THE INFLUENCE OF RAPID MAXILLARY EXPANSION ON CRANIOCERVICAL ANGULATIONS ONE YEAR AFTER TREATMENT

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ABSTRACT

Introduction: Rapid maxillary expansion (RME) has been shown to increase nasal permeability and reduce nasal airway resistance. Numerous studies have examined the relationship between rapid maxillary expansion and the change in airway resistance, or have looked at the relationship between airway resistance and natural head position (NHP). Few studies, to date, have examined the relationship between RME and the change in NHP resulting from the consequent change in nasal airflow and decreased nasal resistance.

Hypothesis tested: The null hypothesis is that rapid maxillary expansion has no significant effect on airway patency which in turn influences craniocervical angulations.

Nature of study: prospective, longitudinal, non-randomised study of 43 consecutive adolescent patients who presented with uni- or bilateral crossbites in the permanent dentition, and who required rapid maxillary expansion as part of their overall orthodontic treatment

Methods: Cephalograms in natural head position were taken before, immediately after, and one year after RME and the craniofacial angulations obtained were compared with an historical control group from an earlier study.

Results: No significant changes in the craniofacial angles were found immediately after expansion. One year post-expansion, however, NSL/VER had reduced by 3.14°, (p<0.01), indicating a drop in head position, while OPT/HOR reduced by 2.13° (p<0.05), and CVT/HOR had reduced by 2.55° (p<0.05), indicating a more forward inclination of the cervical spine.

Conclusions: The results of this study suggest that when the nasal airway resistance decreases as a result of RME, changes in craniocervical angulations do take place, but this takes some time to occur. The decrease in head elevation relative to the true vertical is consistent with previous studies where increased nasal airflow has occurred. The forward inclination of the cervical spine, which, while statistically significant, may not be clinically significant, suggests that a possible small increase in airway resistance at the lower levels of the airway results from the increased nasal airflow. In order to accommodate this, the cervical spine inclines forward to increase the cross-sectional area of the lower airway and thereby achieving a possible equalisation of the total airway resistance between the nasal and the pharyngeal components.

The null hypothesis (that rapid maxillary expansion has no effect on craniocervical angulations in the long term) is not supported in this study.

DECLARATION

I declare that, with the exception of the support acknowledged, that this thesis is entirely the results of my own study.

I declare also that this work has not been submitted, in whole or in part, for a degree at this or any other university.

Signature of candidate.

Signature of advisor……………………………………

Date……20/7/04……

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Behold, I will cause breath to enter into you, and ye shall live

Ezekiel 37:5

DEDICATION

In memory of my eldest brother,

LUKE ROBERT McGUINNESS

1940-2003

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INTRODUCTION

INTRODUCTION

The relationship between airway patency and natural head position has been the subject of interest to many researchers during the course of the twentieth century. Airway patency is essential to life, and as respiration is a continuous activity as long as the individual is alive, it is logical to postulate that it has some influence on the post-natal growth and development of the craniofacial complex.

The environmental effect of respiration on dental and craniofacial development was the subject of much speculation by physicians and orthodontists in the latter part of the nineteenth and the early twentieth, but it was only in the later decades of the 20th century that significant investigations showed a relationship between the airway, natural head position, and craniofacial development. The studies of Linder-Aronson (1970, 1974, 1975) demonstrated that patients with enlarged adenoids differed in their craniofacial development compared to a normal sample of patients. When adenoidectomy was performed, there was a trend towards normalisation of their cephalometric variables, which he ascribed to an improved breathing pattern. Work by Solow and his co-workers (Solow and Tallgren, 1971; Solow and Tallgren, 1976; Solow and Krieborg, 1977; Solow and Siersbaek-Nielsen, 1986; Solow and Sonessen, 1998) have elucidated this relationship to a much greater extent, and have recently developed a theory as to the relationship between head posture and temporomandibular disorders (Solow and Sandham, 2002).

Rapid maxillary expansion (RME) is a well-established technique and had been extensively used by the author in day to day clinical practice, and by other members of this research team (McDonald, 1995) to examine the changes in airway resistance and the changes in craniocervical angulations resulting from this clinical technique. As no work appears to have been done on the long-term effects of rapid maxillary expansion on craniocervical angulations, it was decided to make this the subject of this work.

The use of rapid maxillary expansion has long been advocated to gain space in crowded arches, as well as to improve nasal breathing. Rhinologists, physiologists and orthodontists have all used this technique, first described by Angell in 1860. On the basis that the roof of the mouth is also the floor of the nose, separation of the maxillary bones and widening of the palate will result in an increase in the patency of the nasal airway, and consequently there should be an improvement in nasal respiration, which in turn should have an effect on subsequent craniofacial development, along the lines of the findings described by Linder-Aronsen.

Solow and Krieborg (1977) were the first to formulate the interaction between morphological change, airway patency, neuromuscular feedback, posture, soft tissue changes, and differential forces on the facial skeleton, and numerous investigations on humans and animals show that this relationship does indeed exist.

This study examines the trends in craniofacial angulations that take place subsequent to rapid maxillary expansion (RME), in a follow-up study to work carried out by McDonald (1995), who showed that immediately after RME, changes in the relationship of the head to the true vertical and the cervical column, as demonstrated by cephalometric radiology, did take place. The present study also examines these changes both immediately after and at least one year after RME. The relevance of this work to clinicians is that it will elucidate the changes that take place as a result of rapid maxillary expansion, not just from the orthodontic point of view, but also from the effect that this has on the overall growth of the facial skeleton over a longer period of time, due to the change in airway patency exerting its effect via the soft tissue stretching hypothesis of Solow and Krieborg (1977).

The null hypothesis (H_o) would be that rapid maxillary expansion has ***no significant effect*** on the craniocervical angulations observed at T_2 and T_3, and would be expressed as:

H_o: $\overline{X_1} = \overline{X_2} = \overline{X_3}$

i.e., there is no significant difference between the means of the three different populations (where $\overline{X}$ is the mean of the relevant population)

The other possibilities are as follows:

$\overline{X_1} = \overline{X_2} \neq \overline{X_3}$

or

$\overline{X_1} \neq \overline{X_2} = \overline{X_3}$

The objective of this investigation would be to prove or disprove the null hypothesis, H_o.

CHAPTER 1: LITERATURE REVIEW

CHAPTER 1: LITERATURE REVIEW

(a) Rapid maxillary expansion

Historical background

Rapid maxillary expansion (RME) is a well-established technique for the correction of transverse discrepancies of the maxillary arch. Its mode of action relies on the separation of the two halves of the maxilla in order to achieve true skeletal or "orthopaedic" expansion, followed by orthodontic alignment of the teeth. The earliest expansion devices were usually crude and slow acting: according to Timms (1981) examples were used by Fauchard (1728), Bourdet (1757), and Fox (1803). Timms (1969) quotes the case of a French surgeon, Lefoulon, who in 1839 proposed the idea of lateral maxillary expansion, but he was hampered by lack of a suitable screw device to carry this out. In 1860 Emerson C. Angell, a dentist in San Francisco, made and described the first real expansion device as a method to provide space for crowded maxillary canines. Unfortunately he did not pursue it much after receiving unfavourable comments in the dental press. In 1886, Eysel, a German rhinologist, advocated palatal expansion as a means of improving nasal respiration, but did not meet with any encouragement.

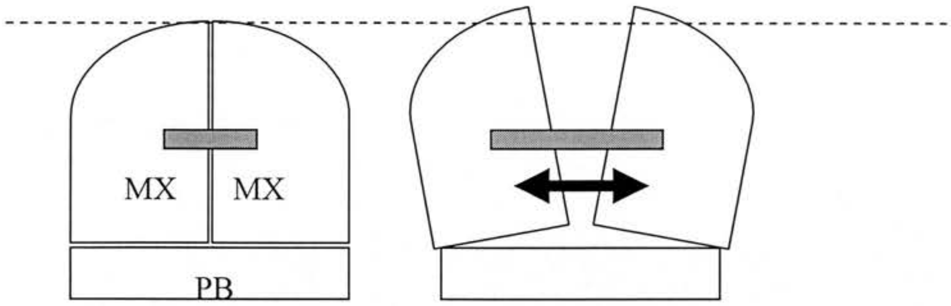
At that stage, before the discovery of X-rays by Röentgen in 1895, it was difficult to state precisely what the effect of RME was on the maxillary bones. Loreille and Béry (1981) cite the case of an unknown surgeon in this period who reflected the palatal mucosa after RME and found that indeed, true separation of the maxillae had occurred.

Wertz (1968) describes the first decades of the 20th century as the "rapid maxillary expansion years"; in 1903, Brown, an oral surgeon from Milwaukee, first described modern rapid expansion; Pfaff (1905) advocated slow expansion of the maxilla as a method to increase nasal permeability, while other researchers described the normal course of nasal respiration as flowing through the middle and superior meatus, considering that RME lowered the palatal vault and induced straightening of the nasal septum, which in turn moved the septum away from the turbinate bones and permitted an increased airflow (Mesnard, 1929) (figure 1).

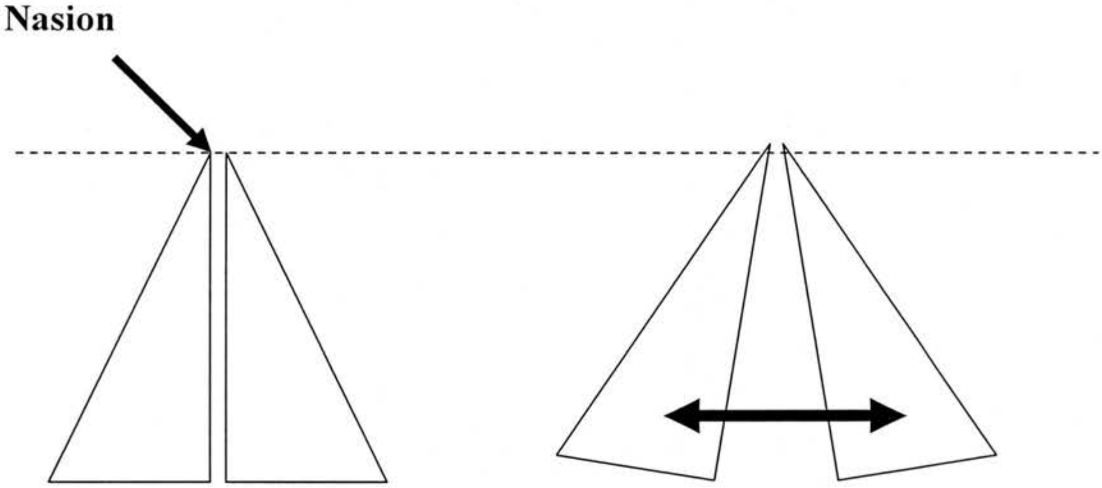
The initial enthusiasm for RME reached a peak in 1912 when an entire issue of the surgical journal, *The Laryngoscope*, was devoted to the ENT aspects of orthodontic therapy (Timms, 1981). However, in another publication, Timms (1969) states that the influence of Edward Angle (1855-1930) was such that rapid expansion fell into disfavour during the first decades of the 20th Century, only to be revived sometime later.

In general, RME seems to have continued in Europe, especially in Germany during the period between the two world wars, largely due to its medical use. Its reintroduction to North American orthodontists appears to have been the result of a visit to the USA by Professor G. Korkhaus in 1958 (Timms, 1981).

A lot of the UK research on rapid maxillary expansion was carried out by Donald Timms, who published a book on the subject in 1981. While some significant results were obtained in his work, it is noticeable that many of them are largely case series, with no control groups and somewhat unsound research methodology.



Palatal view: the two halves of the palate open in a fan-shaped manner, with wider opening anteriorly. The palatine bones (PB) act as a stop and force the maxillary bones (MX) forward). The fulchrum is at the midline of the of the posterior portion of the maxillary bones. Note the increase in anteroposterior dimension due to this effect, which is useful in correcting class III malocclusions



Frontal view:the floor of the nose / vault of the palate moves downwards as the fulcrum of rotation is in the region of nasion (the junction of the nasal and frontal bones). Note the increase in the vertical dimension of the nasal cavity in the midline due to rotation around nasion

Figure 1: Rapid maxillary expansion: mode of action

Rapid maxillary expansion: clinical technique and effects

Many practitioners who use slow as opposed to rapid maxillary expansion question the desirability of a potentially traumatic technique. Timms in his book (1981) stresses that the essence of the rapid technique is that true orthopaedic, as opposed to orthodontic expansion is achieved and that this orthopaedic (i.e. skeletal) expansion is maintained, while the dental expansion may show some relapse. Krebs (1964) in an implant study, showed that skeletal expansion after RME was maintained and that the nasal cavity continued to grow laterally. This supported the study of Linder-Aronson and Aschan (1963), who found that reduction in nasal resistance following RME is not lost one year after expansion. Mayoral and Aristiaguinta (1978) also using a cephalometric implant method, showed that while dental relapse occurred, skeletal width increased by RME was maintained. In contrast, Skieller (1964) in an implant study of slow maxillary expansion, showed minimal gains in the lateral width of the maxilla and the nasal cavity, compared to Kreb's work on RME published in the same year.

Rapid expansion means separating both halves of the maxilla at around 0.3mm – 0.5mm per day, achieving up to 10 mm of lateral expansion in 2-4 weeks. The rapid separation of the midline suture does not allow for any cellular response in the periodontal ligament of the teeth or the suture. The rigidity of the appliance is crucial to the technique, and it has been found also that younger age groups are more likely to achieve true skeletal expansion rather than older age groups.

Other effects of RME have been found by Haas (1961), who found that there was bite opening and rotation of the mandible downwards and backwards, while Wertz (1970) showed that opening of the suture was non-parallel, with wider opening anteriorly than posteriorly. In a later study, Wertz and Dreskin (1977) showed that the upper incisors moved mesially and generally uprighted following stabilisation, which contributed to the rapid closure of the midline diastema produced during expansion. He suggested that increased muscular tension together with interseptal fibre reaction was responsible for this. In other reports, correction of class III malocclusion had been reported to be successful; Timms (1980) reported this effect due to anterior movement of the maxillary bones during lateral expansion: he attributed this to the restraining effect posteriorly of the palatine and pterygoid bones, forcing the maxillary bones (and hence the cephalometric A-point, which is used to denote the forward projection of the maxilla) forward.

More recently, there has been much interest in using reverse pull headgear (or the Delaire facemask (Delaire, 1971) in combination with RME to correct class III malocclusions. Spolyar (1984) was among the first to report favourable results with this type of combination treatment; Baik (1995) showed that the palatal plane angle decreased more in those cases where protraction headgear was used during RME compared to those where protraction was carried out after expansion. Merwin et al (1997) demonstrated that similar orthopaedic maxillary advancement was achieved in patients under the age of 8 years and in patients older than 8, which is at variance with Delaire's findings in his 1971 paper; da Silva Filho et al (1998) using protraction headgear after RME, found that the results consisted of maxillary anterior displacement, and mandibular downward and backward rotation, thereby improving the facial profile, while dento-alveolar alterations were largely confined to incisal tipping. Williams et al (1997) using combination protraction-RME treatment, showed that the maxilla moved forward by 1.54mm on average, and the angle SNA increased by 0.87 degree. The maxillary teeth moved forward 2.73 mm and proclined by 5.23 degrees, with the mandible rotating downwards and backwards. Baccetti (1998) considered that the combination of a bonded maxillary expander and facemask therapy is more effective in the early mixed dentition than in the late mixed dentition, especially with regard to the magnitude of the protraction effects on the maxillary structures. Ngan et al (1998) found in a sample of class III southern Chinese patients that the overjet increased from –2.0 mm to +3.5 mm (an increase of 5.5 mm) using RME, and that there was a relapse in intermolar width of 30-45% after one year; some maxillary relapse was also found by Gallagher et al (1998) in a sample of patients with an average age of 9.8 years. Nartallo-Turley and Turley (1998) reported that combination therapy of this type improves class III malocclusion by a combination of skeletal and dental changes that occur both vertically and horizontally; they considered that the reason for the usefulness of this combination technique relies on the creation of microfractures around the base of the maxilla, which allows easier displacement of the maxilla under force from the protraction headgear. Vardimon et al (1998b), in an experiment in cats, considered that the total effect of rapid maxillary expansion was due to a combination of sutural displacement, tooth tipping, tooth displacement, and alveolar bending and tipping. This latter bone bending effect would concur with the findings of Grimm (1972) who found that between 0.6% and 25% of tooth movement was due to physical displacement of the alveolar process during orthodontic treatment.

In a study on rapid maxillary expansion, Linder-Aronson and Lindgren (1979) showed that there was approximately 50% relapse in transverse dimension in the molar regions and 75% relapse in the canine region post expansion. In an experiment on cats, Vardimon et al (1998a) found that the suture width decreased post expansion by 65%, while the increase in mineralisation was 2.5 times greater posterior than anterior, suggesting that the reorganisation (closure) pattern of the expanded suture is analogous to a zipper closing in a posteroanterior direction, with medial convergence of the maxillary horizontal processes. From this they suggested that anterior retention should be longer than in the posterior region. In a further paper from the same study, Brosch et al (1988) found 55% inter-premolar and 75% intermolar contraction over a two-month period where rapid expansion had been performed. They attributed this to relapse strain stored in the system.

The timing of rapid maxillary expansion is important in relation to the type of result desired. There appears to be a general consensus of opinion that separation of the two halves of the maxilla, with consequent skeletal change in the transverse dimension, is more likely before mineralisation of the midline maxillary suture. In the short-term, the results of rapid maxillary expansion in the transverse dimension have been documented by Cross and McDonald (2000), who showed that small, but statistically significant increases in the maximum nasal width took place, which were in agreement with studies reported previously. They considered that greater changes could have been achieved with a younger age group. Long-term, the skeletal effects of RME have been decribed by Krebs (1964), who showed that rapid expansion of the maxilla as opposed to slow expansion (Skieller, 1964) resulted in long-term increase in the width of the skeletal structures, which was maintained with normal growth. Cameron et al (2002) showed that the lateronasal width increased on average by 4.16 mm in a sample of RME patients compared to a control sample of 1.52mm ($p<0.001$).

Baccetti et al (2001) also found similar changes, and concluded that early expansion (before the growth spurt) was more likely to produce greater transverse changes, which were stable up to 10 years after initial treatment. Such long-term stable effect would contribute to the continued patency of the nasal airway, supporting the findings of Linder-Aronson and Aschan (1963), and would maintain the continuing changes observed in craniocervical, craniovertical and cervicohorizontal angles in such patients, mediated by the physiological and neuromuscular cycle described by Solow and Krieborg (1977).

Baccetti et al (2001) advocate the use of the cervical vertebral maturation method of O'Reilly and Yanniello (1998) to determine the pubertal growth spurt. Rapid maxillary expansion before the peak height velocity was found to induce more pronounced transverse skeletal changes, compared to largely dentoalveolar changes in the group treated later than this. Melsen (1975) showed using autopsy material that up to the age of 10 years, the suture was broad and smooth, while between the ages of 10-13 it had developed into a more typically squamous pattern with overlapping sections; finally after 13-14 years of age the suture was wavier with increased interdigitation. This interlocking of the suture is unique to humans, and is not found in other animals. Persson (1973, 1976) and Persson and Thilander (1977) showed that on average, 5% of the suture is closed by 25 years of age. Further studies by Melsen and Melsen (1982) showed synostoses and numerous bony bridge formations across the suture at age 15. Wertz and Dreskin (1977) provided support for Melsen's studies by showing that there were greater and more stable orthopaedic changes where treatment was done in patients under 12 years of age.

Timms (1981) advocates the use of RME in patients up the age of 25 years, on the basis that separation of the maxillae can be achieved; where it is not possible, surgically assisted RME is needed. Wehrbein and Yildizhan (2001) have shown in a sample of 30 autopsy specimens from 10 subjects ranging from 18 to 38 years of age that actual obliteration of the midline suture as diagnosed radiologically was 0.45% in those samples where the suture was diagnosed as "open" and 1.3% in those diagnosed as "closed". They suggested that the term "suture fusion" should be avoided.

SUMMARY: The clinical technique of RME has been shown to add a considerable amount of space to crowded dental arches, despite the reported degree of relapse. If carried out correctly, it will achieve true skeletal or orthopaedic effect, in lateral expansion of the maxilla, though it may also increase vertical dimensions. It is useful when combined with reverse pull headgear in moderate class III skeletal cases with maxillary retrusion, when some degree of true skeletal advancement of the maxilla can be achieved. The earlier treatment is done, the greater the effect seems to be: it would appear that the patency of the maxillary midline suture continues into adult life, and that diagnosis of such patency depends largely on the radiographic technique used.

