guiliani, M. (1990). "Analysis of chewing movement using elliptic Fourier descriptors." *International Journal of Orthodontic and Orthognathic Surgery* **5**(1): pp. 53-57.

Ferrario, V.F., Sforza, C., Poggio, C.E., Colombo, A. and Cova, M. (1997a). "Effect of growth and development on cephalometric shapes in orthodontic patients: a Fourier analysis." *European Journal of Orthodontics* **19**(6): pp. 669-680.

Ferrario, V.F. Sforza, C., Poggio, C.E. and Schmitz, H.H. (1997b). "Three-dimensional study of growth and development of the nose." *Cleft Palate Craniofacial Journal* **34**(4): pp. 309-317.

Ferrario, V.F., Sforza, C., Poggio, C.E. and Tartaglia, G. (1994a). "Distance from symmetry: a three-dimensional evaluation of facial symmetry." *Journal of Oral and Maxiilofacial Surgery* **52**(11): pp. 1126-1132.

Ferrario, V.F., Sforza, C., Serrao, G. and Miani, A. (1995a). "A computerized non–invasive method for the assessment of human facial volume." *Journal of Craniomaxillofacial Surgery* **23**(5): pp. 280-286.

Ferrario, V.F., Sforza, C., Poggio, C.E. and Tartaglia, G. (1995b). "Facial morphometry of televison actresses compared with normal women." *Journal of Oral and Maxillofacial Surgery* **53**(9): pp. 1008-1014.

Ferrario, V.F. Sforza, C., Serrao, G., Puletto, S.,Bignotto, M. and Tataglia, G. (1994b). "Comparison of soft tissue facial morphometry in children with Class I and Class II occlusions." *International Journal of Adult Orthodontic and Orthognathic Surgery* **9**(3): pp.187-194.

Franco, P. (1556). "Petit traite contenant une des parties principalles de chirurgie." Lyon, Antoine Vincent. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co., Boston.

Fraser, F. (1967). "Cleft lip and cleft palate." *Science* **158**: p. 1603.

Fraser, F.C. (1970). " The Genetics of Cleft Lip and Cleft Palate." *American Journal of Human Genetics* **22:** pp. 336-352.

Friede, H., Moller, M. Lilja, J. Lauritzen, C. and Johanson, B. (1987). "Facial morphology and occlusion at the stage of early mixed dentition in cleft lip and palate patients treated with delayed closure of the hard palate." *Scandinavian Journal Plastic and Reconstructive Surgery* 21: pp. 65-71.

Fright, W.R. and Linney, A.D. (1993). "Registration of 3-D head surfaces using multiple landmarks." *IEEE Transactions on Medical Imaging.* **12:** pp. 515-520.

Galton, F. (1888). "Personal identification and description." *Nature* May-October: pp. 173-177 and 201-203.

Galton, F. (1910). "Numeralised profiles for classification and recognition." *Nature* **83:** pp.127-130.

Giddon, D. (1995). "Orthodontic applications of psychological and perceptual studies of facial esthetics." *Seminars in Orthodontics* **1**(2): pp. 82-93.

Gordon, J.E. and Shy, C.M. (1981). " Agricultural use of and congenital cleft lip and/or palate." *Arch. Envir. Health.* **36:** pp. 213-221.

Goto, K. (1993). "A longitudinal study of craniofacial growth in infants with cleft lip and/or palate: infancy to four years." *Japanese Journal of Oral Maxillofacial Surgery* **39**: pp. 322-338 (In Japanese with English abstract).

Graber, T. (1949). "Craniofacial morphology in cleft palate and cleft lip deformities." *Surgery Gynecology and Obstetrics.* **88:** pp. 359-369

Graber, T.M. (1954). "The congenital cleft plate deformity." *Journal American Dental Association* **48** (1): pp. 375-395.

Grayson, B., Cutting, C., Bookstein, F.L., Kim, K. and McCarthy, J.G. (1988). "The three-dimensional cephalogram: Theory, technique and clinical application." *American journal of Orthodontics and Dentofacial Orthopedics* **94:** pp. 327-337.

Gregg, T., Boyd, D., and Richardson, A. (1994). "The incidence of cleft lip and palate in Northern Ireland from 1980-1990. *British Journal of Orthodontics* **21:** pp. 387-392.

Hale, F. (1937). "Relation of vitamin A deficiency to microphthalmia in pigs." *Texas State Journal of Medicine* **33:** pp. 228-232.

Han, B.J., Suzuki, A. and Tashiro, H. (1995). "Longitudinal study of craniofacial growth in subjects with cleft lip and palate: From cheiloplasty to 8 years of age." *Cleft Palate Craniofacial Journal* **32**(2): pp. 156-165.

Hartidge, T., Illing, H.M. and Sandy, J.R. (1999). "The role of folic acid in oral clefting." *British journal of Orthodontics* **26** (2): pp. 115-120.

Hodgkinson, P. and Rabey, G. (1986). "Three-dimensional nasal morphology in adult bilateral cleft palate patients: a morphanalytic study." *British Journal Plastic Surgery* **39:** pp. 193-205.

Holmberg, P.C., Hernberg, S., Kurppa, K., Rantala, K. and Riala, R. (1982). " Oral clefts and organic solvent exposure during pregnancy." *Int. Arch. Occup. Environ. Health.* **50:** pp. 371-376.

Horswell, B.B. and Levant, B.A. (1988). "Craniofacial growth in unilateral cleft lip and palate: Skeletal growth from eight to eighteen years." *Cleft Palate Journal* **25:** pp. 114-121.

Hotz, M. and Gnoinski, W. (1976). "Comprehensive care of cleft lip and palate children at Zurich University: a preliminary report." *American Journal of Orthodontics* **70:** pp. 481-504.

Hotz, M. and Gnoinski, W. (1979). "Effects of early maxillary orthopaedic co-ordination with delayed surgery for cleft lip and palate." *Journal of Maxillofacial Surgery* **7**: pp. 201-210.

Huntley, H. (1970). "The Divine Proportion. A study in mathematical beauty." New York, Dover Publications.

Jain, R. and Krogman, W. (1980). "Craniofacial growth in clefting from one month to ten years as studied by P-A headfilms." *Cleft Palate Journal* **20:** pp. 314-326.

Janz, D. and Fuchs, U. (1964). "Sind antiepiltische medikamente warend der shwagerschaft schadlich?" *Dtsch. Med. Wochenschr.* **89:** pp. 241-243.

Jensen,B.L., Kreiborg, S. Dahl, E. and Fogh-Anderson, P. (1988). "Cleft lip and palate in Denmark, 1976-1981. Epidemiology, variability, and early somatic development." *Cleft palate Journal* **25:** pp. 258-269.

Joffe, J.M., McDermott, P.J.C., Linney, A.D., Mosse, C.A. and Harris, M. (1992). "Computer Generated Titanium Cranioplasty: report of a new technique for repairing skull defects." *British Journal of Neurosurgery* **6:** pp. 343-350.

Johnston, M. and Sulik, K. (1984). Embryology of the Head and Neck. Paediatric Plastic Surgery. D. G. Serafin, N.G. St. Louis, C.V. Mosby Co: pp. 184-215.

Johnston, M. (1964). "Facial malformations in chick embryos resulting from removal of neural crest." *Journal of Dental Research* **43:** p. 822.

Johnston, M. (1966). "A radioautographic study of the migration and fate of neural crest cells in the chick embryo." *Anat. Rec.* **156**(2): p. 143.

Kanazawa, E and Kamiishi, H. (1978). "Evaluation of facial osteotomy with the aid of Moiré contourgraph." *Journal Maxillofacial Surgery* **6:** pp. 233-238.

Kantero, R.L. and Tiisala R. (1971). "Growth of head circumference from birth to 18 years." *Acta Paediatr Scand Suppl.* **220**: pp. 27-32.

Kaplan, E. (1975). "Soft palate repair by levator muscle reconstruction and a buccal mucosal flap." *Plastic and Reconstructive Surgery* **56:** p. 129.

Kaplan, E. (1978). "Growth of the unilateral cleft lip." *Cleft Palate Journal* **15**(3): pp. 202-208.