(b) General aspects of respiratory physiology and airflow resistance

When a gas or a liquid flows through a tube, it may do so in a laminar or smooth manner, where the streamlines are parallel to the sides of the tube. This usually occurs at low flow rates. As the flow rate increases, there is a tendency for turbulence to develop, especially on the outside edges of the flow, due to differential binding on the vessel walls (West, 1990).

The pressure-flow characteristics of laminar flow were described by the French physician Jean Poiseuille (1797-1869). In straight cross-sectional circular tubes, the volume flow rate is given by

$$V = \frac{P \pi r^4}{8 \eta l}$$

where

P = driving pressure (or pressure difference between the ends of the tube, ΔP)
r = radius of the tube
η = viscosity of fluid or gas
l = length of tube

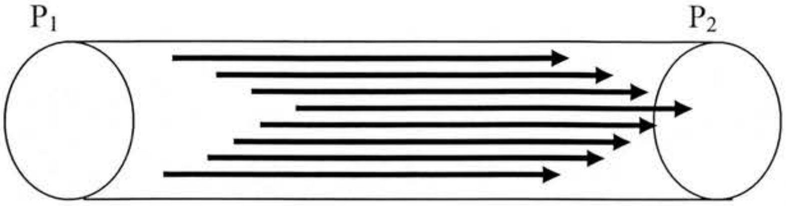
The driving pressure, P, is proportional to the flow rate, V, expressed by the equation

$$P = RV$$

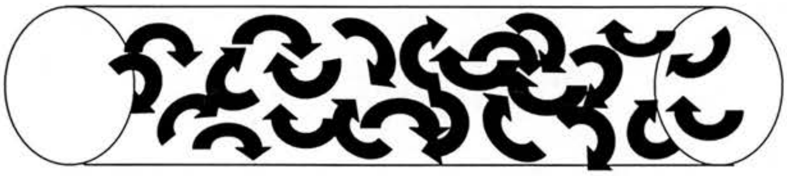
Since flow resistance, R, is driving pressure divided by flow this implies

$$R = \frac{8 \eta l}{\pi r^4}$$

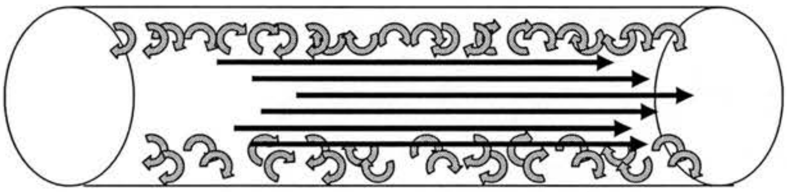
From the above formula, it will be seen that if the radius of the tube is halved, the resistance increases by sixteen times.



Laminar flow



Turbulent flow



Combined laminar and turbulent flow:
laminar flow at centre of tube, turbulent flow due to drag on vessel walls

Figure 2: illustration of laminar and turbulent flow of liquids and gases in tubes

Another feature of laminar flow is that when fully developed, the gas or liquid at the centre of the tube moves twice as fast as that in contact with the walls of the tube. Thus, a spike of rapidly moving material travels down the axis of the tube. This changing velocity across the diameter of the tube is known as the velocity profile (figure 2).

Turbulent flow of air or liquid has different properties. Here the pressure is not proportional to flow rate, but approximately to its square: $P = KV^2$.

Whether flow is laminar or not depends to a large extent on the Reynolds number, Re. This is given by

$$Re = \frac{2\ r\ v\ d}{\eta}$$

where

d = density
v = average velocity
r = radius
η= viscosity

In straight, smooth tubes, turbulence is possible when the Reynolds number exceeds 2000. The expression shows that turbulence is most likely to occur when the velocity of flow is high and the tube diameter is large (for a given velocity). In the nose, pure laminar flow is most unlikely (Timms, 1986b) and a combination of laminar and turbulent flow (figure 2c) is more likely.

In the nose, the nasal passages are lined with mucous membranes which (a) warm, (b) humidify and (c) filter the air before it is delivered to the lungs (Loreille and Béry, 1981); this is called the air conditioning function of the upper respiratory passages.

This process brings the air to within 1°F of body temperature and within 2-3% of the full saturation with water before it reaches the trachea. The total mucosal area involved in this process is approximately 160 cm^2. When breathing is done through a tube (as for example, in a tracheostomy) the drying effect on the lower lung can lead to serious lung crusting and infection (Guyton and Hall, 1996).

The nasal mucous membrane also contains mucous glands and goblet cells, which together with millions of tiny cilia, continually sweep dust and other small particles towards the epiglottis, where it is swallowed. The turbinate bones – the conchae – also increase the size of the surface area of the nasal passage, which aids this process. Patients who are oral breathers do not have the same humidifying mechanisms applied to inspired air and may suffer various ailments as a result.

The filtration process of the nose is aided first by the vibrissae at the entrance to the nostrils, which filter out large particles. Much more important, however, is the removal of air particles by turbulent precipitation, which is the result of air passing over the turbinate bones, the septum, and the pharyngeal wall. Each time the air hits one of these obstructions, it changes direction, but the particles suspended in it cannot change course rapidly, so they continue forward, striking the surfaces of the mucosa, where they are trapped in the mucous coating and transported by the cilia to the pharynx to be swallowed. This mechanism is so effective that almost no particle bigger than 6μm in diameter enters the lung through the nose. This dimension is smaller than the average red blood cell. Of the remaining particles, many between 1 and 5 μm settle out in the smaller bronchioles, as a result of gravitational precipitation. Some of the still smaller particles (< 1μm in diameter) diffuse against the walls of the alveoli and adhere to the alveolar fluid. Many particles smaller than 0.5 μm in diameter remain suspended in the alveolar air and are expelled later by expiration. For example, particles of cigarette smoke have a particle size of 0.3 μm. Almost none of them are precipitated in the respiratory passages before they reach the alveoli. However, up to one-third of them do precipitate in the alveoli by the diffusion process, with the balance remaining suspended and expelled in the inspired air.

Many of the particles that become entrapped in the alveoli are removed by alveolar macrophages, and others are carried away by the lung lymphatics. An excess of particles causes growth of fibrous tissue in the alveolar septa, leading to permanent disability (Figures 3a and 3b).

From figure 2, it will be seen that the two states of flow – turbulent and laminar – can exist at the same time. The turbulent flow of air will be advantageous where it allows trapping of the inspired particles onto the nasal mucosa, while the laminar flow allows air to pass freely in and out of the lungs.

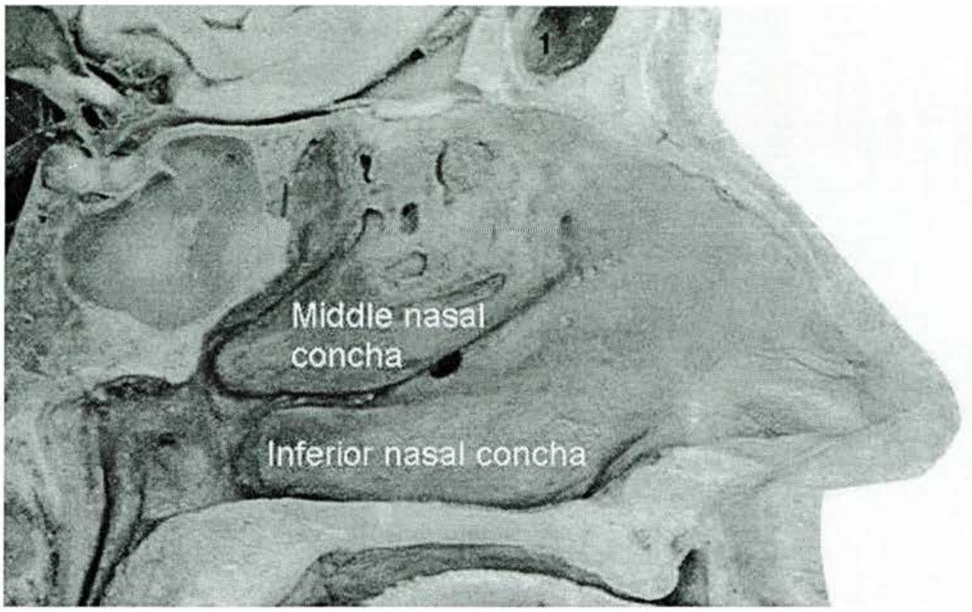


Figure 3a: sagittal view through nasal cavity

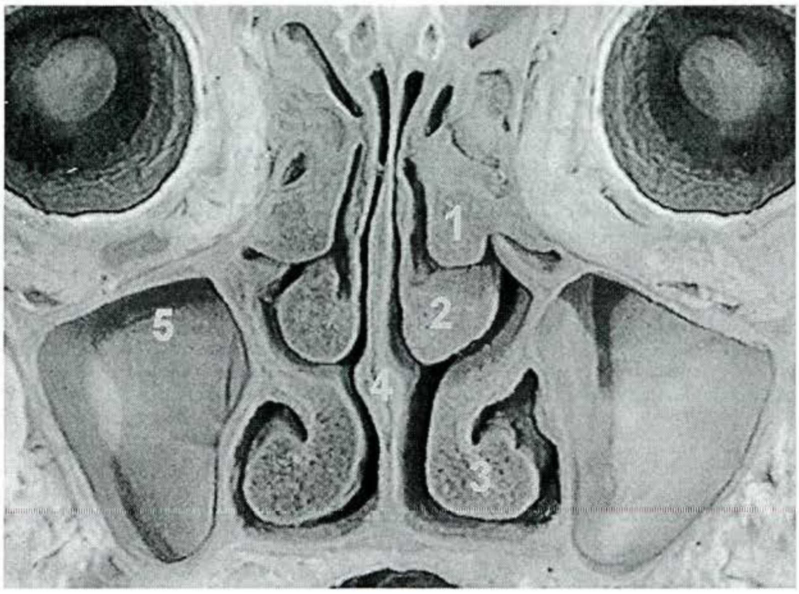


Figure 3b: coronal view through nasal cavity

1 = ethmoidal air cell

2 = middle nasal concha

3 = inferior nasal concha

4 = nasal septum

5 = maxillary sinus

(c) Rapid maxillary expansion and the nasal airway

Patients may be nasal breathers or oral breathers. With an increase in the dimensions of the nasal airway, and consequent improved nasal breathing, patients who were formerly mouth breathers were found to be able to breathe through their nose. Korkhaus (1960) advocated RME for this reason; Gerlach (1956) cautioned that while RME was useful for nasal stenosis, not every mouth breather could be treated in this way.

Nasal stenosis occurs when the inferior turbinate bones or their mucosal covering are enlarged and obstruct passage of the air. Numerous techniques (pharmacological and non-pharmacological, injection procedures, cryosurgery, laser surgery, electrocautery, surgery, and vidian neurectomy) have been advocated to treat nasal obstruction (Jackson, 1999). Most surgical correction is by partial or total resection of the inferior turbinate. This operation is commonly performed by ENT surgeons, requiring admission to hospital and a general anaesthetic. In a major review of the surgical techniques available for inferior turbinate hypertrophy, Jackson (1999) described how the inferior turbinates could swell and shrink in a nasal cycle in the majority of individuals lasting 3-4 hours. Hol and Huizing (2000) in a critical review of the various techniques for the treatment of inferior turbinate pathology, suggested that techniques such as electrocautery, chemocautery, subtotal turbinectomy (partial resection of the turbinate), cryosurgery, and laser surgery should not be used, as they were too destructive. The method of choice was, they suggested, intraturbinal turbinate reduction, where the bone of the turbinate was reduced but the soft tissue covering remained largely intact, a much more conservative procedure. Clement and

White (2001) carried out a non-systematic 35-year review of the literature on MEDLINE, and found 561 papers, 283 of which dealt specifically with turbinate surgery. Of the total of 561 papers, 64% were comparative case series, case series, case reports, or technical descriptions. It was found that endoscopic and laser surgery had become more popular in recent years. No evidence was found to support the assumption that surgery will increase the nasal volume and thereby result in an improvement in patient symptoms. No randomised controlled clinical trials were found in this study, and the authors considered that technology, rather than research, was responsible for driving the popularity of any particular new surgical technique.

Cook et al (1995) in a prospective consecutive non-randomised and uncontrolled study, reported on 31 patients who had partial middle turbinectomy. Nasal airflow increased and nasal airway resistance decreased as a result of this procedure, and no adverse effects were reported.

Other cases where nasal obstruction resulting in mouth breathing occurs is in patients with enlarged adenoids or tonsils, or where allergic rhinitis exists. Linder-Aronson (1970) demonstrated that patients with upper airway obstruction due to enlarged adenoids had significantly different craniofacial morphology compared to a control group. The effect on the dental structures included retroclination of the upper and lower incisors and reduction of the overjet, with a narrow upper arch between the upper molars, which often resulted in a crossbite. These patients were obligate mouth breathers (Schweiger, 1966). Similar skeletal and dental cephalometric findings have been observed in patients with enlarged tonsils (Behlfelt et al, 1990) and obstructive sleep apnoea (Solow et al, 1993).

After adenoidectomy, Linder-Aronson (1974, 1975, 1979) found that there was a trend for the differences between the sample and the control group to decrease significantly; this reversibility of the differences in morphology suggesting that the differences had been caused originally by adenoidal obstruction. He suggested that in mouth breathing the tongue position is lowered, and when the adenoids are removed the resting tongue position can be raised resulting in reversal of the anomaly trends. The relationship between craniofacial morphology and rhinomanometrically measured airway adequacy in adenoid subjects had been subsequently shown by Bushey (1979), and the relationship between craniofacial morphology and radiographically measured nasopharyngeal airway adequacy has been measured by Sosa et al (1982). As well as research into the effect of adenoids on the airway, other airway anomalies have been studied. Respiratory obstruction in patients with cleft lip and palate was shown by Drettner (1960), Warren et al (1969), and Sandham and Solow (1987). Improved nasal airflow was demonstrated in orthodontic patients after rapid maxillary expansion as demonstrated by Hershey et al (1976), and Loreille and Béry (1981), who demonstrated an average increase in nasal permeability of 13.6%. Timms (1986b) in a sample of 26 patients found an average 36.2% decrease in nasal airway resistance after RME; the correlation between intermolar width and airway resistance was weak ($r = 0.32$). Other uses to which RME has been put include the correction of nocturnal enuresis (Timms, 1990; Kurol et al, 1998) and these report encouraging results.

SUMMARY: Rapid maxillary expansion is of help in increasing nasal airflow. Surgical methods to widen the nasal airway generally require admission to hospital and a general anaesthetic, and any non-surgical method that could avoid this is to be welcomed. However, RME is not suitable for every patient and careful assessment is needed in order that the maximum benefit is gained in each case: in some cases, it may be prudent to avoid rapid expansion altogether.

(d) Natural head position – Cephalometry

Interest in the subject of head position and posture dates to the middle part of the nineteenth century, when it was realised that for reproducible and meaningful comparison of craniometric analyses between dry skulls that some orientation reference was needed, preferably in relation to the living or natural head position. Von Baer and Wagner (1861) and Broca (1862) decided that a horizontal or vertical reference line outside the cranium should be used, preference being given mainly to the horizontal. In 1884 the Frankfurt horizontal plane was adopted at the craniometrical conference in Frankfurt am Main (Proffit, 2000). The Frankfurt horizontal plane is defined cephalometrically as a line connecting the lowest point on the border of the orbit (Orbitale) with the most superior point (Porion) on the border of the external auditory meatus. With the advent of cephalometric radiography in the 1930's this plane was utilised as the basis for many analyses (figure 4).

The availability of a reliable and reproducible method of measuring natural head position obviously makes for more meaningful research into the complex interaction between head posture, morphology and airway adequacy. The early Transactions of the British Society for the Study of Orthodontics in the first decades of the twentieth century show a great interest in environmental causes of malocclusion - especially the relationship between nasal obstruction and malocclusions (Foster, 1988). In 1931 Sir Norman Bennett, in his book "*The Science and Practice of Dental Surgery*" referred to nasal stenosis and adenoids as a cause of malocclusion, especially upper arch narrowing. With cephalometric radiographs not then available, a great deal of the conclusions made were somewhat tentative. However with the increasing input of research

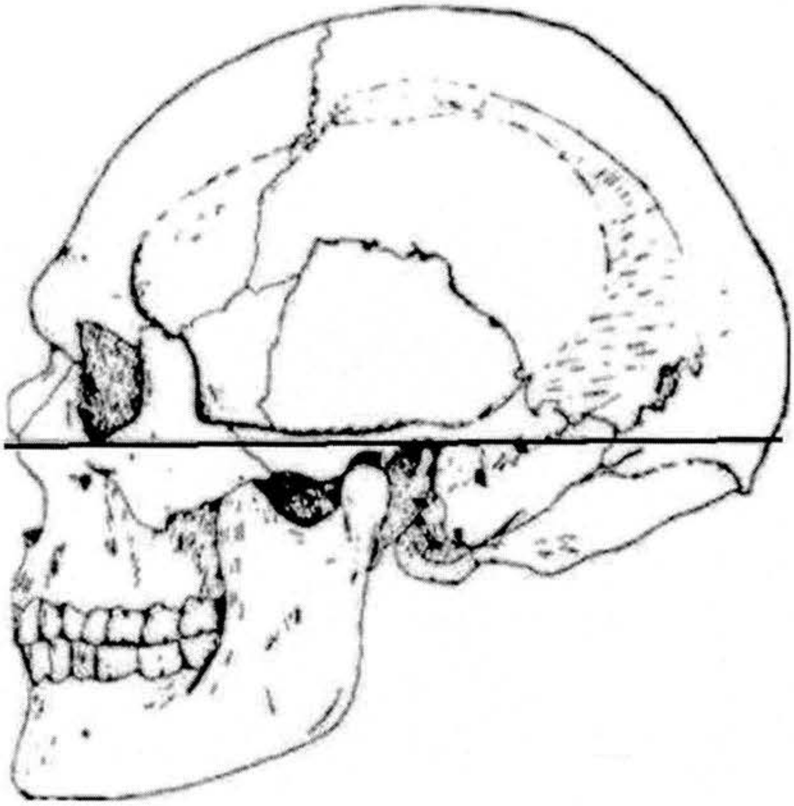


Figure 4: Frankfort horizontal plane on human skull (from Scott and Symons, 1972)

findings on genetics and heredity, the environmental hypothesis lost favour (Foster, 1988).

Schwartz (1926) was among the first to suggest a relationship between head posture and craniofacial morphology when he attributed the development of a class II malocclusion to hyperextension of the head relative to the cervical column during sleep. Gresham and Smithels (1954) supported this hypothesis, noting a larger prevalence of class II malocclusions in subjects with "poor neck posture", while Björk (1955) observed a raised head position and facial retrognathism in subjects with a flat cranial base angle.

Natural head position was used in the orthodontic field for assessment of facial aesthetics in orthodontic analysis and treatment planning (Downs, 1956; Bjerin, 1957; Moorees and Kean, 1958; Mills, 1968). It was also used for orientation of the head in studies of mandibular rest position (Tallgren, 1957, 1966) and of the oropharyngeal structures (Bench, 1963, Cleall, 1965; Cleall et al, 1966; Fromm and Lundberg, 1970).

The theories of Moss in relation to the "functional matrix theory" proposed that function of any particular part determined form: for example, increased respiration widened the nasal airway, while increased chewing developed the oral cavity (Moss, 1968). Frankel (1980) adopted this as the basis for his functional regulator, which proposes that by changing the soft tissue environment of the teeth, that significant anteroposterior and vertical discrepancies can be corrected. However, most studies of natural head position were directed towards the relationship of the head to their surroundings. Up to 1971, no studies appear to have been done of the relationship of the head to the cervical column, and only minor attention was paid to the position of the cervical column to the true vertical.

Ophthalmology textbooks describe two controlling mechanisms for the control of head posture. One is the input from the proprioceptive receptors in muscles, tendons, joints, and the balancing position of the inner ear (the "crude") positioning system. The other mechanism is determined by input from the visual righting system when the subject fixes the gaze on an external object (the "fine" positioning system). The self-balance position may be defined as that without external reference (the "crude" system) while the position where the subject looks at his or her own eyes in the mirror in the distance is the "fine" or mirror positioning system (Solow and Sandham, 2002).

The first study to elucidate these relationships in any detail was performed by Solow and Tallgren (1971) in a cephalometric study of 120 male dental students, both in the self-balance position (where the subject defined their own feeling of a natural head balance) and in the mirror position (where the subject looked at their own eyes in a mirror). These cephalograms were taken in the orthoposition as defined by Mølhave (1958); this is defined as "the intention position from standing to walking".
A repeat series of films was made two months later, from 21 subjects to determine reproducibility of the two head positions. It was found that these were reproducible with a method error of 2.48° for the self-balance position and 1.43° for the mirror position. It was also found that on average, subjects tended to hold their heads 3° higher in the mirror position compared to the self-balance position, which was found

to be statistically significant at the 1% level. In that study, the various points, planes and angles were defined according to definitions by Bjork (1960), and Solow (1966) (Figure 5 and Table 1,). Solow and Tallgren, in their 1971 paper, discussed the Frankfort horizontal plane as a reference line, and found that on average it made an angle of 89.6° to the true vertical, but in view of the large inter-individual variability of the craniofacial reference lines in relation to the true vertical, they stated that its use is questionable in relation to the individual subject.