Katsuki, T., Yoshida, Y., Halim, B. and Tashiro, H. (1976). "Cephalometric roentgenographic study on maxillofacial growth of grown-up unoperated cleft palates." *Journal of Japanese Cleft Palate Association* **1:** pp. 29-36 (In Japanese with English abstract).

Kawai, T., Natsume, N., Shibata, H. and Yamamoto, T. (1990). "Three-dimensional analysis of facial morphology using Moiré stripes. Part 1. Method." *International Journal of Oral and Maxillofacial Surgery* **19:** pp. 356-358.

Khoury, M., Gomez-Farias, M., and Mulinare, J (1989). "Does maternal cigarette smoking during pregnancy cause cleft lip and palate in offspring?" *American Journal Diseases of Children* **143:** pp. 333-337.

Krogman, W., Mazaheri, M. and Harding, R. (1975). "A longitudinal study of the craniofacial growth pattern in children with clefts as compared to normal, birth to six years." *Cleft Palate Journal* **12:** pp. 59-84.

Kyrkanides, S., Bellohusen, R. and Subtelny, J.D. (July 1996). "Asymmetries of the Upper Lip and Nose in Noncleft and Postsurgical Unilateral Cleft Lip and Palate." *Cleft Palate Craniofacial Journal* **33** (4): pp. 306-3101.

Levret (1772). "Des nouvelles observations sur l'allaitement des enfants." *J. Med. Chir. Pharm.* Paris **37:** p. 233. Cited in: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co., Boston.

Lewin, M. (1964). "Management of cleft lip and palate in the United States and Canada: Report of a summary." *Plastic and Reconstructive Surgery* **33:** p. 383.

Lieff, S., Olshan, A.F., Werler, M., Strauss, R.P., Smith, J. and Mitchell, A. (1999). "Maternal cigarette smoking during pregnancy and risk of oral clefts in newborns." *American Journal Epidemiology* **150** (7):pp. 683-694.

Liggett, J. (1974). "The Human Face." Ed. Constable & Co. Ltd., London.

Lindsay, W. (1971)."Von Langenbeck Palatorraphy. Cleft Lip and Palate, Surgical, Dental and Speech Aspects." W. Grabb, S. Rosenstein and K. Bzoch., K.R. Little Brown and Co. Boston: pp. 393-403.

Lindsay, W.K. and Farkas, L.G. (1972). "The use of anthropometry in assessing the cleft-lip nose." *Journal of Plastic and Reconstructive Surgery* **49:** pp. 286-293.

Lohmander-Agerskov, A., Soderpalm, E., Friede, H. and Lilja, J. (1995). "A longitudinal study of speech in 15 children with cleft lip and palate treated by late repair of the hard palate." *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery* **29**(1): pp. 21-31.

Lohmander-Agerskov, A., Friede, H., Lilja J. and Soderpalm E. (1996). "Delayed closure of the hard palate: A comparison of speech in children with open and functionally closed residual clefts." *Scandinavian Journal of Plastic and Reconstructive Surgery and Hand Surgery* **30**(2): pp. 121-127.

Lowe, C. (1959). "Effect of mothers' smoking habits on birth weight of their children." *British Medical Journal* **2:** pp. 673-676.

Luke, D. (1976). "Development of the secondary palate in man." *Acta Anat* **94:** pp. 596-608.

MacKay, F., Bottomley, J., Semb, G. and Roberts, C. (1994). "Dentofacial form in the five year-old child with unilateral cleft lip and palate." *Cleft Palate Craniofacial Journal* **31**(5): pp. 372-375.

Mansbach, M. (1922). "Die stereophotogrammetrie als hilfsmittel in der orthodontie." *Deutsche Zeitschrift für Zahnartzliche Orthopädie* **14:** pp. 105-113.

Markus, A. and Precious, D. (1997). "Effect of primary surgery for cleft lip and palate on mid-facial growth." *British Journal of Oral and Maxillofacial Surgery* **35**(1): pp. 6-10.