In a further paper by Solow and Tallgren (1976) on the data derived from their 1971 study, the relationships between craniofacial morphology and head posture were analysed by correlations between 42 linear and angular variables for the craniofacial features, and 18 angular variables for the postural features. It was found that correlations were similar for both head positions investigated; the position of the head in relation to the cervical column (NSL/OPT) displayed the most comprehensive set of correlations with craniofacial morphology: ***extension*** of the head in relation to the cervical column was found to correlate with large anterior and small posterior facial heights, small antero-posterior craniofacial dimensions, large inclination of the mandible to the anterior cranial base and to the nasal plane, facial retrognathism, a large cranial base angle, and a small nasopharyngeal space. In contrast, ***flexion*** of the head in relation to the cervical column showed exactly the opposite (figure 6). A distinction should also be made between ***neck extension and flexion*** and ***head extension and flexion***. Further analysis of the same data (Solow and Tallgren, 1977) showed positive correlations between craniocervical angulations with both dento-alveolar heights and the inclinations of the upper and lower occlusal planes: the greater the extension of the head in relation to the cervical column, the greater the

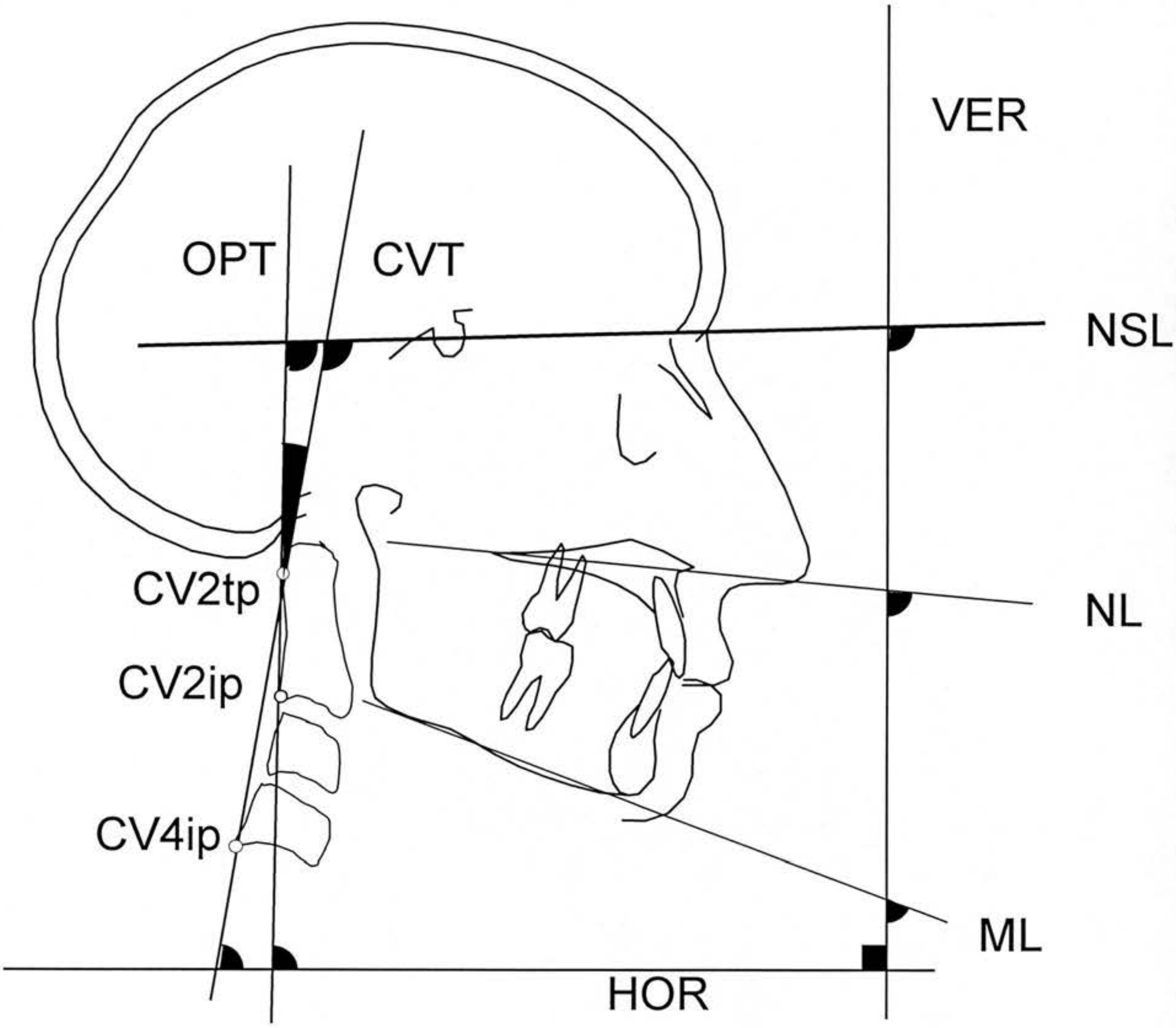


Figure 5: reference points and lines on the cephalometric film: see Table 1 for definitions (after Solow and Tallgren, 1976)

TABLE 1: Definitions of points, planes and angles (after Solow and Tallgren, 1976)

N	Nasion. The junction of the nasal and front bones
S	Sella. The centre of the sella turcica
NSL	The line connecting Nasion and Sella
NL	Nasal line: the line connecting anterior nasal spine (ANS) and posterior nasal spine (PNS)
ML	Mandibular line: the tangent to the lower border of the mandible through gnathion (the most inferior point on the bony symphysis)
cv2tp	Tangent point of the odontoid process tangent on the odontoid process of the second cervical vertebra
cv2ip	The most inferior and posterior point on the corpus of the second cervical vertebra
cv4ip	The most inferior and posterior point on the corpus of the fourth cervical vertebra
OPT	Odontoid process tangent. The posterior tangent to the odontoid process through cv2ip
CVT	Cervical vertebrae tangent. The posterior tangent to the odontoid process through cv4ip
VER	True vertical (determined by a hanging chain attached to the cassette film)
HOR	True horizontal

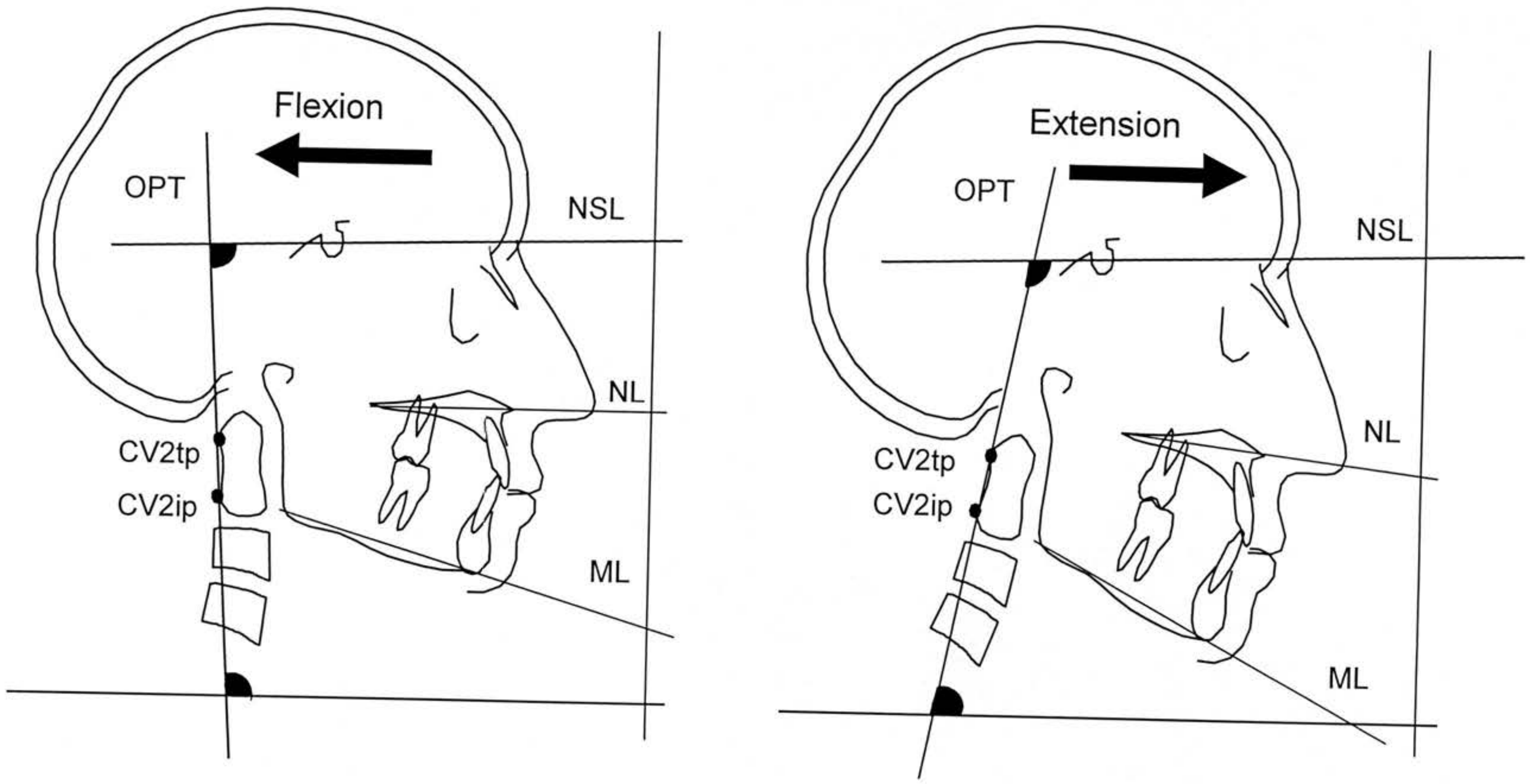


Figure 6: subjects with a low (left) and high (right) craniocervical angles (OPT-NSL). Lower craniocervical angles show flexion of the head in relation to the cervical column: craniofacial features include small anterior and large posterior facial heights, large A-P craniofacial dimensions, smaller inclination of the mandible to the anterior cranial base and to the nasal plane, facial prognathism, a small craniofacial base angle, and a large nasopharyngeal space. Subjects with a high craniocervical angle, or extension of the head in relation to the cervical column, on the other hand, show exactly the opposite features.

dento-alveolar heights. In a study of Australian aboriginals, it was found that the cervical column was shorter, and that there was a more extended head posture, with the craniocervical angle being about 6° greater than in the Danish sample (Solow et al, 1982); other findings included a larger lower anterior face height, with an increased maxillo-mandibular plane angle, which correlated well with the previous findings by Solow and Tallgren. These findings were similar to those made by Opdebeek et al (1978), and Marcotte (1981).

Timms and Trenouth (1988) in a cross-sectional study of orthodontic patients with increased nasal resistance found an increase in maxillo-mandibular plane angle, palate-tongue distance, palatal width, and facial index. The disadvantage of such studies is that correlational associations do not necessarily mean causal associations. Longitudinal studies to determine the effect of growth coordinating mechanisms have been carried out by Solow and Siersbaek-Nielsen (1986). A prospective study of 43 children, using lateral cephalometric radiographs in the natural head position, was taken before and after orthodontic treatment (average observation period 2.7 years). The correlations showed strongest associations between growth rotation of the mandible and change in the cranio-cervical (i.e. OPT / NSL and CVT / NSL) angles. Flexion of the head produced more forward growth rotation of the mandible, while extension produced reduced forward rotation or even backward rotation of the mandible.

Other workers have carried out a number of studies of natural head position in cephalometry. The reproducibility of head posture on lateral cephalograms, taken by three different auxiliary personnel in a community orthodontic clinic setting between

1 and 35 days after the first radiograph, was determined by Siersbaek-Nielson and Solow (1982). Overall, the method error ranged from 2.3° for NSL / VER, to 3.4° for NSL/OPT, and 0.9° for OPT / CVT. A study by Sandham (1988), for 12 patients who had their cephalograms repeated after 1 hour found lesser method errors, ranging from 1.5° for OPT / HOR to 0.38° for NSL/CVT.

Estimates of reproducibility of natural head position have been investigated by Cooke and his co-workers in a study that looked at the effect of using the self-balance position compared to the mirror position, the use of ear posts versus no ear posts, the effect of time between repeat cephalograms, and the effect of gender (Cooke and Wei, 1988): in this study it was found that boys tended to look up more when changing from the self-balance to the mirror position (NSL-VER difference 2°, $p<0.001$). If radiographs were repeated on the same day, the method error was 1.9°; if repeated 3-6 months later the method error was 2.4°. The mirror position produced a more reproducible head position (with mirror the method error was 1.9°, without the mirror, method error was 2.7°). A five-year follow-up by Cooke (1990) on the same group showed that the method error was 2.34° at 3-6 months after the initial radiograph, 2.89° at 1-1½ years, 3.37° at 2-4 years, and 3.04° at 5 years. In general, it appeared that reproducibility deteriorated over time but seemed to stabilise after 1-1½ years; this was probably due to the small numbers that took part in the study at the 1½ -4 year period. Cooke considered that the variance of NHP (9.24° [= $3.04^{\circ 2}$]) remained much less than variance of the intracranial reference lines (25° - 36°) to the true vertical. At 15 years follow-up, the method error was found to be 2.2° (Peng and Cooke, 1999), further strengthening the case for utilisation of natural head position cephalograms over time. This was confirmed by an earlier study by Foster et al (1981) in which the relationship of the internal cranial reference lines to each other showed much greater variation than when these lines were compared to an external reference (such as true vertical or horizontal) in natural head position.

Usumez and Orhan (2001) used an inclinometer attached to a spectacles frame to record NHP, using two tilt sensors to record the pitch and roll of the head. The reproducibility of the method was high, and the method errors were of the order of 0.6° - 0.7°. In a follow-up study, Usumez and Orhan (2003) demonstrated that the change in NHP measurement was –0.3° with variance of 1.21° ($= 1.1^2$), over 2 years using the inclinometer.

Luyk et al (1986) investigated NHP radiographs in 18 patients who were due to undergo orthognathic surgery. The method error was found to be of the order of 4.85 – 4.9°. The reasons for this were considered to be due to radiographer positioning variation. There was also weekly change in the radiography staff in the unit concerned, and continuity of experienced personnel may have contributed to this variation. Other factors considered by Luyk and his colleague included using the edge of the film as a vertical reference (found to have variations of less than 1°) or identification of cephalometric points (no significant variation) or patient related variables. More recently, the issue of reproducibility of cephalometric radiographs in NHP taken by radiographers or other auxiliary personnel has been investigated by Bister et al (2002). Using the standard error of the method (sometimes called the Dahlberg coefficient, but which is now deprecated – Newcombe, 1994), reproducibility of such cephalograms was found to be less favourable than in other reported studies (method error of 2.99°). In order to improve the reproducibility without exposing the patients to unnecessary radiation, a photographic method was instituted to help train the radiographer. After a simplified protocol for taking NHP cephalograms was introduced, the reproducibility improved substantially (Standard error of the method = 1.41°). It was considered that the standard error of the method did not provide an extreme enough interval to allow a sufficient clinical assessment of a method to be undertaken, so the Bland and Altman graphical representation (Bland and Altman, 1986) was used instead; this provided a 95% range, compared to 52% for the standard error of the method.

The position of the patient when taking the radiograph (sitting or standing) has been investigated by Huggare (1993) who showed that using a spirit level attached to the patient's forehead, transfer from a standing to a sitting position could be done in the cephalostat without any systematic change in craniocervical, craniovertical, or cervicohorizontal relationships. Subjects were asked to look into the far distance, instead of into a mirror. For another part of this study, 20 subjects had repeat radiographs taken, 10 using the mirror method, and 10 using the fluid-level method. In the hands of the radiographers, there was loss of reproducibility due to the fact that these repeat radiographs were taken under normal working conditions, and the attention to accuracy was likely to be less than it would have been in a predesigned study; however the method errors reported were similar to those found by Siersbaek-Nielson and Solow (1982).

Determination of the true horizontal on a cephalometric radiograph which has not been taken in natural head position may be difficult: in many institutions, machine porion is used as the most posterior point of defining the Frankfurt plane, which may often be some distance removed from the true external auditory meatus. Also, cephalometric radiographs may not always be taken in the natural head position. In the living patient the landmarks may be difficult to identify accurately, giving rise to errors of positioning. On a cephalometric radiograph, if there is a very obvious discrepancy between the machine porion and true porion, and if machine porion is used to determine the Frankfurt plane, there may be a significant discrepancy between this and the true horizontal. In many cases the maxillary plane is tipped relative to the Frankfurt plane, and the two may not necessarily be parallel. In a literature review, Houston (1991) showed that the S-N line to the true horizontal showed an average of 6°, and that large cross-sectional cephalometric studies that are not of clinical value to the individual patient are not ethically acceptable. He suggested that the true horizontal could be derived from existing studies for individual patients. Viazis (1991) stressed that Frankfort horizontal, the palatal plane, the mandibular plane angles and the incisor angulations to these may give misleading readings if the cephalometric radiograph was taken in a non-natural head position. Lundstrom and Lundstrom (1992) advocated the use of NHP cephalograms and photographs in that the latter could be transferred to former with a high degree of accuracy, and that such an approach gives a more natural appearance to the patient. The reproducibility of photographic images of patients' profiles in NHP has been confirmed also by Chiu and Clark (1991) who compared the head position of patients in both the "self-balance" position and the "mirror" position on two separate occasions, 4-6 hours apart, using sticky markers attached to the subjects' faces. However, Halazonetis (2002) in a photographic study using 7 experienced orthodontists, found that chin position had an influence on how practitioners orientated heads in natural head orientation: the more prominent the chin, the more likely would the head be orientated downwards compared to where the chin was more retrusive.

Clinically, the assessment of the skeletal pattern depends on the way that the patient holds their head - if the head is held habitually upwards and forwards, this may give the impression of a prognathic mandible, or class III skeletal pattern; if the patient holds the head downwards and backwards, the impression is that of a retrognathic mandible or class II skeletal tendency.

SUMMARY: assessment of head posture has progressed from a somewhat anecdotal and speculative one to one that that can be measured accurately and reproducibly. Statistical correlations exist, both cross-sectionally and longitudinally, with cephalometric changes; a habitually extended head will result in increased vertical facial dimensions; decreased vertical facial dimensions will be seen with habitual flexion of the head. Cross-sectional studies of airway resistance and head posture have shown positive correlations between increased airway resistance and increased facial vertical dimensions; while correlations might be statistically significant, they do not tell anything about causal relationships, and simple bivariate statistics do not take account of any other factors involved. Estimates of reproducibility over time suggest that NHP has about one-third of the variance of normal intracranial reference lines, and many clinicians advocate the use of NHP in treatment planning for this reason. However, it is important that radiological staff are trained in the use of such cephalograms, as change of personnel can give rise to wide variations in head positions on cephalograms.

(e) Natural head position, airway and craniofacial development

The head is the location of four out of the five senses (taste, hearing, sight, and smell), and the oronasal area is the entry for food, water and air, on which life depends. One important function of head posture is to maintain adequate nasal and oro-pharyngeal airways (Bosma, 1963). The position of the head – "natural head position" – can be expected to conform to physiological requirements associated with (a) resistance to gravity, (b) respiration, (c) deglutition, (d) sight (the visual axis), (e) vestibular balance mechanism and (f) hearing (Vig et al, 1980). Cole (1988) has defined natural head position as "the relationship of the head to the true vertical", and head posture as "the relationship of the head to the cervical column". As breathing, sight, balance, hearing and resistance to gravity are in constant use when the patient is awake, it would seem logical that these mechanisms would have the greatest influence on head position. Harvold et al (1973) showed that artificial obstruction of the nasal airway in monkeys resulted in altered mandibular posture and changes in the shape of the mandible with development of anterior open bite after one year of nasal obstruction. Vig et al (1980) in a study of human volunteers, found that total nasal obstruction and forced mouth breathing resulted in an average 5° extension of the head that reached a peak 1-1½ hours after starting. The method used was a protractor with a plumb line that was placed over two ink dots on the subjects' faces. Visual deprivation using a blindfold did not produce any effect even when combined with the nasal obstruction. In a more recent study, Hiyama et al (2002) showed that forward mandibular posture increases airway patency, and the more upright a subject is, the greater the airway patency. Linder-Aronsen (1970, 1974, 1975) has confirmed that the mode of breathing has an effect on craniofacial development, in a study of patients with enlarged adenoids who underwent adenoidectomy.

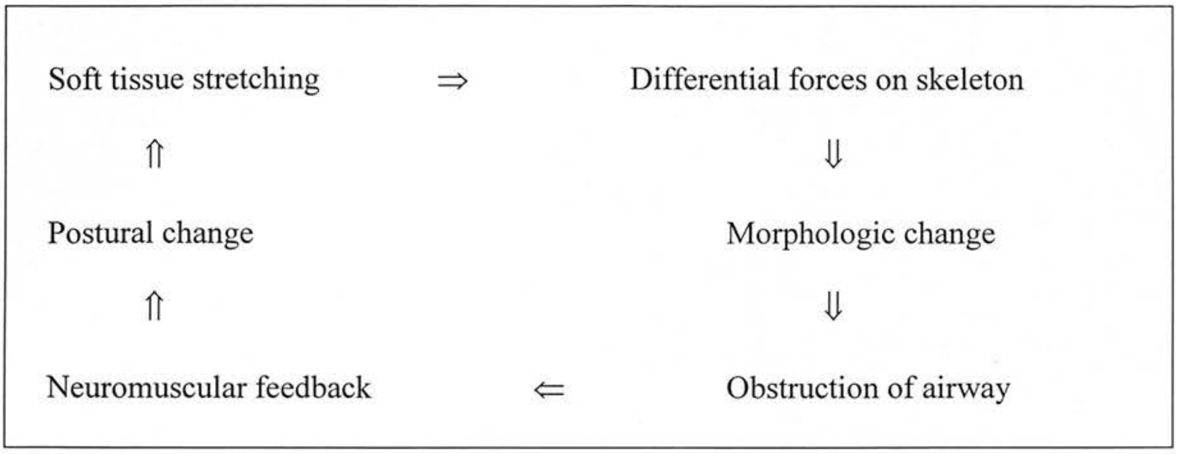
The upper airway may be divided into the nasal, nasopharyngeal, and oro-pharyngeal segments, and each may be the site of obstruction. The commonest cause of nasal obstruction (Table 2) is rhinitis, with allergic rhinitis being the most common cause of long-term nasal obstruction. The typical clinical appearance is of dark rings under the eyes due to an enlarged subcutaneous venous plexus, and a running nose. Wenzel et al (1985) in a study of patients with asthma and perennial nasal allergy, found that after administration of a nasal decongestant, there was an immediate reduction in craniocervical angle. This indicated that the nasal obstruction resulted in an extension of the head that was reversible after treatment.

Oro-pharyngeal obstruction also occurs in obstructive sleep apnoea (OSA) which is characterised by repeated collapse of the oropharynx. In a study of OSA patients by Solow et al (1993) it was found that the craniocervical angle (NSL / OPT) was 9-12 degrees higher than in six different non-OSA control groups, which was highly significant.; the average value for OPT / HOR in the OSA cases was found to be 81° compared to a range of control samples (83.6° – 90.4°), indicating neck extension. Obstructive sleep apnoea was also associated with an average OPT / NSL angle that was approximately 10° higher than six different reference samples without OSA. Ozbek et al (1998) in a comparable study, found an ***increase*** in OPT / HOR and

TABLE 2: CAUSES OF UPPER AIRWAY OBSTRUCTION		
Nasal	**Soft tissue**	Allergies
		Hyperplasia
	Hard tissue	Natural anomalies
		Deviated nasal septum
		Trauma
Nasopharyngeal	**Tonsils – pharyngeal** **- lingual**	Allergy / infection
	Adenoids	
Oropharyngeal	**Large tongue**	
	Low / posterior tongue position	
	Waldemeyer's ring hyperplasia	

CVT / HOR in patients with OSA. In contrast, in the study by Huggare and Laine-Alava (1997), a wider nasal cross-sectional area in asymptomatic patients was found to have a significant association with forward cervical inclination, i.e., the angle OPT / HOR was found to be reduced,). In a further study (Solow et al, 1996) a series of correlations between neck extension (OPT / HOR and CVT / HOR) and airway dimensions was found, among others, which were considered to be a compensatory mechanism serving to maintain airway adequacy in sleep apnoea patients. Hellsing (1989) showed in a study of 20 adult patients that extending the head 20° resulted in an increase in the cross-sectional area of the pharyngeal airway. Therefore, there is evidence to suggest that obstruction of the upper airway can have an effect on the craniocervical angles, but the relationship between these angles and the subsequent craniofacial development proved initially somewhat elusive.

Solow and Sandham (2002) give a history of the reasoning and the associations between the various factors involved in cervical angulations. Obstruction of the airway led to a postural change resulting in extension of the craniocervical angulation, but the precise mechanism was unknown: it was therefore given the general designation "neuromuscular feedback". The link between craniocervical angulation and craniofacial morphology was postulated as "soft tissue stretching". In all the studies examined, there was little or no association between craniovertical angles and craniofacial development, so the force of gravity was excluded. The passive soft tissue stretching resulting from extension of the head in relation to the cervical column would increase the forces on the skeletal structures, and would therefore restrict the forward growth of the mandible and the maxilla and direct it more caudally. The final link is “differential forces on the skeleton”. Solow and Krieborg (1977) summarised this in the following diagram:



The evidence for this chain reaction mechanism was postulated from studies of patients with bilateral condylar hypoplasia, where the lack of forward growth of the mandible locates the tongue too far posteriorly, and in mandibulofacial dysostosis, where the zygomatic arches are also affected, as well as from observations of patients that had airway inadequacy, where the reaction will be extension of the head in relation to the cervical column, with stretching of the soft-tissue investing fascia of the neck. The marked antegonial notching seen in cases of bilateral condylar hypoplasia is explained by the investing neck fascia inserting into the pterygomasseteric sling, which is firmly attached to the lower mandibular border in the gonial region. During marked extension of the head a downward traction will be transferred to this region, and should result in gonial apposition. Further evidence is provided by a study by Hellsing and L’Estrange (1987) in which pressure transducers attached to the labial surface of upper and lower incisors in subjects who were asked to extend and flex their heads through 10 degrees. This resulted in marked changes in pressures on the teeth being recorded by the transducers, and such differences could influence dentofacial and craniofacial development. Further work by Solow and

Sonnessen (1998) showed that in patients with extended head posture, there was more significantly more crowding of the teeth in the upper and lower labial segments, which would confirm the theory that soft-tissue stretching over the teeth would result in more crowding.

With regard to the relationship between airway adequacy and the type of malocclusion, Watson et al (1968) found no association between airway adequacy and type of malocclusion or craniofacial morphology.

(f) Effects of surgery and other interventions on airway and craniocervical angulation

Adenoidal hypertrophy causes obstruction at the nasopharyngeal level. Solow and Greve (1979) found in a study of patients with adenoidectomy, that the craniocervical angles also reduced, and the head again came down over the tongue. In patients with enlarged tonsils, Behlfelt et al (1990) showed that the craniocervical angles were 4-8 degrees higher than a normal control group. More recent work by Arun et al (2003) compared two post-adenoidectomy groups with a control group of non-adenoidal children; one of the surgery groups had had surgery before the age of 4 years, and the other had had surgery after the age of 4. No statistical differences were found between the two surgical groups. When they were compared to the non-surgical group, overall the vertical dimensions of the surgically treated groups were significantly higher than the vertical dimensions of the surgically treated groups were significantly higher than those in the non-surgical group. This contrasts with Linder-Aronson's work (1970-1975) that did not have a control group of unoperated adenoidal patients. The subjects were also a lot younger than Linder-Aronson's patients, and a good deal of growth would have occurred in the period of observation.

Linder-Aronson's studies are of particular interest here. These showed a tendency towards normalisation of the cephalometric variables in those patients who had undergone adenoidectomy compared to the control group. This was found to be due to reduced nasal airway resistance, with consequent decrease of the craniocervical angle. More recent work by Arun et al (2003) compared post-adenoidectomy groups with a control group of non-adenoidal patients. One of the control groups had had surgery before the age of 4 years, while the other had surgery after the age of 4 years. The average age of the 2 surgery groups was 11.6 years (s.d. 2.08 years) and 12.18 years (s.d. 2.68 years), while the average age of the control group was 11.18 years (s.d. 2.3 years). No significant differences in craniocervical angles were found between the two surgical groups, when combined and compared to the control group, however, there were significant differences, in that the vertical dimensions were greater, similar to Linder-Aronson's findings.

Other surgical interventions have also had an effect on airway dimensions and consequently, on natural head position. Mandibular advancement is performed in cases of marked skeletal class II discrepancy, and sometimes also for obstructive sleep apnoea where the mandible is retrusive: it has been shown by Achilleos et al (2003a) to result in the neck angulation (OPT / HOR and CVT / HOR) becoming more flexed and upright by approximately 6° in both cases, which the authors considered to be due to the increase in pharyngeal airway dimensions resulting from surgery. Roberstson (2000) in a study of mandibular advancement surgery for obstructive sleep apnoea, found that head elevation in relation to the true vertical (NSL /VER) had decreased by 6.7°, which again would be consistent with in increase in pharyngeal airway dimensions increasing. Conversely, mandibular setback surgery for class III malocclusions was found by Achilleos et al (2000b) to result in increased craniocervical angulations (OPT / NSL and CVT / NSL) indicating cervical hyperflexion postsurgery, but no significant changes in angles OPT / HOR and CVT / HOR were seen at follow-up. Airway dimension changes on radiographs may occur post-surgery (Liukkonen et al, 2002), however, Wenzel et al (1989b) state that reduction in airway dimensions on radiograph may not necessarily imply increased nasal airway resistance, due to the cross-sectional nature of the data involved.

Rapid maxillary expansion of skeletal structures has been shown by Krebs (1964) in an implant study, to be stable in the long-term, compared to expansion with removable appliances (Skieller, 1964) which appear to have little or no effect on the transverse dimensions of the nasal cavity. In rapid maxillary expansion, the lateral width of the nose should also increase, giving rise to increased nasal breathing, thereby decreasing nasal respiratory resistance (N R R). If this skeletal expansion is stable, a decrease in craniocervical angulation is likely to occur, according to Solow and Krieborg's (1977) hypothesis.

SUMMARY: Rapid maxillary expansion has been shown to be skeletally stable in the long term even though dental stability is only moderate. The transverse skeletal change has an effect on the nasal aperture and has been shown to reduce nasal airway resistance. Various studies have shown that improved nasal breathing does have an effect on head posture, with the consequent effects on the dental and skeletal elements of the skull mediated via the soft tissues being modified as a result of head posture changes. Surgical intervention (such as adenoidectomy, mandibular setback or advancement, or turbinate surgery) have been shown, to a greater or lesser extent, to have an effect on airway patency and also on the craniocervical, craniovertical, and cervico-horizontal cephalometric angles; however, the results of the soft tissue changes as seen on cephalometric radiographs must be interpreted with caution, especially where these are cross-sectional, as such studies can be misleading, especially where only two variables are involved. It is stressed that multifactorial reasons exist for such changes.

While studies have been done to evaluate head posture changes due to airway resistance, and others have been done documenting airway resistance changes due to RME, very few studies have examined the head posture changes resulting from RME over a longer term.

CHAPTER 2: AIMS AND OBJECTIVES

CHAPTER 2: AIMS AND OBJECTIVES OF THIS INVESTIGATION

From the foregoing, there is evidence to suggest that rapid maxillary expansion can increase the nasal airflow by widening the base of the nose, thereby reducing nasal respiratory resistance. Decrease in nasal respiratory resistance should, ultimately, have an effect on the position of the head in relation to the true vertical and the cervical column, and may, according to Solow and Kreiborg's (1977) hypothesis, alter the craniocervical angulations.

The objective of this investigation is to investigate the changes in craniocervical and craniovertical angulations that accompany rapid maxillary expansion, measured immediately before expansion (T_1), immediately after expansion (T_2), and a minimum of 12 months after expansion (T_3). If the craniocervical angulation change observed remains changed and does not alter between T_2 and T_3, this would suggest a continued patency of the airway due to RME; if the craniocervical angulation tended to return to pretreatment values, this would imply a decrease in patency of the nasal airway with consequent change in craniocervical angulation, possibly due to transverse skeletal relapse (however, Krebs (1964) has shown that this is somewhat unlikely). If the values tend to alter from the pre-treatment values, this could imply a continuing ongoing morphological change due to the increased airway patency, initiated by the rapid maxillary expansion and which would act according to Solow and Krieborg's hypothesis (1977)

The null hypothesis (H_o) would be that rapid maxillary expansion has ***no significant effect*** on the craniocervical angulations observed at T_2 and T_3, and the objective of this investigation would be to prove or disprove the null hypothesis, H_o.

CHAPTER 3: MATERIALS AND METHODS

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(a) Patient selection

The patients in this study were selected from the assessment / referrals clinic of a district general hospital department and were included in the study in the order of presentation. It was decided to collect a certain number of routine orthodontic patients, as these are the ones that make up the bulk of clinical practice, and also to ensure that an adequate number remained in the sample at the follow-up period, in case any should drop out.

The protocols for treatment and the study were already in place as part of normal departmental clinical practice; RME patients routinely have a lateral cephalogram taken immediately after expansion and then have another taken just prior to debond. For the purposes of this study, the third cephalogram was taken one year after the completion of initial expansion and no cephalogram was taken prior to debond. Ethical approval for the initial part of this study (McDonald, 1995) was already given.

The criteria for inclusion for the patients were that they be:

1. Between 10 – 16 years of age
2. In good general and dental health
3. With either (a) a bilateral crossbite in the buccal segments, or
   (b) a unilateral crossbite with displacement on closure where the maximum retruded contact position in tooth contact before

displacement indicated that the upper and lower arches were normally related.

4. With a full permanent dentition in the maxillary arch, consisting of 654321/123456
5. No history of surgery to the nasal, paranasal, or oral cavities.

In addition, patients were excluded from the study if they demonstrated poor oral hygiene, exhibited caries, or if they or their parents did not wish them to take part in the study. The sample consisted of 43 patients in total; 25 females and 18 males.

The historical control sample comprised 36 children, 24 female and 12 male, again all within the age group 10 - 16 inclusive. This sample had been used as a control group in a previous study (McDonald, 1995) and were included sequentially if they fulfilled the agreed criteria on age, having no transverse cusp bilateral crossbite and they had not undergone surgery to the tonsils, nasal passages or adenoids. All subjects were of the same northern European racial background (white Caucasians). Ideally studies of this type should be conducted as a prospective, randomised controlled clinical trial (RCT). However, the time factor and the unavailability of other personnel to assist in this study mean that it took this particular form.

Full orthodontic records were obtained prior to treatment, consisting of study casts, clinical photographs, and radiographs. The lateral headfilm was taken in the natural head position as described by Tallgren and Solow (1971). The cephalogram used was a Siemens Orthophos CD machine with a standard magnification of 6.8%. The patient was positioned in the machine by the principal investigator (N.McG.) on each occasion. The reason for this was that regular rotation of staff within the radiology department took place and there was no guarantee that the same radiographer would be present when the NHP cephalograms were being taken. The ear rods were placed lightly touching the skin surface overlying the condyles after the patient had been told nod their head up and down in order to relax, in accordance with the recommendation by a number of authors that the patient's head must not be forced into position by the operator, as this would defeat the whole object of the study (Siersbaek-Nielson and Solow, 1982). It was important that the patients themselves found the final position where they stood in a comfortable and relaxed position and looked at their own eyes in a mirror at least six feet away. (Figure 7). The position of the patients in a front-to-back direction was controlled by placing the operator's foot in front or behind the patient's feet, and allowing them to move slightly backwards or forwards but continuing to look at their own eyes in the mirror so that natural head position was maintained. A hanging chain was placed over the film cassette to indicate true vertical (figure 8). Panoral radiographs and upper anterior occlusal views of the maxilla were also obtained at this appointment.

The important structures on the cephalogram were a clear view of the sella turcica, nasal bone, frontal bone, and the first, second, third and fourth cervical vertebrae. If any of these structures were not visible, the radiograph was repeated immediately.

Figure 7: patient positioned in cephalometer. Note hanging chain over film cassette (arrowed) to show true vertical on radiograph.

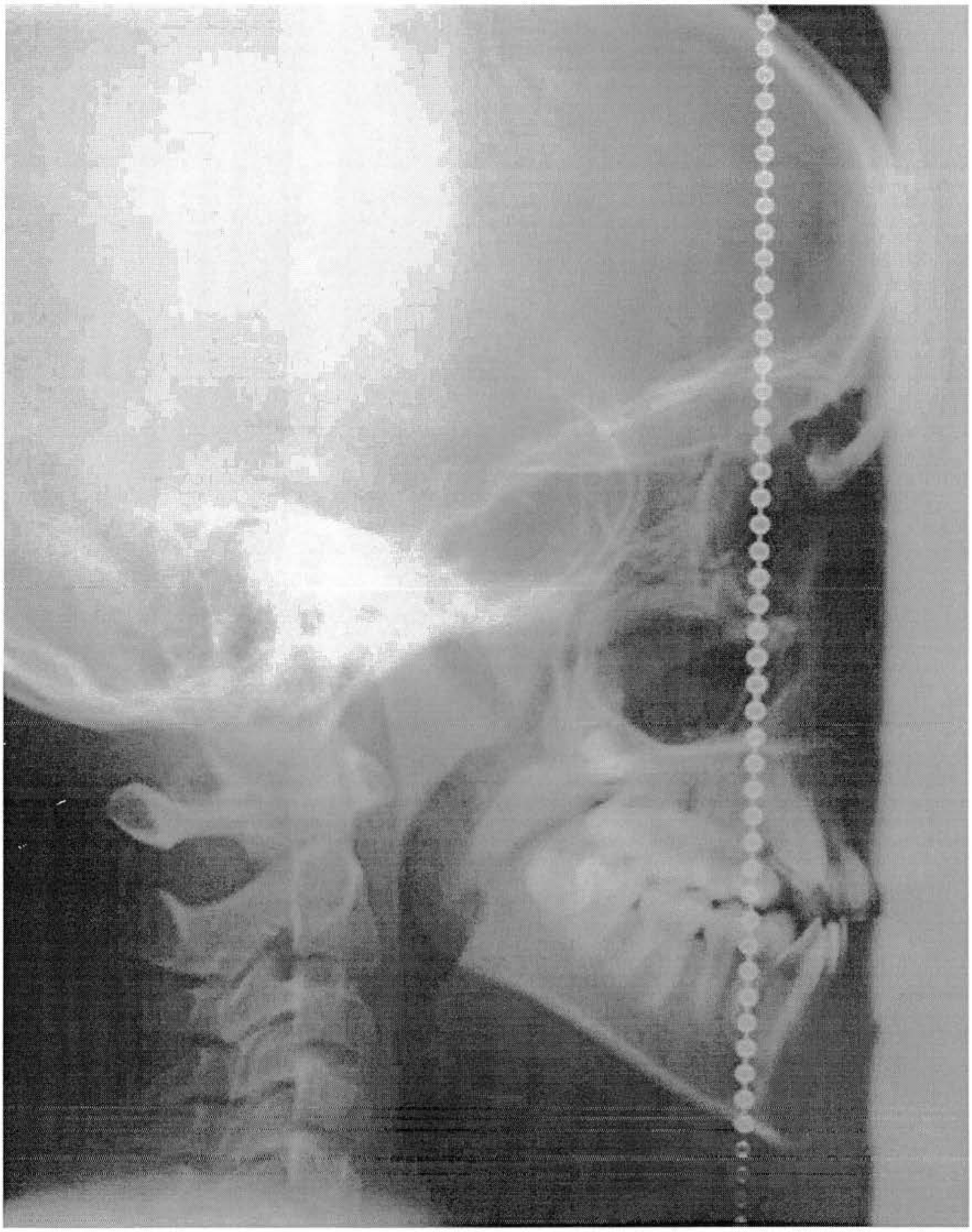


Figure 8: example of lateral cephalogram used in this study. Hanging chain denotes true vertical

The rapid maxillary expansion splint (figures 9 and 10) was constructed according to the same pattern and in the same laboratory as that used by McDonald (1995). This consisted of an appliance giving full metal cast coverage of the buccal teeth (654/456), with the addition of 3/3 where necessary. Buccal edgewise tubes with hooks were soldered or cast into the buccal surface overlying the most anterior teeth covered by the metal splint, to reduce the length of unsupported wire to used to align the incisors in the later fixed appliance phase. The technician was specifically requested to ensure that buccal cusps of the teeth protruded at least 2-3 mm above the level of the metal splint covering the teeth to facilitate its easy removal with a standard orthodontic debanding pliers. The metal cast cap splints included an integral cast metal mesh extending into the palate on both sides, to which was added palatal acrylic coverage, the whole appliance being connected across the midline by a Hyrax screw, which made the appliance extremely rigid, in order to ensure bodily separation of the two halves of the maxilla and to reduce the possibility of tooth tipping. The Biedermann or Haas (banded) appliances do not give this rigidity (Timms, 1974a). Generally, each screw had 40 turns available, each giving transverse expansion of 0.25 mm, with a total potential expansion of up to 10mm. Occasionally, where the maxillary arch was very narrow, a smaller screw (25 turns) was used, and a second appliance used to complete any further expansion.