Mars, M. and Houston, W. (1990). "A preliminary study of facial growth and morphology in unoperated male unilateral cleft lip and palate subjects over 13 years of age." *Cleft Palate Journal* **27**(1): pp. 7-10.

Mars, M. (1993). "The Effects of Surgery on Facial Morphology in Sri-Lankan Unilateral Cleft Lip and Palate Subjects." PhD. Thesis, University of London.

McCance, A.M., Moss, J.P., Fright, W.R. Linney, A.D. and James D.R. (1992). "A three-dimensional analysis of soft and hard tissue changes following bimaxillary orthognathic surgery in skeletal III patients." *British Journal of Oral and Maxillofacial Surgery* **30:** pp. 305-312.

McCance, A.M., Moss, J.P., Fright, W.R. and Linney, A.D. (1993). " A three-dimensional analysis of bone and soft tissue to bone ratio of movements in seventeen skeletal III patients following surgery." *European Journal of Orthodontics* **15:** pp. 97-106.

Meadow, S. (1970). "Congenital Abnormalities and Anticonvulsant Drugs." *Proceedings of Royal Society of Medicine* **63:** pp. 48-49.

Mestre, J., De Jesus, J. and Subtelny, J. (1960). "Unoperated oral clefts at maturation." *Angle Orthodontist* **30:** pp. 78-85.

Microsoft Excel *Version 5*

Mishima, K., Sugahara, T., Mori, Y. and Sakuda, M. (1996). "Application of a New Method for Anthropometric analysis of the nose." *Plastic and Reconstructive Surgery* **98** (4): pp.637-644.

Mitgard, J., Bjork, G., and Linder-Aronson, S. (1974). "Reproducability of cephalometric landmarks and errors of measurement of cephalometric cranial distances." *Angle Orthodontist* **44:** pp. 56-61.

Moss, J.P, Linney, A.D., Grindrod, S. and Mosse, C. (1989). "A laser scanning system for the measurement of facial surface morphology." *Optics and Lasers in Engineering* **10:** pp. 179-190.

Moss, J.P., Linney, A.D., Grindrod, S.R., Arridge, S.R. and Clifton, J.S. (1987). "Tree-dimensional visualisation of the face and skull using computerised tomography and laser scanning techniques." *European Journal of Orthodontics* **9:** pp. 247-253.

Moss, J.P., Linney, A.D., Grindrod, S.R., Arridge, S.R. and James, D.R. (1988). "A computer system for the interactive planning and prediction of maxillofacial surgery." *American Journal of Dentofacial Orthopedics* **94:** pp.469-475.

Moss, J.P., Coombs, A.M., Linney, A.D. and Campos, J.C. (1991). "Methods of three dimensional analysis of patients with asymmetry of the face." *Proceedings of the Finnish Dental Society* **87:** pp.139-149.

Moss, J.P., Linney, A.D. and Lowey, M.N. (1995). "The use of three-dimensional techniques in facial esthetics." *Seminars in Orthodontics* **1**(2): W.B. Saunders Co. pp. 94-104.

Murray, J.C. (1995). Invited editorial. "Face facts: genes, environment, and clefts." *American Journal Human Genetics* **57:** pp. 227-232.

Myrrhen, A. (1721). "Uvulae, ab ortu, defectum resarciunt vicinae partes, sine incomodo." Bibliotheca Chirurgica. J. J. Mangetti. Genevae, Gabrielis de Tournes & Filiforum: p 352. Cited by: Rogers, B.O. (1971) History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects.* eds Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Nanda, RS., Meng, H., Kapila, S., and Goorhuis, J. (1990). "Growth changes in the soft tissue profile". *Angle Orthodontist* **60** (3): pp. 177-190.

Natsume, N., Kawai, T. and Suzuki, T. (1995). "Preference for vegetables rich in β carotene and manifestation of cleft lip and/or cleft palate." *Plastic and Reconstructive Surgery* (Letter) **95:** pp. 934-935.

Niswander, and Wertelecki (1973). " Congenital malformation among offspring of epileptic women." *Lancet* (Letter) p. 1062.

Nute, S.J. (1997). " A Cross-Sectional Study of the Three-dimensional Facial Morphology of Caucasian children using the Optical Surface Scanner". MSc Thesis, University of London.

Owens, J.R., Jones, J.W. and Harris, S.F. (1985). "Epidemiology of facial clefting." *Arch. Dis. Childhood* **60:** p. 521.

Orticochea, M. (1983). "The harelipped king: A pre-Columbian ceramic statue over 2,000 years old." *British Journal of Plastic Surgery* **36**: pp. 392-394.

Ortiz-Monasterio, F., Serrano, R., Valderrana, M and Cruz, R. (1959). "Cephalometric measurements on adult patients with non-operated cleft palates. "*Plastic and Reconstructive Surgery* **24**: pp. 53-61.

Peer, L., Bryan, W. and Strean, L. (1958). "Induction of cleft palate in mice by cortisone and its reduction by vitamins." *J. Int. Coll. Surg.* **30:** p. 249.

Pickerill, H. (1914). "The anatomy and physiology of cleft palate and a new method of treatment. In" Transactions of the Sixth International Dental Congress, London." pp. 453-469.

Poswillo, D. (1979). "The pathogenesis of submucous cleft palate." *Scandinavian Journal of Plastic and Reconstructive Surgery* **8:** pp. 34-41.

Prahl-Andersen, B.; Ligtheim-Bakker, A.S.W.M.R; Wattel, E.; and Nanda, R. (1995)."Adolescent growth changes in soft tissue profile." *American Journal Orthodontics and Dentofacial Orthopedics* **107**: pp. 476-483.

Prahl-Andersen, B. and. Kowalski, C.H.J. (1973). "A mixed longitudinal, interdisciplinary study of the growth and development of Dutch children." *Growth* **37:** pp. 281-295.

Pruzansky S. (1977). "Time: The fourth dimension in syndrome analysis applied to craniofacial malformations." *Birth Defects* **13:** pp. 3-28.

Rabey, G.P. (1971). "Cranio-facial morphanalysis." *Proceedings of the Royal Society* **64:** p. 103.

Rabey, G. (1977). "Current principles of morphanalysis and their implications in oral surgical practice." *British Journal of Oral Surgery* **15:** pp. 97-109.

Ras, F., Habets, L., VanGinkel, F.C., and B. Prahl-Andersen (1994). "Facial left-right dominance in cleft-lip and palate - 3-dimension evaluation." *Cleft Palate-Craniofacial Journal* **31**(6): pp. 461-465.

Ras, F., Habets, L., Van Ginkel, F.C. and B. Prahl-Andersen (1995). "Longitudinal-study on 3-dimensional changes of facial asymmetry in children between 4 to 12 years of age with unilateral cleft-lip-and- palate." *Cleft Palate-Craniofacial Journal* **32**(6): pp. 463-468.

Rhodes, T.F. (1956). "Alphonse Bertillon-Father of Scientific Detection." G.G. Harrap & Co., London.

Richardson, A. (1966). "An investigation into the reproducibility of some points planes and lines used in cephalometric analysis." *American Journal of Orthodontics* **52:** pp. 637-651.

Rintala, A., Ponka, A., Sarna, S and Stegars, T. (1983). "Cleft lip and palate in Finland in 1948-75: correlations to infections, seasonal and yearly variations." *Scandinavian Journal of Palstic and Reconstructive Surgery* **17**(3): pp. 197-201.

Roberts-Harry, D., Semb, G., Hathorn, I. and Killingback, N. (1996). "Growth in patients with unilateral clefts of the lip and palate - A Two Centre Study." *Cleft Palate Craniofacial Journal* **33**(6): pp. 489-493.

Rogers, B.O. (1971). History of cleft lip and palate treatment. In: *Cleft Lip and Palate, Surgical, Dental, and Speech Aspects.* eds. W. Grabb, S. Rosenstein and K. Bzoch., K.R. Little Brown and Co. Boston. pp. 142-169.

Rogers, B. (1967). "Palate surgery prior to Von Graefe's pioneering staphylorraphy (1816)." *Journal of Plastic and Reconstructive Surgery* **39**: p. 1.