Once the appliance was checked and found to be fitting correctly, the teeth were polished and the appliance cemented with glass ionomer cement. The parent was then instructed to turn the midline screw twice a day, in the morning after breakfast and once again in the evening after the evening meal. (Figure 11, a-c). Both patient and parent were warned about the appearance of a midline upper diastema between the

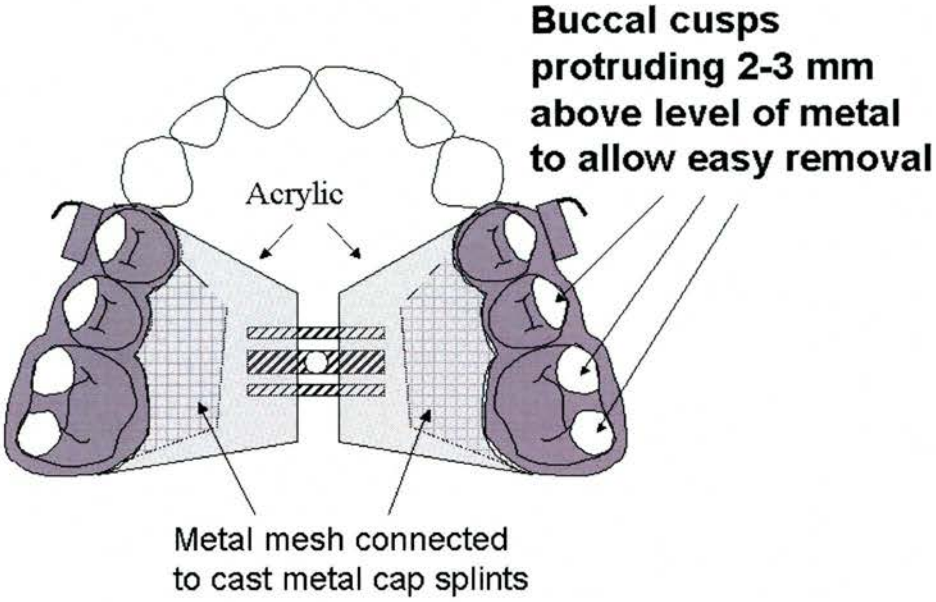


Figure 9: schematic diagram of rapid maxillary expansion splint used in this study.

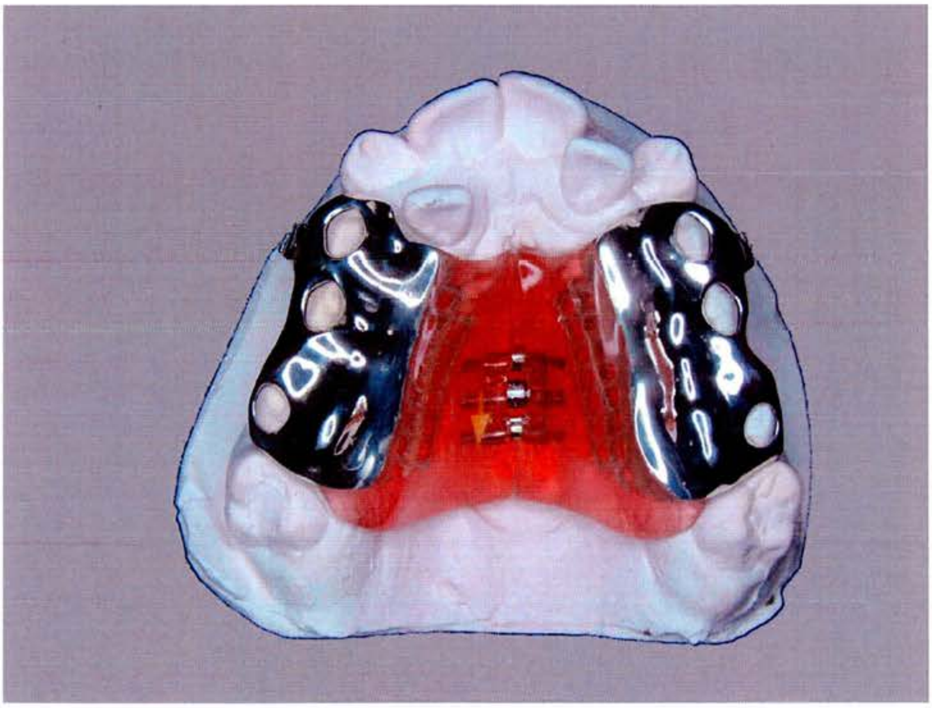


Figure 10: example of rapid maxillary expansion splint used in this study

Figure 11a: Patient RM prior to treatment

Figure 11b: Patient RM after expansion

Figure 11c: Patient RM – occlusal view of RME splint after expansion

upper central incisors, and were given verbal and written instructions on the care of the appliance

Normally patients were reviewed after three weeks, but some patients required further activation of the appliance, or a new appliance, before the crossbite was sufficiently corrected, usually until the palatal cusps of the upper molars were in contact with the buccal cusps of the lowers. At this stage, the appliance was removed, the teeth cleaned and polished, and new impressions for study casts were taken. A second lateral headfilm in natural head position was obtained at this stage, according to the protocol outlined previously. The appliance was recemented, and the upper anterior teeth were bonded with straight-wire brackets and the teeth aligned with a series of progressively heavier archwires inserted into the tubes on the cast splint. After three months, the RME splint was removed, the teeth cleaned and polished, and the remaining upper teeth bonded and banded, and a transpalatal bar connecting the molars across the palate was placed to maintain intermolar width. A series of progressively heavier wires was used until a single heavy rectangular stainless steel wire of 018" x 025" dimension could be placed. Orthodontic treatment proceeded in the normal way, and a minimum of one year after cessation of maxillary expansion, a third lateral skull headfilm was obtained. At the end of orthodontic treatment the appliances were removed in the usual way, and upper and lower removable Hawley appliances were provided for retention. Full records were obtained at the debonding visit.

Ethical approval was given under the terms of the research protocol submitted by McDonald (1995) as this was an extension of this study. The procedures involved in the study were those normal clinical procedures that would be undertaken for any orthodontic patient; all procedures were fully explained to the patients and their parents before treatment. All parents or guardians gave full written consent to the treatment. There were no refusals.

(b) Cephalometric data

The cephalograms were traced onto acetate paper with a 3H hard pencil by the author using a light viewing box. The shadow of the hanging chain indicated true vertical (VER) and this was traced onto to the acetate sheet. The horizontal plane (HOR) was constructed by drawing a line perpendicular to the line VER. Of particular interest were the craniocervical angulations to the vertical and horizontal plane. The following were the angulations traced (figure 12 and table 3).

OPT / NSL	The angle formed by the line tangent to the odontoid process through cv2ip (the most inferior and posterior point on the corpus of the second cervical vertebra), and the Nasion-Sella line.
CVT / NSL	The angle formed by the line tangent to the odontoid process through cv4ip (the most inferior and posterior point on the fourth cervical vertebra), and the Nasion-Sella line
OPT / CVT	The angle between the odontoid process tangent through cv2ip and the tangent to the odontoid process through cv2ip
NSL / VER	The angle between the Nasion-Sella line and true vertical
OPT / HOR	The angle between the line OPT and true horizontal
CVT / HOR	The angle between the line CVT and true horizontal

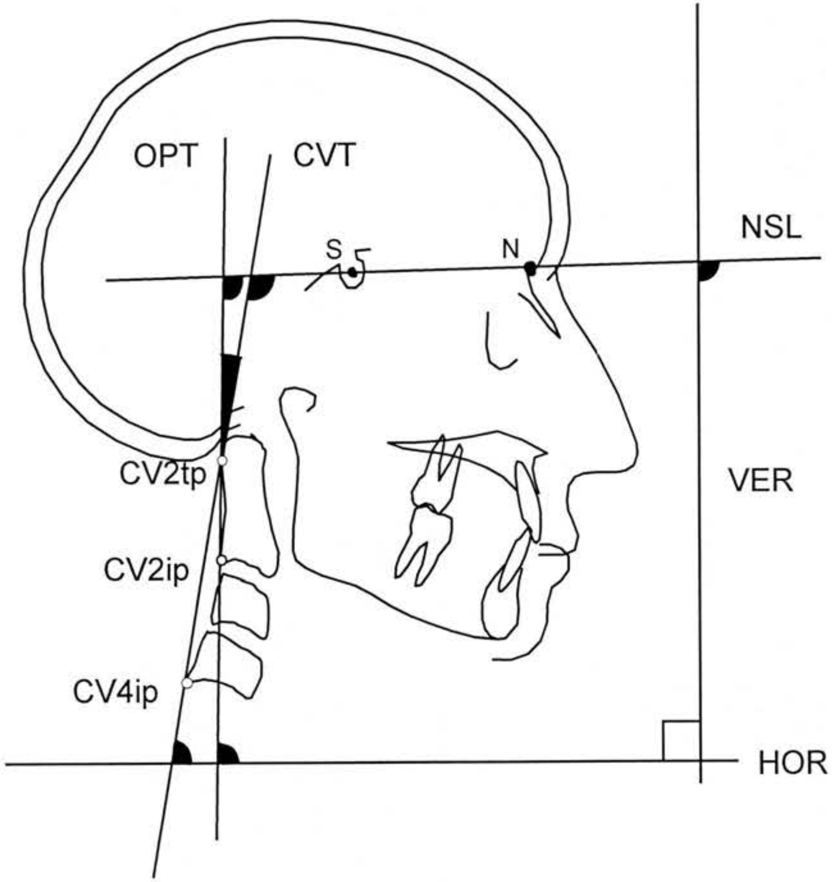


Figure 12: Cephalometric points, planes and angles used in this study

TABLE 3: DEFINITIONS OF CEPHALOMETRIC POINTS, PLANES AND ANGLES USED IN THIS STUDY (Figure 12)

N	Nasion. The junction of the nasal and front bones
S	Sella. The centre of the sella turcica
NSL	The line connecting Nasion and Sella
cv2tp	Tangent point of the odontoid process tangent on the odontoid process of the second cervical vertebra
cv2ip	The most inferior and posterior point on the corpus of the second cervical vertebra
cv4ip	The most inferior and posterior point on the corpus of the fourth cervical vertebra
OPT	Odontoid process tangent. The posterior tangent to the odontoid process through cv2ip
CVT	Cervical vertebrae tangent. The posterior tangent to the odontoid process through cv4ip
VER	True vertical (determined by a hanging chain attached to the cassette film)
HOR	True horizontal

(c) Study cast analysis

Twenty-eight maxillary study casts were available for examination at time 1 (pre-treatment), and 25 casts at time 2 (immediately post-expansion)(Tables 6a – 6f). The tips of the canines and the tips of the mesiobuccal cusps of the first molars were marked with a pencil and the expansion was measured with an electronic vernier gauge accurate to 0.01mm. The value for expansion (in millimetres) was the difference between the pre-treatment and post-expansion widths.

The intercanine and intermolar widths prior to treatment between males and females were compared with unpaired t-tests. Pre and post-treatment intermolar and intercanine widths were compared using paired t-tests.

(d) Statistical analysis

The principal investigator initially entered the data obtained into a Microsoft Office 2000 Excel spreadsheet (Microsoft, Seattle, WA, USA), before being transferred to an SPSS statistical package (SPSS v.11, Chicago, Illinois, USA). Comparison of the control group (McDonald, 1995) and test group pretreatment cephalometric data was performed using a one-sample t-test. Comparison of the pretreatment age data, cephalometric angulations, and intercanine and intermolar width between the sexes in the test group were examined using independent t-tests. Craniocervical and craniovertical angulations at T_1, T_2, and T_3 were compared using the General Linear Model – Repeated Measures form of Analysis of Variance (GLM-RM ANOVA). The reason why this was used is because ordinary ANOVA does not take account for the correlation at different times within subjects. Where small changes occur, high correlations between the different sets of data for the same variables at different times can occur, and this can have an effect on the statistical analysis. Individual student t-tests performed between the three sets of data would run the risk of increasing the number of Type I errors to the 14.3% level. In carrying out such an analysis using GLM-RM ANOVA (a form of multivariate analysis), certain assumptions are made: firstly, that the data is normally distributed and secondly, that the variances are homogenous. In order to check that the data is normally distributed, statistical tests such as the Kolmogorov-Smirnov or the Shapiro-Wilk are used. Normal (or between-group) ANOVA uses the Levene statistic to check for homogeneity of variances: however, in repeated measures ANOVA, Mauchly's test for sphericity is performed. Sphericity can be likened to the assumption of homogeneity of variances in between-group ANOVA, and is a more general assumption of compound symmetry and refers to the equality of variances of the differences between different treatment levels (Field, 2000).

In order to detect where or at what times significant changes take place, a further analysis (test of within subjects contrast) is done to detect the population average that is significantly different, i.e., which of the readings for any particular cephalometric reading at a particular time is significantly different from the others.

(e) Error analysis

A total of 3 cephalometric radiographs were obtained for each patient included in the study, one each at T_1, T_2, and T_3. A random sample of 15% of the total initial radiographs, 18 in all, representing 90 measurements, were retraced at least one week after the initial tracing to check for method and systematic errors and to determine the coefficient of reliability. Method errors were examined using the formula

$$\sqrt{\frac{\sum d^2}{2n}}$$

where d = difference between replicates and n is the number of replicates.

For the coefficient of reliability, the formula

$$1 - \frac{S_e^2}{S_t^2}$$

(Houston 1983) was used, where S_e^2 is the variance due to random error and S_t^2 is the total variance of the measurement.

Systematic error was checked using a student's t-test with $p = 0.05$ as the level of significance.

In order to test the accuracy of the repeated tracings, the method of Bland and Altman (1986) was used, where the mean of two readings was plotted against the difference.

These error measurements were also carried out on a random selection of 24 study casts.

CHAPTER 4: RESULTS

CHAPTER 4: RESULTS

Of the original 43 patients who had a cephalometric radiograph taken at T_1, enrolled in the study, 41 (24 females, 17 males) had a cephalometric radiograph taken at T_2, and 39 (23 females, 16 males) had one taken at T_3, which meant that a total of 4 patients radiographs (2 females and 2 males, 9.3%) were unavailable due to filing errors or where patients did not have their follow-up radiograph taken. The average period between T_1 and T_2 was 0.28 years (S.D. 0.12 yrs) and between T_2 and T_3 was 1.22 years (S.D. 0.35 years)

The average age for females at the start of treatment was 13.43 years (s.d. 0.8 years, range 11.7 – 16.9 years) while for males it was 13.34 years (s.d. 1.14 years, range 11.8 – 15.3 years). Using an independent samples t-test it was found that there was no statistically significant difference in age between the sexes at the start of treatment (Table 3). The average age for females in the control group was 12.58 years and for males was 12.42 years. The control group (McDonald, 1995) was, on average, one year younger than the test group (Table 4).

Study cast analysis is presented in tables 6a to 6f. The average pre-expansion intercanine width for females was 30.78 mm (s.d. 2.32 mm) and for males it was 32.16 mm (s.d. 3.53 mm). Intermolar width (measured to the mesiobuccal cusp tips of the upper first permanent molars on either side) was 46.38 mm (s.d. 4.1 mm) in females and 46.38 mm (s.d. 3.53 mm) in males. An independent samples t-test found that the intercanine and intermolar widths between the sexes did not differ significantly (Table 6a, Table 6b)

The average intercanine width in females post-expansion was 35.19 mm (s.d. 2.4 mm) and in males was 37.04 mm (s.d. 3.97 mm). Intermolar width post-expansion figures were 52.03 mm (s.d. 2.61 mm) for females and 52.58 mm (s.d. 3.32 mm) for males (Table 6c, Table 6d). Again, there was no significant statistical difference between males and females when these data were subjected to an independent samples t-test.

Average intercanine expansion was 5.02 mm for females (s.d. 2.17 mm) and 5.13 mm (s.d 1.68 mm) for males. Average intermolar expansion was 6.41 mm (s.d. 2.55 mm) for females and 6.47 mm (s.d. 1.66 mm) for males. No statistically significant inter-sex differences were found using an independent samples t-test for either of these two parameters (Table 6e, Table 6f).

The cephalometric variables from the control group used by McDonald (1995) were compared to the test data at T_1 and were found to be virtually identical (Table 7) using a one-sample t-test.

No significant differences for age or for any of the pretreatment cephalometric variables were found between the sexes, using an independent samples t-test, for the test group (tables 8 and 9), except for the angle OPT / CVT (difference 1.91°, $p = 0.005$). Despite this it was considered appropriate to combine the data from both males and females for the purposes of this study.

Cephalometric data errors were examined as described in the previous section. The results are presented in table 10. It was found that there was no significant systematic bias between the first and second readings using a student t-test. The coefficient of reliability (Houston, 1983) was of the order of 0.92-0.99. Standard error of the method for repeated tracings ranged between 0.41° – 0.93°. The accuracy of the tracings using Bland and Altman's method of plotting the mean of two readings against the difference is shown in the method errors section following table 10 and were found to be acceptable.

Tests of normality revealed that the data for all variables at the three different time periods was normally distributed (Kolmogorov-Smirnov and Shapiro-Wilk tests, table 11). The sphericity of the data was also tested using Mauchly's test and the assumption of sphericity was found not to be violated (Table 12).

As these assumptions for parametric data had been met, it was considered appropriate to use the General Linear Model – Repeated Measures Analysis of Variance (GLM-RM ANOVA) test on the data (Table 15). Utilising multiple t-tests (as is used for bivariate data) increases the risk of Type I errors (in the present study, with 3 sets of data for each cephalometric variable, to 14.3%).

The average values at each stage of the study, with standard deviations, standard errors, 95% confidence intervals, and ranges, for all six of the cephalometric variables is presented in tables 12 and 13.

The average pretreatment value for each cephalometric variable was found not to differ significantly from the control group used by McDonald (1995)(Table 7). The means for the cranio-cervical angles, OPT / NSL and CVT / NSL, were 98.54° (s.d. 7.7°) and 103.51° (s.d. 7.91°) respectively. The angle OPT / CVT, measuring cervical lordosis, averaged 4.97° (s.d. 2.27°) prior to treatment. NSL / VER, the craniovertical angle, gave a value of 95.64° (s.d. 7.19°) at T_1, while the cervico-horizontal angles (OPT / HOR and CVT / HOR) measured 87.08° (s.d. 7.04°) and 82.14 (s.d. 6.96°) respectively.

The actual changes that took place over the course of the study are given in Table 13 and shown graphically in Figures 13 to 18.

Craniocervical angles OPT / NSL and CVT / NSL

The angles OPT / NSL and CVT / NSL both increased very slightly between T_1 and the immediate post-expansion period, T_2, but then declined when measured at follow-up (T_3). OPT / NSL increased from 98.54° at T_1 to 98.98 at T_2, an increase of +0.44°, but then declined at T_3 to a value of 97.64°, which resulted in an ***overall change*** of –0.9° over the course of the study (Figure 13).

The angle CVT / NSL showed an increase from 103.51° to 104.37° before declining to 102.94° over the same period (Figure 14). The overall change (-0.57°) was less than that for the previous angulation, OPT / NSL.

Neither of these angulation changes were found to be statistically significant when GLM-RM ANOVA statistics was applied, with $p = 0.37$ for OPT/SNL and $p = 0.261$ for CVT / NSL (Table 15), and are clinically insignificant. No statistically significant difference in between-subjects contrasts was found for either angle; OPT / NSL3 when compared to the values obtained earlier was not significantly different (p = 0.283), and both OPT/SNL1 and OPT / NSL2 when compared gave a p-value = 0.477, again indicating no significant difference between them; CVT / NSL3 compared to the values obtained earlier showed no statistically significant difference (p = 0.401) and when CVT / NSL1 and CVT / NSL2 were compared they were found not to be significantly different (p = 0.241).

Cervical lordosis angle, OPT / CVT

This angle showed a pretreatment value of 4.97° (s.d. 2.27°) at the beginning of treatment (T_1), which increased to 5.4° (s.d 2.53°) at T_2, and remained unchanged at this value at T_3 (s.d. 2.68°) (Table 13 and Figure 15). The average change between the beginning and end of the study was an increase of +0.43°. This change was found not to be statistically significant with GLM-RM ANOVA (Table 16) with p = 0.399. The within-subjects contrast tests (Table 16) also showed no significant differences in the populations (p = 0.824 for OPT / CVT3 versus the earlier readings; and p = 0.177 for the comparison between OPT / CVT1 versus OPT / CVT2). These changes were neither clinically or statistically significant.

Cranio-vertical angle, NSL / VER

This angle gave an average value of 95.64° (s.d. 7.19°) at T_1, which declined slightly to 95.43° (s.d. 7.14°) at T_2 (immediately post-expansion). When examined at T_3 (one year after initial expansion) the angulation was found to be 92.5° (s.d. 6.69°)(Table 13 and Figure 16). Between T_1 and T_2 the change in angulation was a decrease of –0.21°, followed by a further decline of –2.93° at T_3, giving an overall reduction for NSL / VER of –3.14° over the course of the study (Table 14). This change was found to be statistically significant using GLM-RM ANOVA (Table 15) with $p = 0.005$. When the within-subjects contrasts test was performed (Table 16), the population NSL / VER3 was found to be statistically significantly different to both NSL / VER1 and NSL / VER2 ($p = 0.001$). When NSL / VER1 and NSL / VER2 were compared using this test, no statistically significant difference was found between these two populations ($p = 0.667$). The overall change is statistically significant and is likely to be clinically significant.

Cervico-horizontal angles, OPT / HOR and CVT / HOR

OPT / HOR showed an average value of 87.08° (s.d. 7.04°) prior to expansion at T_1 (Table 13). Post-expansion (T_2) this value changed to 86.55° (s.d. 7.64°) and one year post-expansion (T_3) the average was 84.95° (s.d. 6.51°). The average change in angulation of OPT / HOR between T_1 and T_2 was – 0.53°, and between T_2 and T_3 the change was –1.6°, with an overall change of –2.13° during the course of the study (Table 14 and Figure 17). This change was found to be statistically significant ($p = 0.048$, Table 15). It was also found that OPT / HOR3 was significantly different from OPT / HOR1 and OPT / HOR2 using the within-subjects contrasts ($p = 0.014$), and that OPT / HOR1 and OPT / HOR2 did not show significant difference using this test ($p = 0.368$).

CVT / HOR showed an average pretreatment value of 82.14° (s.d. 6.96°) prior to expansion, with a value at T_2 of 81.16° (s.d. 6.82°) and at T_3 of 79.59° (s.d. 5.71°)

(Table 13). The change between T_1 and T_2 was –0.98°, between T_2 and T_3 was -1.57° (Table 14). The overall change between T_1 and T_3 was –2.55°, which was found to be statistically significant using GLM-RM ANOVA ($p = 0.025$). Within subjects contrast showed a similar pattern as found for NSL / VER and OPT / HOR, in that CVT / HOR3 was found to be statistically significantly different from CVT / HOR1 and CVT / HOR2 ($p = 0.008$) and that CVT / HOR1 and CVT / HOR2 were not statistically significantly different ($p = 0.14$). The overall changes in CVT / HOR can be seen in Figure 18.

Overall, these two angular changes are statistically significant. Their small change, however, suggests that they may not be very clinically significant; but with future growth and development, this may change in the future.

TABLE 4: GENDER AND AGE ANALYSIS, TEST GROUP

	Numbers	**Mean age (years)**	**Range (years)**	**St. dev.**	**Independent t-test for age difference between sexes**
Females	25	13.43	11.7 – 16.9	0.8 years	t = 0.226 sig (2 tailed) = 0.882 (n.s.)
Males	18	13.34	11.8 – 15.3	1.14 years	
Total	43				

TABLE 5: GENDER AND AGE ANALYSIS, CONTROL GROUP (McDonald, 1995)

	Numbers	Mean age (years)	St. dev
Females	24	12.58	1.39 years
Males	12	12.42	1.20 years
Total	36		

TABLE 6a: Intermolar and intercanine widths, pretreatment

	Sex	n	Mean	St. dev.	St. Error of mean
Intercanine width	Females	17	30.78	2.32	0.56
	Males	11	32.16	3.53	1.06
Intermolar width	Females	17	46.38	4.1	0.99
	Males	11	46.38	3.53	1.06

Table 6b: Comparison of intercanine and intermolar widths between females and males using independent samples t-test: pretreatment

		Levene' test for equality of means	**t-test for equality of means**							
		F	**sig**	**t**	**df**	**Sig (2-tailed)**	**Mean difference**	**St. error of difference**	**95% confidence interval of difference**	
									Lower	Upper
Intercanine width	Equal variances assumed	4.725	0.039	-1.253	26	0.222	-1.38	1.102	-3.645	0.885
	Equal variances not assumed			-1.146	15.62	0.269	-1.38	1.204	-3.937	1.177
Intermolar width	Equal variance assumed	0.249	0.622	0.001	26	0.999	0.0018	1.505	-3.092	3.095
	Equal variance not assumed			0.001	23.775	0.999	0.0018	1.456	-3.004	3.008

TABLE 6c: Intercanine and intermolar widths post-expansion

	Sex	n	Mean (mm)	St. dev.	St. error of mean
Intercanine width	Females	14	35.19	2.4	0.64
	Males	11	37.04	3.97	1.101
Intermolar width	Females	14	52.03	2.61	0.70
	Males	11	52,58	3.32	0.92

TABLE 6d: Comparison of intercanine and intermolar widths between males and females using an independent samples t-test: post-expansion

		Levene's test for equality of variances	t-test for equality of means						
		F	**Sig**	**t**	**df**	**Sig (2-tailed)**	**Mean difference**	**St. error of difference**	**95% confidence interval of difference**	
									Lower	Upper
Intercanine width	Equal variances assumed	5.159	0.32	-1.479	25	0.152	-1.852	1.252	-4.43	0.727
	Equal variances not assumed			-1.453	19.461	0.162	-1.852	1.275	-4.52	0.812
Intermolar width	Equal variances assumed	0.493	0.489	-0.486	25	0.631	-0.557	1.145	-2.91	1.801
	Equal variances not assumed			-0.482	22.773	0.634	-0.557	1.155	-2.95	1.834

TABLE 6e: Mean intercanine and intermolar expansion achieved

	Sex	n	Mean (mm)	Std. deviation	St. error of mean
Intercanine expansion	Females	14	5.02	2.166	0.579
	Males	11	5.13	1.68	0.506
Intermolar expansion	Females	14	6.41	2.55	0.683
	Males	11	6.47	1.66	0.501

TABLE 6f: Comparison of mean intercanine and intermolar expansion achieved between between females and males using an independent samples t-test

		Levene's test for equality of variances	**t-test for equality of means**							
		F	**Sig**	**t**	**df**	**Sig (2-tailed)**	**Mean difference**	**St. error of difference**	**95% confidence interval of the difference**	
									Lower	Upper
Intercanine width increase	Equal variances assumed	1.492	0.234	-0.137	23	0.892	-0.1091	0.793	-1.75	1.532
	Equal variances not assumed			-0.142	23	0.888	-0.1091	0.769	-1.699	1.482
Intermolar width increase	Equal variances assumed	2.226	0.149	-0.06	23	0.952	-0.0538	0.891	-1.897	1.79
	Equal variances not assumed			-0.064	22.355	0.950	-0.0538	0.847	-1.809	1.701

TABLE 7

COMPARISON OF CRANIOCERVICAL ANGULATIONS IN THE CONTROL GROUP (McDonald, 1995) AND TEST GROUP, USING A ONE-SAMPLE T-TEST

	Control Sample (McDonald, 1995)						Test sample before treatment									
	No	**Mean**	**Min**	**Max**	**S.D.**		**No**	**Mean**	**Min**	**Max**	**S.D.**		**Diff**	**t**	**p**	**Sig**
OPT / NSL	36	98.85	80.8	115.9	8.91		43	98.54	82.0	118.0	7.7		0.31	-0.263	0.794	n.s.
CVT / NSL	36	103.86	86.3	123.5	8.83		43	103.51	88.5	123.5	7.9		0.35	-0.287	0.775	n.s.
OPT / CVT	36	5.01	-3.77	13.79	4.17		43	4.97	1.0	8.5	2.27		0.04	-0.110	0.913	n.s.
NSL / VER	36	95.34	82.6	110.0	6.89		43	95.63	76.5	114.0	7.19		-0.29	0.269	0.789	n.s.
OPT / HOR	36	86.49	68.5	102.9	8.17		43	87.08	68.5	99.0	7.04		-0.59	0.553	0.583	n.s.
CVT / HOR	36	81.47	64.7	95.4	7.62		43	82.14	67.3	95.0	6.96		-0.67	0.635	0.529	n.s.

TABLE 8: PRETREATMENT CRANIOCERVICAL ANGULATIONS FOR MALES AND FEMALES

	Sex	N	Mean	St. Deviation	St Error of mean
OPT / NSL	**Female**	25	98.14	7.8	1.56
	Male	18	99.1	7.74	1.82
CVT / NSL	**Female**	25	103.9	7.62	1.52
	Male	18	102.96	8.47	1.99
OPT / CVT	**Female**	25	5.77	2.36	0.47
	Male	18	3.86	1.62	0.38
NSL / VER	**Female**	25	94.46	7.1	1.42
	Male	18	97.27	7.2	1.69
OPT / HOR	**Female**	25	86.28	7.12	1.42
	Male	18	88.19	6.98	1.64
CVT / HOR	**Female**	25	80.56	6.46	1.29
	Male	18	84.34	7.21	1.69

TABLE 9: Pretreatment craniocervical angulations for males and females compared using an independent samples t-test

		Levene's test for equality of variances	t-test for equality of means							
		F	Sig	t	df	Sig (2-tailed)	Mean difference	St. error of difference	95% confidence interval of difference	
									Lower	Upper
OPT / NSL1	Equal variances assumed	0.148	0.703 n.s.	-0.399	41	0.692	-0.96	2.404	-5.814	3.894
	Equal variances not assumed			-0.4	36.963	0.691	-0.96	2.4	-5.824	3.903
CVT / NSL1	Equal variances assumed	0.000	0.990 n.s.	0.385	41	0.702	0.951	2.469	-4.035	5.937
	Equal variances not assumed			0.378	34.3	0.707	0.951	2.513	-4.155	6.056
OPT / CVT1	Equal variances assumed	2.547	0.118 n.s	2.966	41	0.005*	1.911	0.644	0.61	3.211
	Equal variances not assumed			3.149	40.944	0.005*	1.911	0.607	0.685	3.137
NSL / VER1	Equal variances assumed	0.012	0.914 n.s.	-1.271	41	0.211	-2.81	2.208	-7.265	1.652
	Equal variances not assumed			-1.268	36.48	0.213	-2.81	2.213	-7.292	1.679
OPT / HOR1	Equal variances assumed	0.001	0.980 n.s.	-0.875	41	0.387	-1.91	2.183	-6.319	2.499
	Equal variances not assumed			-0.878	37.202	0.386	-1.91	2.176	-6.319	2.498
CVT / HOR1	Equal variances assumed	0.134	0.716 n.s.	-1.801	41	0.079	-3.775	2.096	-8.008	0.458
	Equal variances not assumed			-1.768	34.224	0.086	-3.775	2.135	-8.113	0.563

TABLE 10: METHOD ERRORS: Summary for all variables

Systemic bias tested using t-tests; coefficient of reliability; standard error of the method

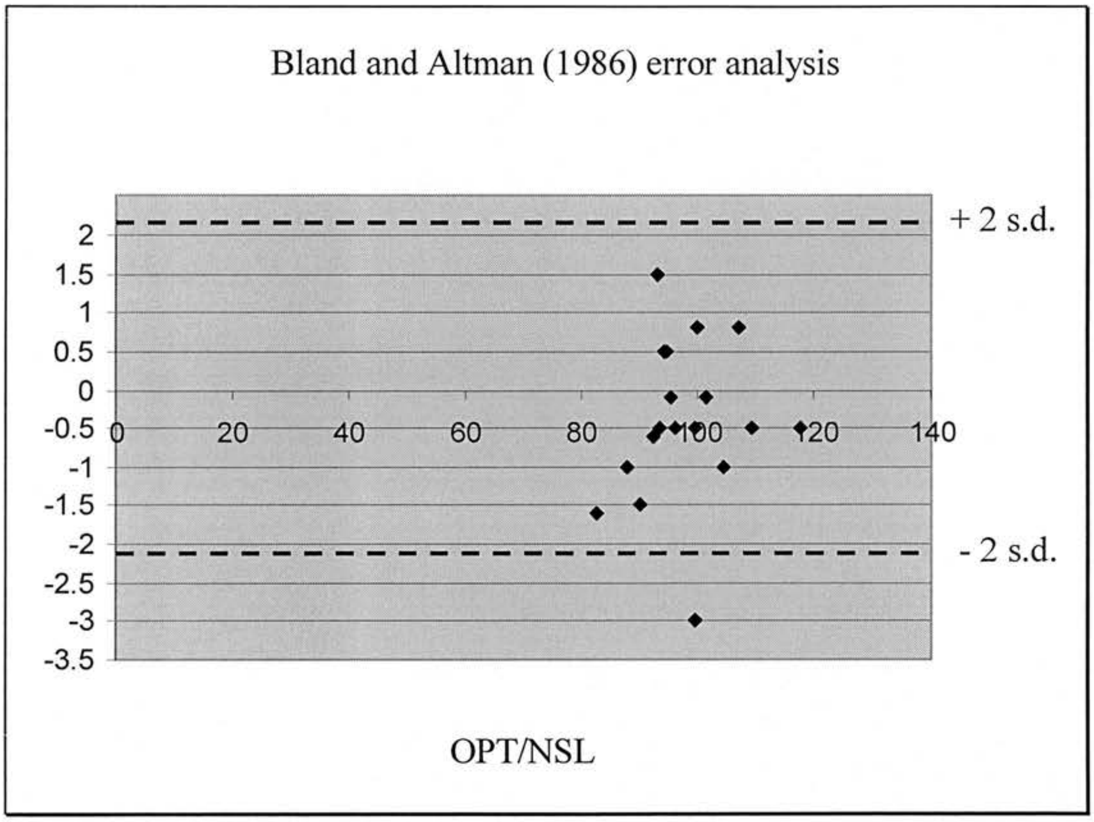
	t	p	sig	Coefficient of reliability	Standard error of the method (º)
OPT / NSL	-0.147	0.884	n.s.	0.98	0.77º
CVT / NSL	-0.032	0.975	n.s.	0.99	0.71º
OPT / CVT	0.341	0.367	n.s.	0.92	0.59º
NSL / VER	-0.011	0.992	n.s.	0.99	0.53º
OPT / HOR	0.162	0.872	n.s.	0.98	0.93º
CVT / HOR	0.076	0.939	n.s.	0.99	0.41º
Study cast dimensions	-0.268	0.791	n.s.	0.99	0.17 mm

Method errors were assessed by retracing a random selection of 15% of the total number of cephalometric radiographs (or 18 in total)

TABLE 10a: METHOD ERROR ANALYSIS FOR OPT / NSL

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = -0.147, p = 0.884: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.98
- Standard method error: 0.77°
- Accuracy:

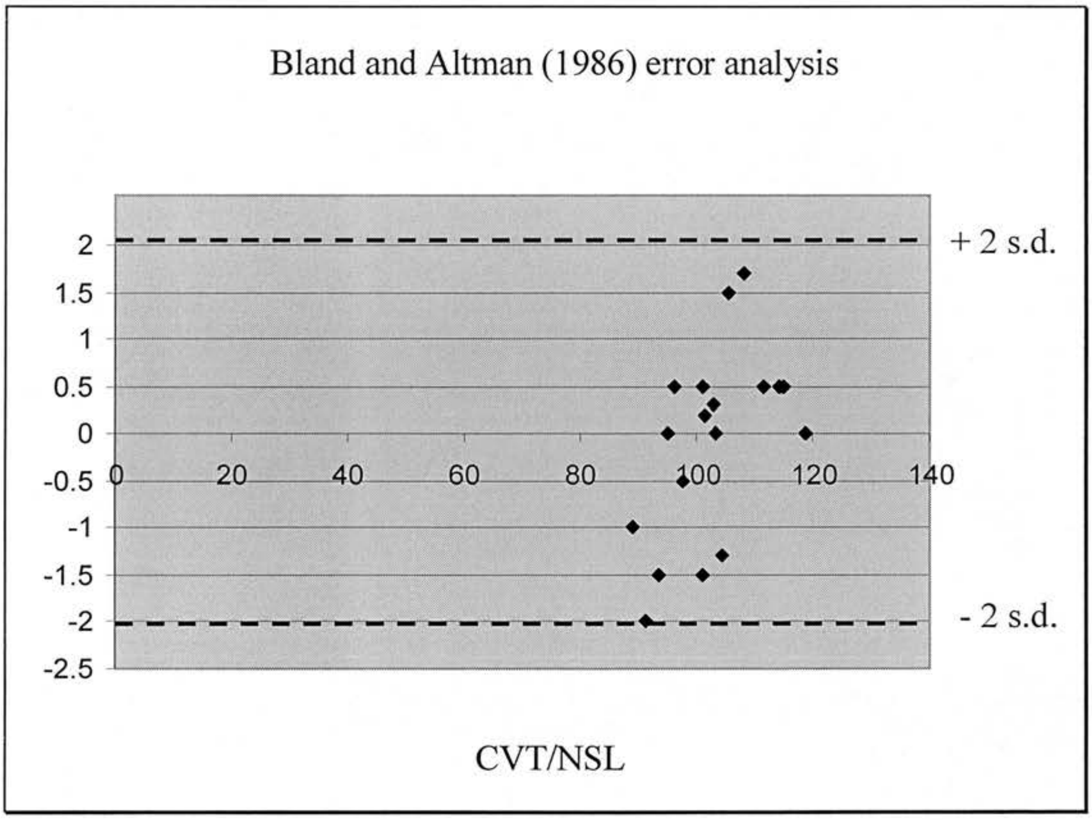


Comment: one point outside the 2 s.d. limits

TABLE 10b: METHOD ERROR ANALYSIS FOR CVT / NSL

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = -0.032, p = 0.975: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.99
- Standard method error: 0.71°
- Reproducibility:

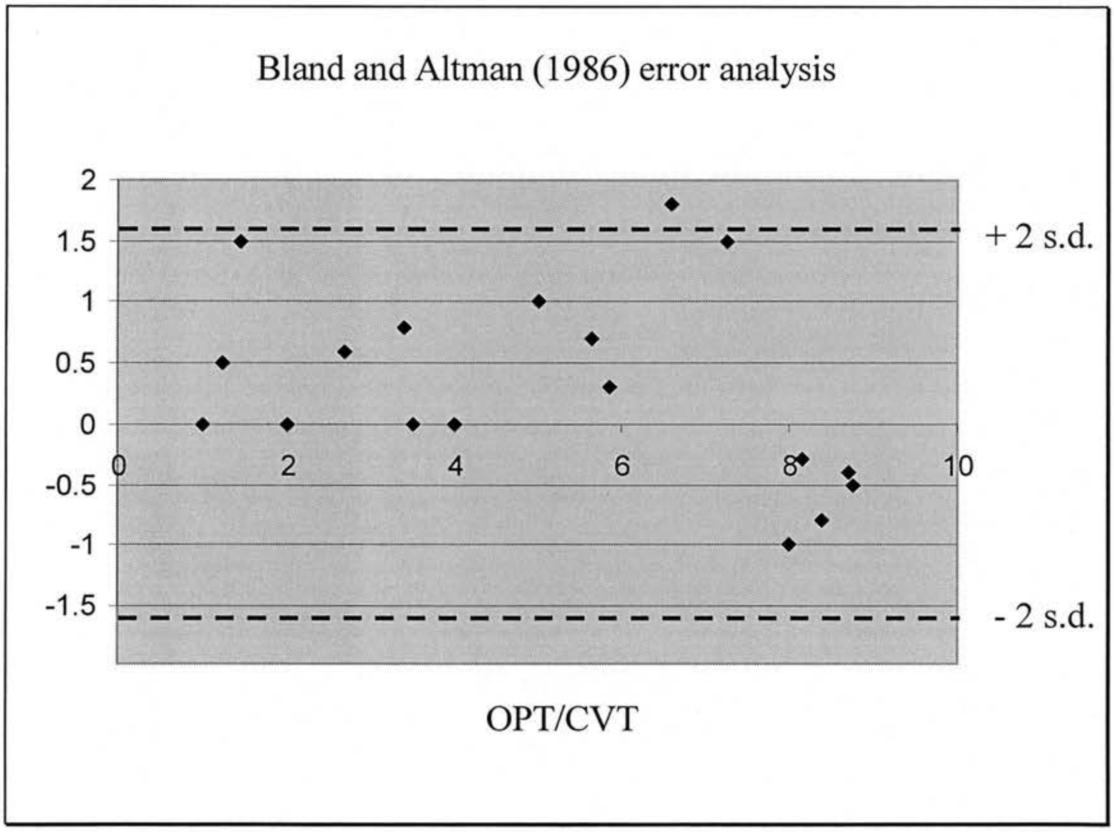


Comment: no points outside the 2 s.d. limits

TABLE 10c: METHOD ERROR ANALYSIS FOR OPT / CVT

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = 0.341, p = 0.367: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.92
- Standard method error: 0.59°
- Reproducibility:

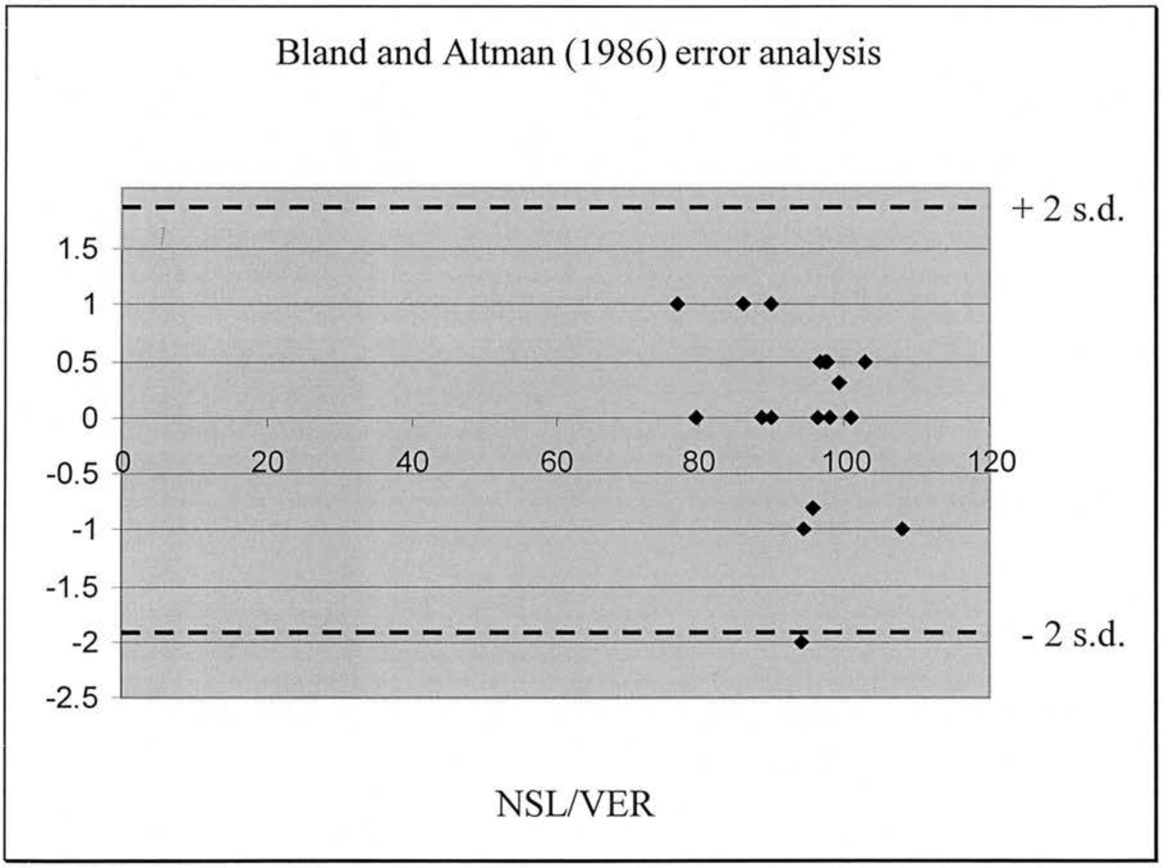


Comment: one point outside the 2 s.d. limits

TABLE 10d: METHOD ERROR ANALYSIS FOR NSL / VER

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = -0.011, p = 0.992: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.99
- Standard method error: 0.53°
- Reproducibility:

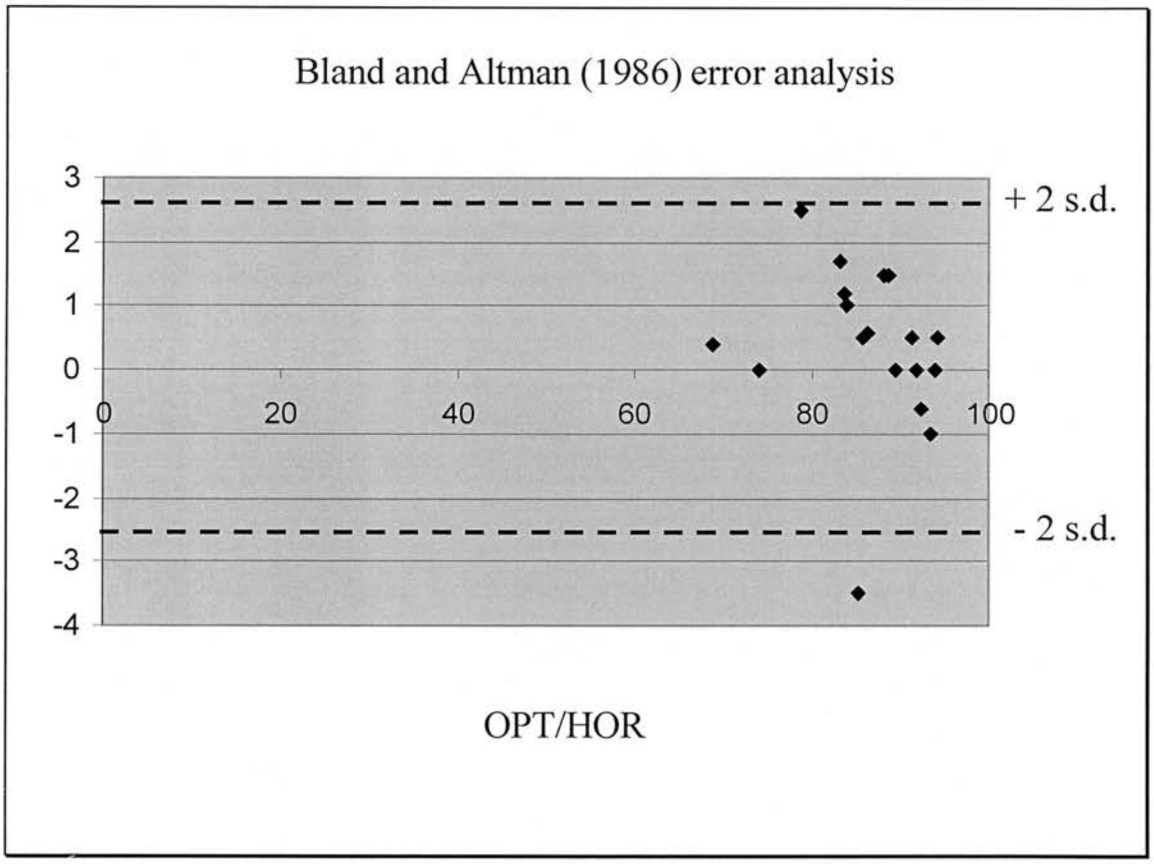


Comment: one point outside 2 s.d. limits

TABLE 10e: METHOD ERROR ANALYSIS FOR OPT / HOR

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = 0.162, p = 0.872: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.98
- Standard method error: 0.93°
- Reproducibility:

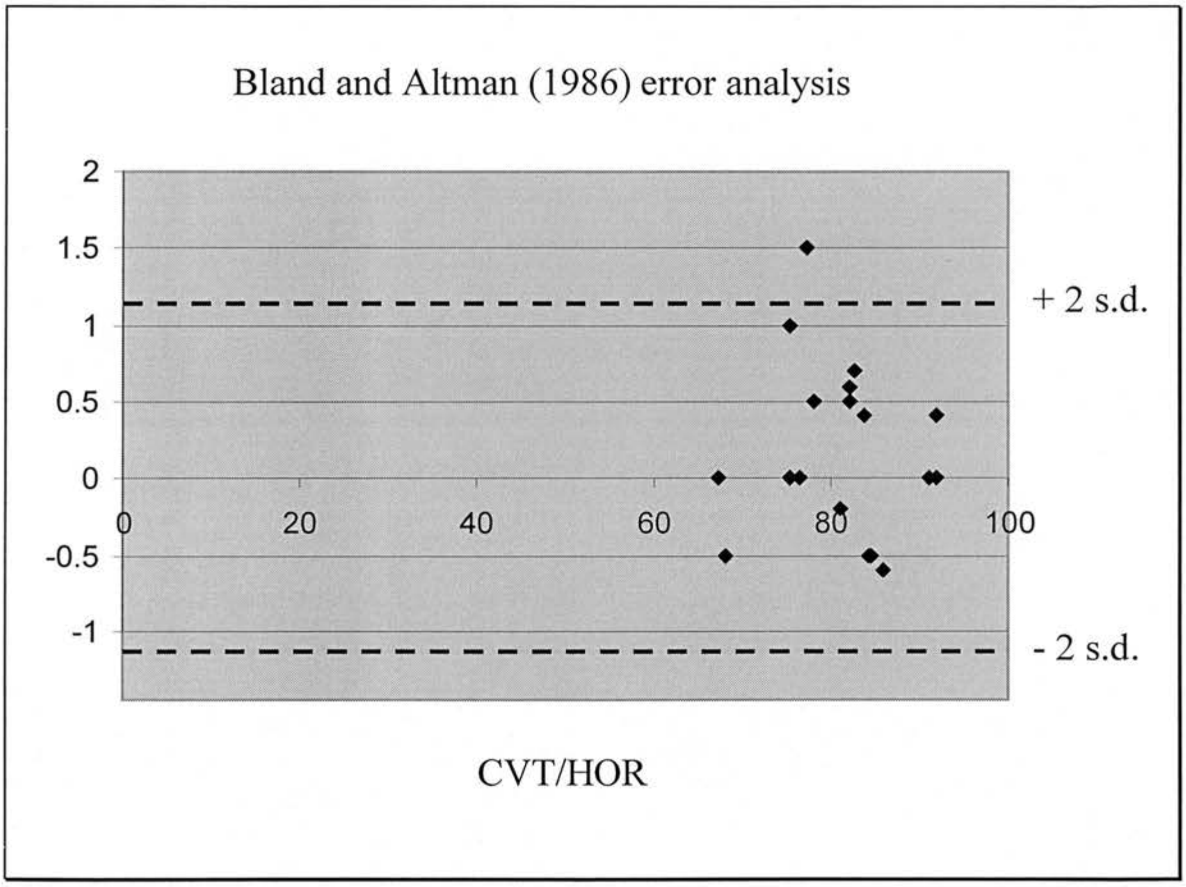


Comment: one point outside 2 s.d. limits

TABLE 10f: METHOD ERROR ANALYSIS FOR CVT / HOR

Method errors were assessed by retracing a random selection of 15% of the total cephalometric radiographs (18 in total)

- t-test to detect systematic bias: t = 0.076, p = 0.939: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.99
- Standard method error: 0.41°
- Reproducibility:

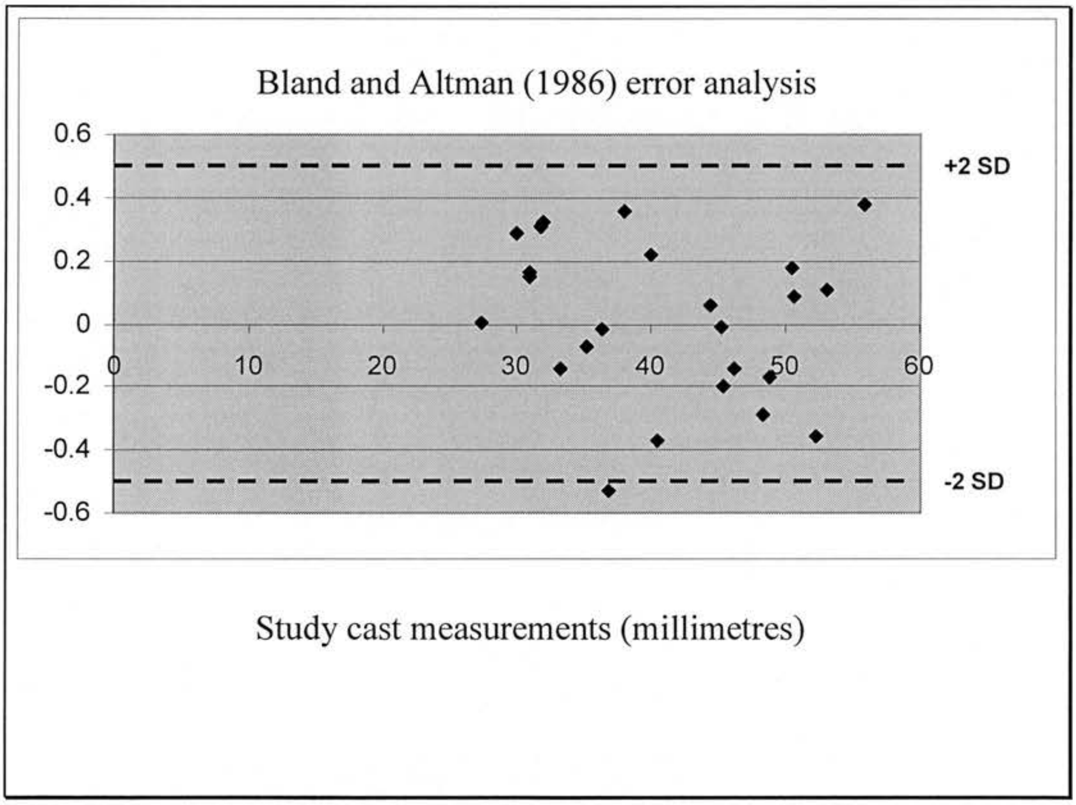


Comment: one point outside 2 s.d. limits

TABLE 10g: METHOD ERROR ANALYSIS FOR STUDY CAST MEASUREMENTS

Method errors were assessed by re-examining a random selection of 24 study casts at least a fortnight after the first assessment

- t-test to detect systematic bias: t = -0.268, p = 0.791: no systematic bias detected
- Coefficient of reliability (Houston, 1983): 0.99
- Standard method error: 0.17 mm
- Accuracy:



Comment: one point outside the 2 S.D. limits

TABLE 11: Tests for normality of data: Kolmogorov-Smirnov and Shapiro-Wilk

	Kolmogorov- Smirnov statistic				Shapiro-Wilk statistic			
	Statistic	df	p	Sig	Statistic	df	p	Sig
OPT / NSL1	0.121	39	0.16	n.s.	0.963	39	0.233	n.s.
CVT / NSL1	0.124	39	0.134	n.s.	0.968	39	0.321	n.s.
OPT / CVT1	0.097	39	0.2	n.s	0.949	39	0.077	n.s
NSL / VER1	0.117	39	0.194	n.s	0.98	39	0.699	n.s
OPT / HOR1	0.103	39	0.2	n.s	0.966	39	0.278	n.s
CVTHOR1	0.1	39	0.2	n.s.	0.968	39	0.317	n.s.
OPT / NSL2	0.092	39	0.2	n.s	0.952	39	0.094	n.s
CVT / NSL2	0.069	39	0.2	n.s.	0.988	39	0.94	n.s.
OPT / CVT2	0.145	39	0.37	n.s.	0.954	39	0.108	n.s.
NSL / VER2	0.083	39	0.2	n.s.	0.98	39	0.716	n.s.
OPT / HOR2	0.087	39	0.2	n.s.	0.966	39	0.271	n.s.
CVT / HOR2	0.072	39	0.2	n.s.	0.988	39	0.945	n.s.
OPT / NSL3	0.071	39	0.2	n.s.	0.98	39	0.690	n.s.
CVT / NSL3	0.097	39	0.2	n.s.	0.984	39	0.847	n.s.
OPT / CVT3	0.072	39	0.2	n.s.	0.985	39	0.869	n.s.
NSL / VER3	0.084	39	0.2	n.s.	0.965	39	0.269	n.s.
OPT / HOR3	0.114	39	0.2	n.s.	0.973	39	0.471	n.s.
CVT / HOR3	0.085	39	0.2	n.s.	0.957	39	0.147	n.s.

Table 12: Mauchly's test for sphericity of data

Within-subject effects	**Mauchly's W**	**Approx chi-square**	**df**	**p**	**sig**
OPT / NSL	0.958	1.569	2	0.456	n.s.
CVT / NSL	0.930	2.674	2	0.263	n.s.
OPT / CVT	0.990	0.389	2	0.823	n.s.
NSL / VER	0.951	1.884	2	0.398	n.s.
OPT / HOR	0.935	2.490	2	0.288	n.s.
CVT / HOR	0.892	4.220	2	0.121	n.s.

TABLE 13: Craniocervical angles at the different time points in the study, T_1, T_2 and T_3

	Time	n	Mean	St. dev.	St. Error	95% confidence interval for mean		Minimum	Maximum
						Lower bound	Upper bound		
OPT / NSL	1	43	98.54	7.7	1.17	96.17	100.91	82.0	118.0
	2	41	98.98	7.81	1.22	96.52	101.44	83.5	123.0
	3	39	97.54	7.69	1.23	95.05	100.03	77.0	115.0
CVT / NSL	1	43	103.51	7.91	1.21	101.08	105.95	88.5	123.5
	2	41	104.37	7.84	1.23	101.9	106.85	87.5	125.0
	3	39	102.94	7.68	1.23	100.45	105.45	85.0	120.0
OPT / CVT	1	43	4.97	2.27	0.35	4.27	5.67	1.00	8.5
	2	41	5.40	2.53	0.4	4.60	6.20	0.50	10.5
	3	39	5.40	2.68	0.43	4.54	6.27	-0.50	13.0
NSL / VER	1	43	95.64	7.19	1.1	93.42	97.85	76.5	114.0
	2	41	95.43	7.14	1.12	93.18	97.68	82.6	112.5
	3	39	92.50	6.69	1.07	90.33	94.67	80.5	104.0
OPT / HOR	1	43	87.08	7.04	1.07	84.92	89.25	68.5	99.0
	2	41	86.55	7.64	1.19	84.14	88.96	64.5	99.0
	3	39	84.95	6.51	1.04	82.84	87.06	71.0	99.0
CVT / HOR	1	43	82.14	6.96	1.06	80.0	84.29	67.3	95.0
	2	41	81.16	6.82	1.07	79.01	83.31	63.0	95.0
	3	39	79.59	5.71	0.91	77.74	81.43	67.5	88.0

TABLE 14: Changes in craniocervical angles during the study

	T_1 (Pretreatment)	T_2 (Immediately post-expansion)	T_3 (One year post-expansion)	Change between T_2 and T_1	Change between T_3 and T_2	Change between T_3 and T_1
OPT / NSL	98.54	98.98	97.64	0.44	-1.44	-0.9
CVT / NSL	103.51	104.37	102.94	0.86	-1.43	-0.57
OPT / CVT (combined)	4.97	5.4	5.4	0.43	0.0	0.43
NSL / VER	95.64	95.43	92.5	-0.21	-2.93	-3.14
OPT / HOR	87.08	86.55	84.95	-0.53	-1.6	-2.13
CVT / HOR	82.14	81.16	79.59	-0.98	-1.57	-2.55

TABLE 15: ANOVA (General Linear Model Repeated Measures) for all cephalometric variables

	Value range	**F**	**Hypothesis df**	**Error df**	**p**	**Sig**
	(Pillai's trace, Wilk's Lambda, Hotelling's Trace, Roy's Largest Root)					
OPT / NSL	0.052 – 0.948	1.021	2	37	0.37	n.s.
CVT / NSL	0.070 – 0.930	1.394	2	37	0.261	n.s.
OPT / CVT	0.047 – 0.953	0.942	2	37	0.399	n.s.
NSL / VER	0.246 – 0.754	6.039	2	37	0.005	**
OPT / HOR	0.151 – 0.849	3.302	2	37	0.048	*
CVT / HOR	0.181 – 0.819	4.084	2	37	0.025	*

* = $p \leq 0.05$,
** = $p \leq 0.01$

Table 16: tests of within-subjects contrasts

Source	**Time**	**Type III sum of squares**	**df**	**Mean square**	**F**	**P**	**Sig**
Time	**OPT / NSL3 v earlier**	22.09	1	22.09	1.19	0.283	n.s
	OPT / NSL1 v. OPT / NSL2	11.63	1	11.63	0.52	0.477	n.s
	CVT / NSL3 v. earlier	14.46	1	14.46	0.72	0.401	n.s
	CVT / NSL1 v. CVT / NSL2	34.91	1	34.91	1.42	0.241	n.s
	OPT / CVT3 v. earlier	0.138	1	0.138	0.05	0.824	n.s
	OPT / CVT1 v. OPT / CVT2	5.7	1	5.7	1.89	0.177	n.s
	NSL / VER3 v. earlier	297.14	1	297.14	12.32	0.001***	***
	NSL / VER1 v. NSL / VER2	5.1	1	5.1	0.19	0.667	n.s.
	OPT / HOR3 v. earlier	163.9	1	163.9	6.71	0.014 *	*
	OPT / HOR1 v. OPT / HOR2	25.44	1	25.44	0.83	0.368	n.s.
	CVT / HOR3 v. earlier	187.22	1	187.22	7.97	0.008**	**
	CVT / HOR1 v. CVT / HOR2	58.83	1	58.83	2.27	0.14	n.s.