Rogers, B. (1964). "Harelip repair in colonial America: A review of 18th century and earlier surgical techniques." *Journal of Plastic and Reconstructive Surgery* **34**: p. 142.

Rohrich, R., Rowsell, A., Johns, D., Drury, M., Grieg, G., Watson, A., Godfrey, D. and Poole, M. (1996). "Timing of hard palatal closure: A critical long-term analysis." *Journal of Plastic and Reconstructive Surgery* **98**(2): pp. 236-246.

Romitti, P.A., Lidral, A.C., Munger, R.G., Daack-Hirsch, S., Burns, T. and Murray, J.C. (1999). "Candidate genes for nonsyndromic cleft lip and palate and maternal cigarette smoking and alcohol consumption: evaluation of genotype-environment interactions from a population based case-control study of orofacial clefts." *Teratology* **59**(1): pp. 39-50.

Ross, R. (1987). "Treatment variables affecting facial growth in unilateral cleft lip and palate. Part 4: Repair of the cleft lip." *Cleft Palate Journal* **24**(1): pp. 5-77.

Roux, P. (1819). "Observation sur une division congenitale du voile du palais et de la luette, guerie au moyen d'une bec-de-lievre." *J. univ. Sci. Med.* **15**: p. 356. Cited by Rogers, B.O. (1971). In: History of cleft lip and palate treatment: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Roux, P. (1843). "Staphylorraphy in case of cleft palate." *American Journal Medical Science* **6**: p. 229. Cited by: Rogers, B.O. (1971). In: History of cleft lip and palate treatment: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Russell, C.S., Taylor, R. and Law, C.E. (1968). "Smoking in pregnancy, maternal blood pressure, pregnancy outcome, baby weight and growth and other related factors: A prospective study." *British Journal Prev. Soc. Med.* **22:** pp. 119-126.

Sakuda, M., Kakiuchi, Y. and Tsuchiya, M. (1983). "Unoperated complete unilateral cleft lip and palate: a case report on occlusion, craniofacial morphology and oral function." *Journal of Japanese Cleft Palate Association* **8**: pp. 105-115 (In Japanese with an English Abstract).

Savara, B.S. (1965). "Applications of Photogrammetry for Quantitative Study of Tooth and Face Morphology." *American Journal of Physical Anthropology* **23:** pp. 421-434.

Savolini, U., Cabanis, E.A., Iba-Zizen, M.T., De Nicola, M. and Hemmy, D.C. (1984). "Apport diagnostique de la recontruction tri-dimensionelle en scanner RX: Coupes et surfaces de l'anatomie céphalique." *Ann. Chir. Plast. Esthet.* **29**(4): pp. 339-357.

Schubert, J., Schmidt, R. and Rampach, H. (1990). "New findings explaining the mode of action in the prevention of facial clefting and first clinical experience." *Journal Cranio-maxillofacial Surgery* **18:** pp. 343-347.

Schweckendiek, W. (1978). "Primary veloplasty: Long term results without maxillary deformity. A twenty five year report." *Cleft Palate Journal* **15**: pp. 268-274.

Schweckendiek, H. (1951). "Zur Frage der Fruh-und Spatoperationen der angerborenen Lippen- Kieffer Gaumen Spalten (mit demonstrationen) *Z. Laryngol. Rhinol. Otol.* **30:** p.51

Sell, D.A. and Grunwell, P. (1990). "Speech Results Following Late Palatal Surgery in Previously Unoperated Sri Lankan Adolescents with Cleft Palate."*Cleft Palate Journal* **27** (2): pp. 162-168.

Semb, G. (1991). "A study of facial growth in patients with unilateral cleft lip and palate treated by the Oslo CLP team." *Cleft Palate-Craniofacial Journal* **28**: pp. 1-21.

Shapiro, Y., Lubit, E., Luftinec, M.M. and Borell, G. (1999). "The distribution of clefts of the primary and secondary palates by sex, type, and location ." *Angle Orthodontist* **69**(6): pp. 523-528.

Shaw, W. (1988). "Social aspects of dentofacial anomalies." In: Alley, T.R.

Shaw, W.C., Asher-McDade, C. Mars, M. Mølsted, K Prahl-Andersen, B. and Semb, G. (1992). "A six centre international study of treatment outcome in patients with clefts of the lip and palate: Part 5. General Discussion and Conclusions." *Cleft Palate-Craniofacial Journal* **29**(5): pp. 413-418.

Shaw, W.C., Williams, A. Sandy, J. and Devlin, H. (1996). "Minimum standards for the management of cleft lip and palate: efforts to close the audit loop." *Ann. R. Coll. Surg. Engl.* **(78):** pp. 110-114.

Simpson, W. (1957). "A preliminary report on cigarette smoking and the incidence of prematurity." *American Journal of Obstetrics and Gynecology* **73:** pp. 808-815.

Smahel, Z. and Mullarova, Z. (1994a). "Facial growth and development during puberty in unilateral cleft lip and palate, A longitudinal study." *Journal of Craniofacial Genetics and Developmental Biology* **14**(1): pp. 57-68.

Smahel, Z. and Mullerova, Z. (1994b). "Facial growth and development in unilateral cleft lip and palate during the period of puberty, Comparison of the development after perioplasty and after primary bone grafting." *Cleft Palate Craniofacial Journal* **31**(2): pp. 106-115.

Smahel, Z. and Z. Mullerova (1995). "Craniofacial growth and development in unilateral cleft lip and palate: Clinical implications (a review)." *Acta Chirurgiae Plasticae* **37**(1): pp. 29-32.

Smahel, Z. (1984). "Variations in craniofacial morphology with severity of isolated cleft palate."

Smith, G.E. and Dawson, W.R. (1924). "Egyptian Mummies." London: George Allen & Unwin Ltd., p.157.

Smithless, R.W. (1976). "Environmental teratogens of man." *Br Med Bull* **32:** pp. 27-33.

Sommerlad, B.C. (1994). "Management of cleft lip and palate." *Current Paediatrics* **4:** pp.189-195.

Sperber, G.H. "Craniofacial Embryology." (1989). 4th Edition Butterworths.

Strauss, O. (1914). "Predisposing causes of cleft palate and harelip." In: Transactions of the Sixth International Dental Congress, London." pp.470-471.

Subtelny, J.D. (1959). "A longitudinal study of soft tissue facial structures and their profile characteristics, defined in relation to underlying structures." *American Journal of Orthodontics* **45:** pp.481-507.

Sulaiman, R.B. (1995). "A three-dimensional evaluation of the facial form of two ethnic groups using an optical surface scanner." MSc. Thesis, University of London.

Sulik, K. and Schoenwolf, G. (1985). "Highlights of craniofacial morphogenesis in mammalian embryos, as revealed by scanning electron microscopy." *Scanning Electron Microscopy* **4:** pp. 1735-1752.

Suzuki, A., Takenoshita,Y., and Matsuura, C. (1999). "Dentocraniofacial morphology in parents of children with cleft lip and/or palate." *Cleft Palate Craniofacial Journal Mar;* 36(**2**)**:** pp. 131-138.

Takasaki, H. (1970). "Moiré Topography." *Applied Optics* **9:** pp. 1461-1472.

Takeda, M. and Mutoh, K. (1983). "Fourier transform profilometry for the automatic measuremnt of 3-D object shapes." *Applied Optics* **22:** pp. 3977-3982.

Takkunen, RL. (1962) "Anthropometric studies of Finnish children." *Acta Paed Finn Suppl.* **8:** p. 19.

Tanner, J.M. "Growth at Adolescence." 2nd Ed. Springfield, IL: CC Thomas 1962

Tessier, P. and Hemmy, D. (1986). "Three Dimensional Imaging in Medicine-A critique by Surgeons." *Scandinavian Journal of Plastic and Reconstructive Surgery* **20:** pp. 3-11.

Thalmaan-Degen (1944) "Die Stereophotogrammetrie ein diagnostisches hilfsmittel in der kierferorthopadie". Ph.D. University of Zurich.

Tolarová, M. (1982). "Periconceptional supplementation with vitamins and folic acid to prevent recurrence of cleft lip." *Lancet* (Letter) **2**: p. 217.

Tolarová, M. (1987). "A study of the incidence, sex-ratio, laterality and clinical severity in 3660 probands with facial clefts in Czechoslovakia." *Acta Chir Plast* **29:** pp 77-87.

Trasler, D. (1965). "Aspirin induced cleft lip and other malformations in mice." *Lancet* **1:** p. 606.

Trasler, D. (1968). "Pathogenesis of cleft lip and it's relation to embryonic face shape in A/J and C57BL mice." *Teratology* **1**(1): p. 33.

Trasler, D. and Fraser, F. (1963). "Role of the tongue in producing cleft palate in mice with spontaneous cleft lip." *Developmental Biology* **6:** p. 45.

Turner-Smith, A.R. (1988). "A television/computer three-dimensional surface shape measurement system." *Journal Biomechanics* **21**(6): pp. 515-529

Vanderas, A.P. (1987). "Incidence of Cleft Lip, Cleft Palate, and Cleft Lip and Palate Among Races: A Review." *Cleft Palate Journal* **24:** (3) pp. 216-225.

Veau, V. (1938). Bec-de-Lievre. Parais, Masson et Cie. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Von Graefe, C. (1817). "Kurze Nachrichten und Auszuge." J. Pract. Arznek. Wundarzk 44: p. 116. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Von Langenbeck, B. (1859). "Beitraege zur Osteoplastik." Deutsche Klin. 2: p. 471. Cited by: Rogers, B.O. (1971). History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Von Langenbeck, B. (1861). "Operation der angeborenen totalen Spaltung des harten Gaumens nach einer neuer Methode." Deustche Klin. 8: p. 231. Cited by: Rogers, B.O. History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Von Roonhuyse, H. (1674). "Historischer Heil-Curen in zwey Theile verfassete Anmerckungen". Nurnberg, Michael und Johann Friedrich Endtern. Cited by: Rogers, B.O. History of cleft lip and palate treatment. In: *Cleft Lip and Palate: Surgical, Dental and Speech Aspects* (1971). Eds. Grabb, W.C., Rosenstein, S.W., and Bzoch., K.R. Little Brown and Co. Boston.

Wang, R.Z. and Weiner, S. (1998). "Strain-structure relations in human teeth using moiré fringes." *Journal of Biomechanics* **31**(2): pp. 135-141.

Ward, R.E., Bixler, D. and Jamison, P.L. (1994). " Cephalometric evidence for a dominantly inherited predisposition to cleft lip-cleft palate in a single large kindred." *American Journal Medical Genetics* **50:** pp. 57-63.

Werler, M.M., Hayes, C., Louik, C., Shapiro, S. and Mitchell, A.A. (1999). "Multivitamin supplementation and risk of birth defects." *American Journal of Epidemiology* **150**(7): pp. 675-682.

Williams, A.C., Shaw, W.C., Sandy, J.R., and Devlin, B.H. (1996). "The surgical care of cleft lip and plate patients in England and Wales." *British Journal of Plastic Surgery* **49**: pp. 150-155.

Wyszynski, D.F., Duffy, D.L. and Beatty, T.H. (1997). "Maternal Cigarette Smoking and Oral Clefts: A Meta-analysis." *Cleft Palate-Craniofacial Journal* **34:** pp. 206-210.

Wyszynski, D.F. and Beaty, T.H. (1996). " Review of the Role of Potential Teratogens in the Origin of Human Nonsyndromic Oral Clefts." *Teratology* **53:** pp. 309-317.

Yuen, K., Inokuchi, I, Maeta, M., Kawakami, S.I. and Masuda, Y. (1997). "Evaluation of facial palsy by moiré topography index." *Journal Otolaryngology Head and Neck Surgery* **117**(5): pp. 567-572.

Zeller, M. "Lehrbuch der Photogrammetrie (English Translation 1952). H.K.Lewis and Co. Ltd., London, 1949.

Zenofos, S.S. and Jones, C.H. (1979). "Theoretical aspects and practical applications of Moiré topography." *Physics and Medical Biology* **24**(2): pp. 250-261.