* = $p \leq 0.05$ ** = $p \leq 0.01$ *** = $p \leq 0.001$

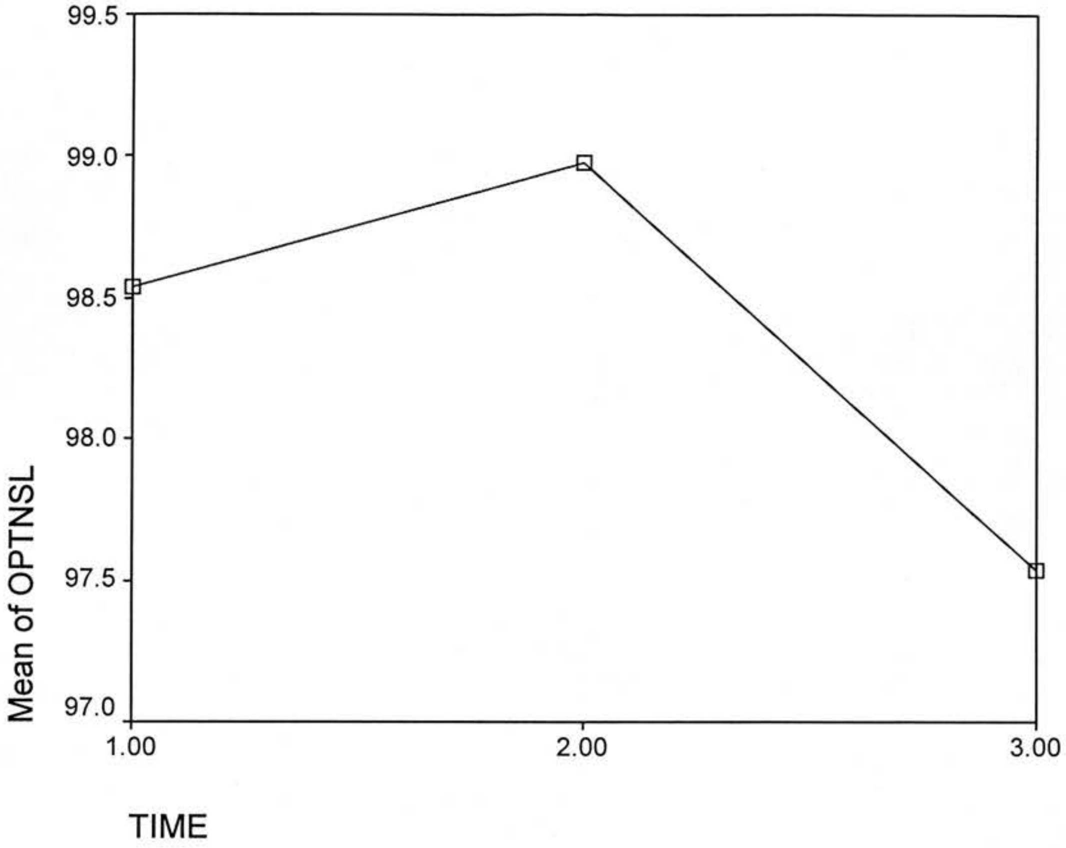
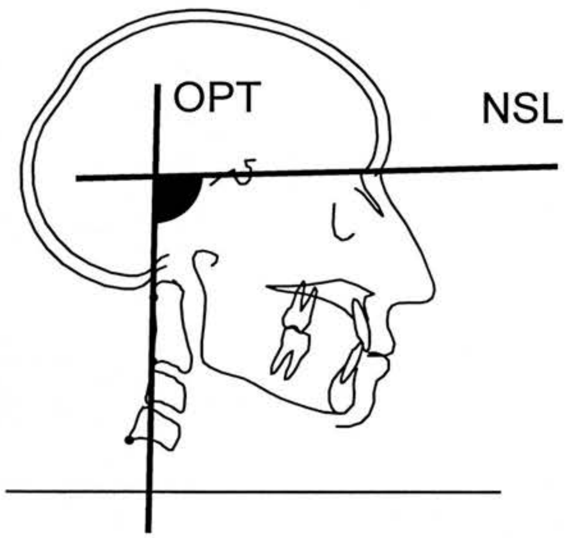


Figure 13: changes in angle OPT / NSL over the course of the study



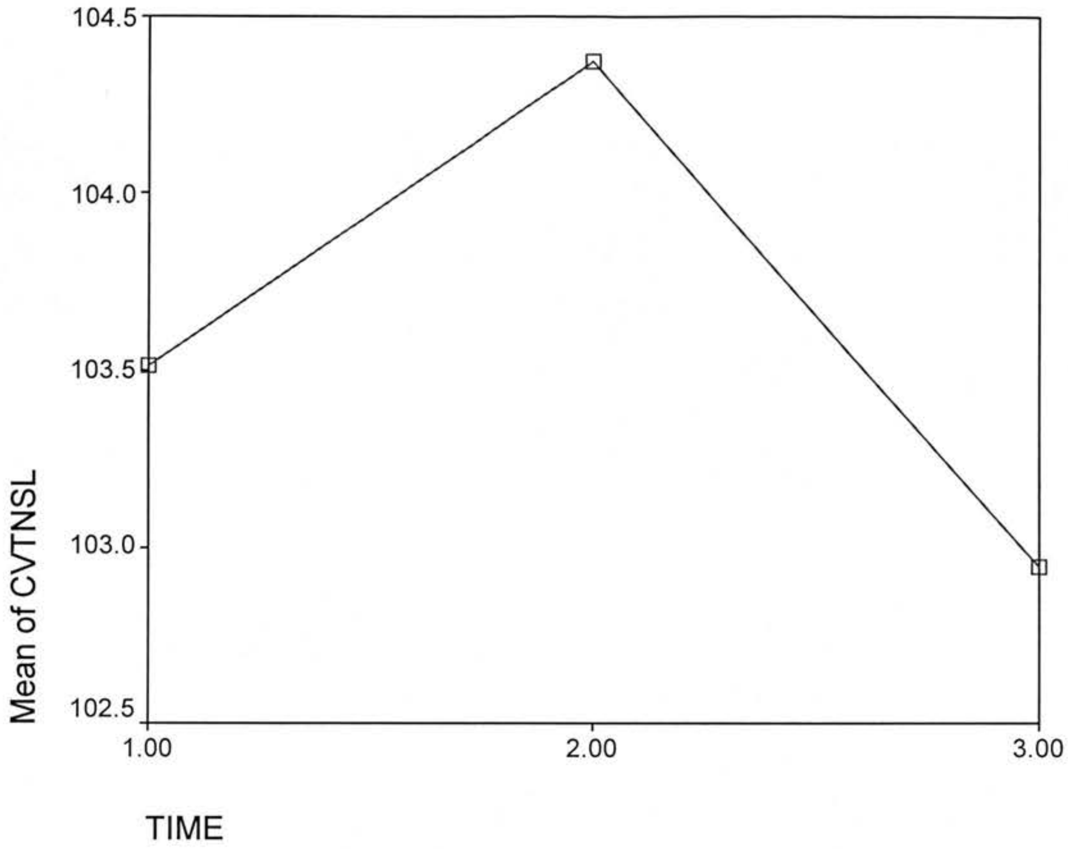
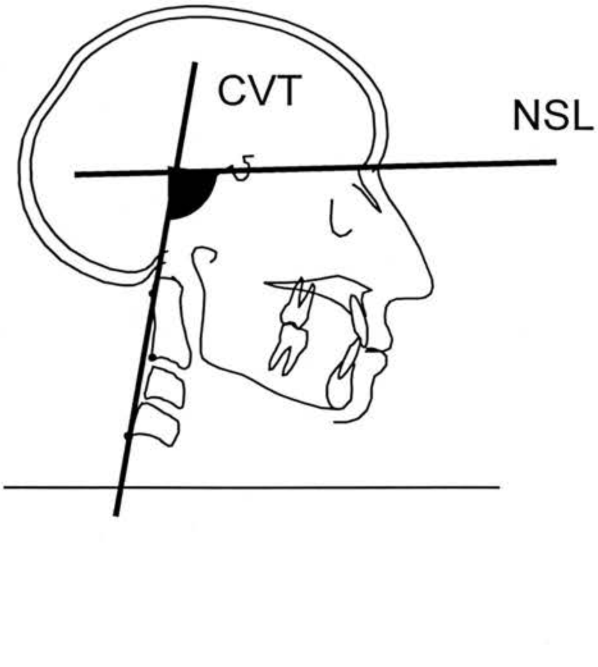


Figure 14: changes in angle CVT / NSL over the course of the study



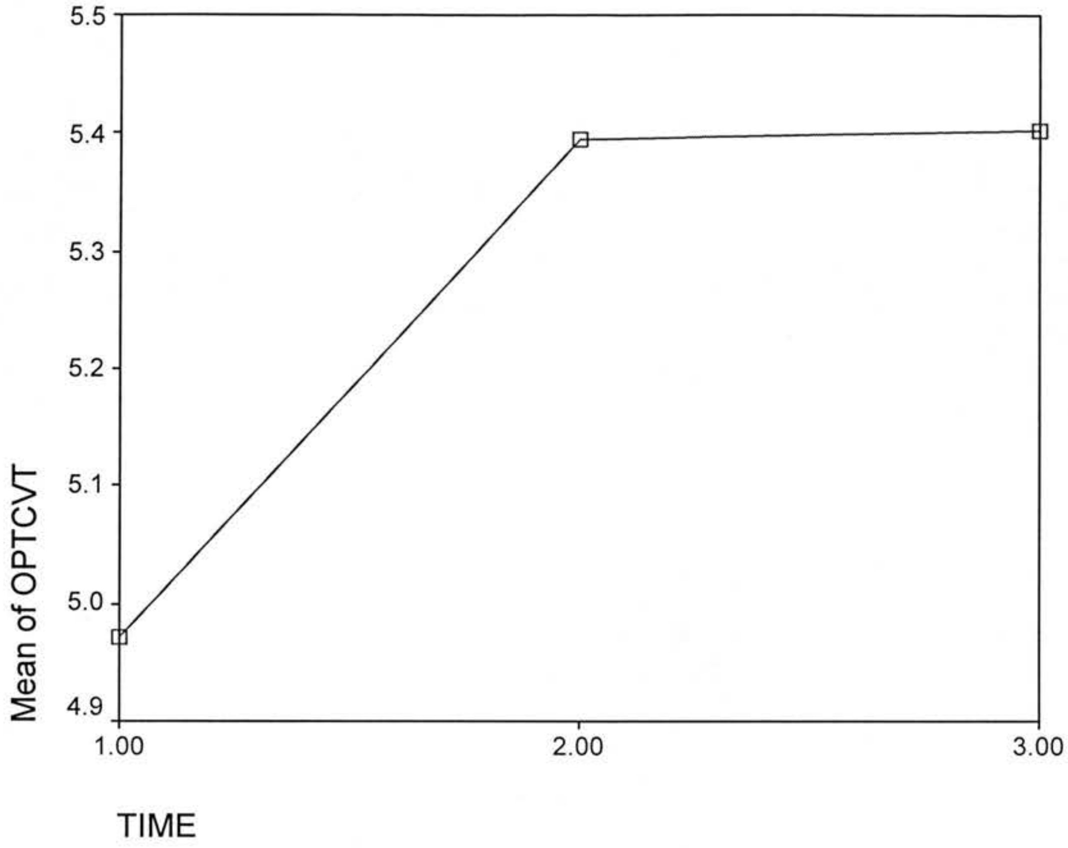
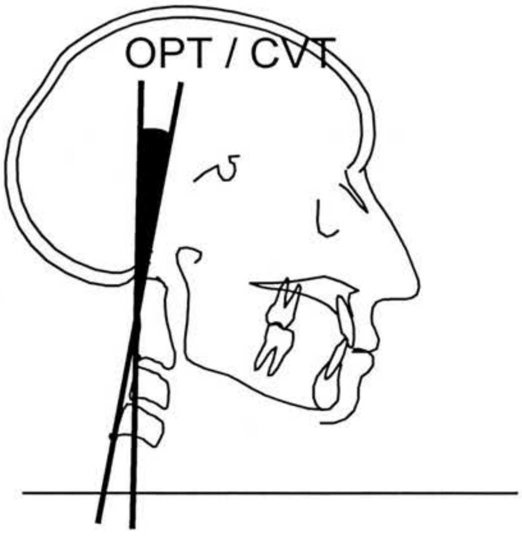


Figure 15: changes in angle OPT / CVT over the course of the study



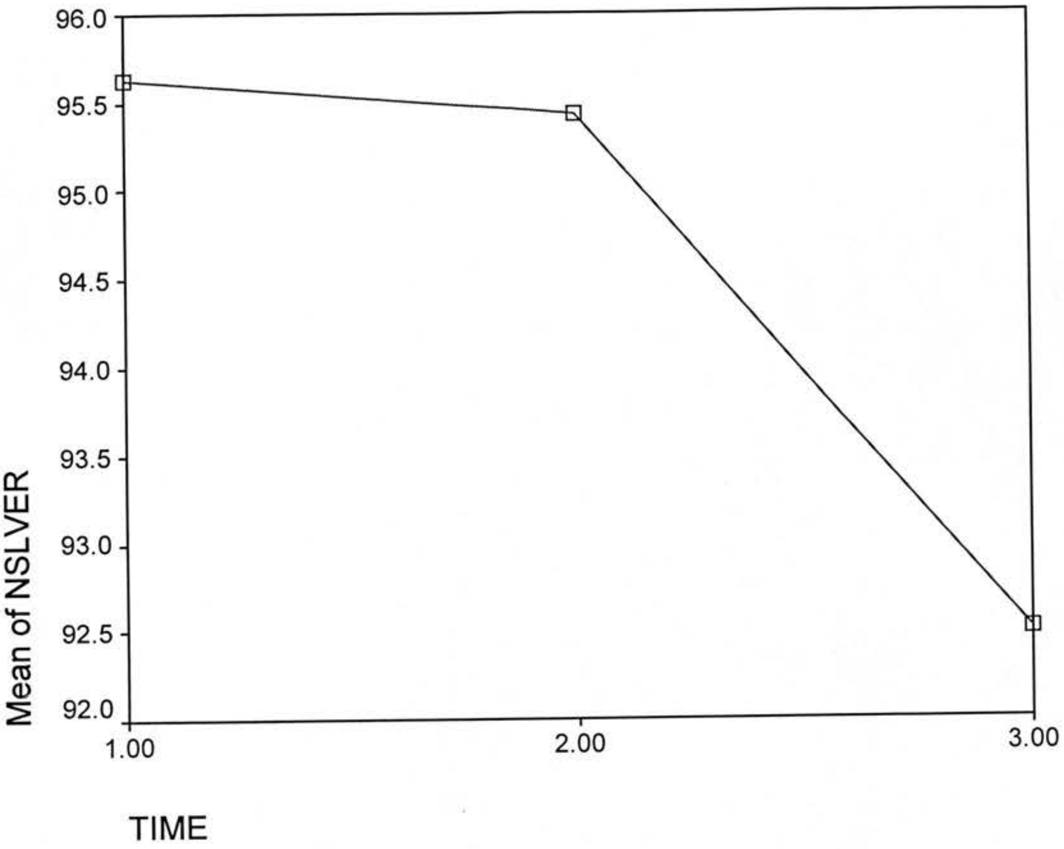
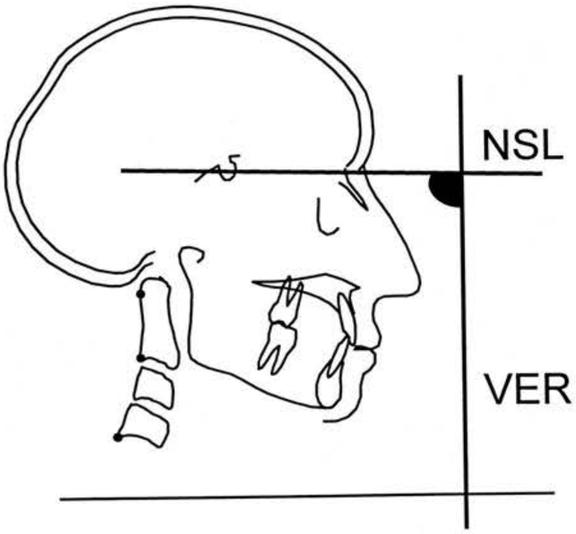


Figure 16: changes in angle NSL / VER over the course of the study



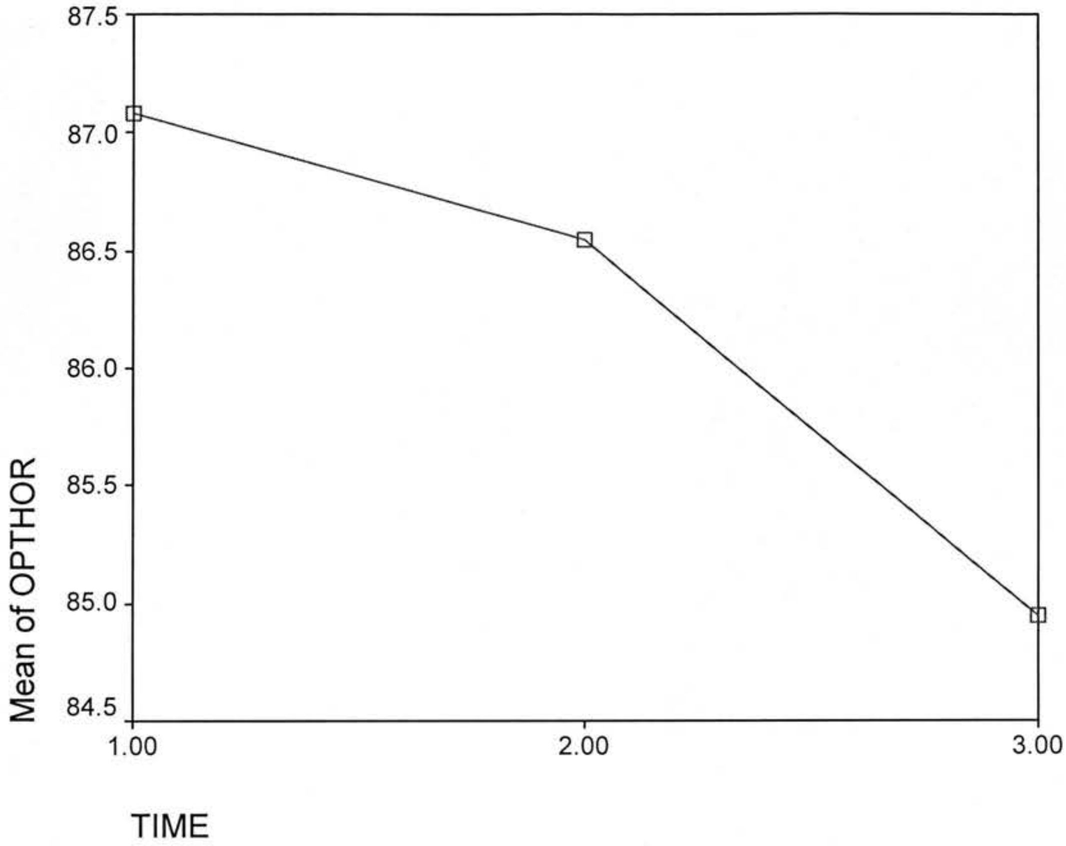
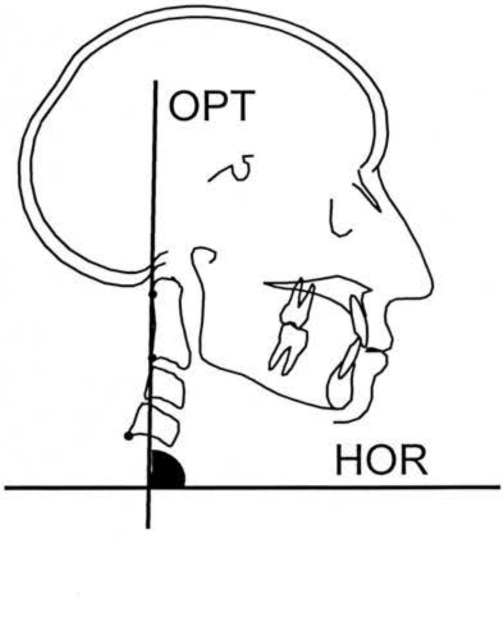


Figure 17: changes in angle OPT / HOR over the course of the study



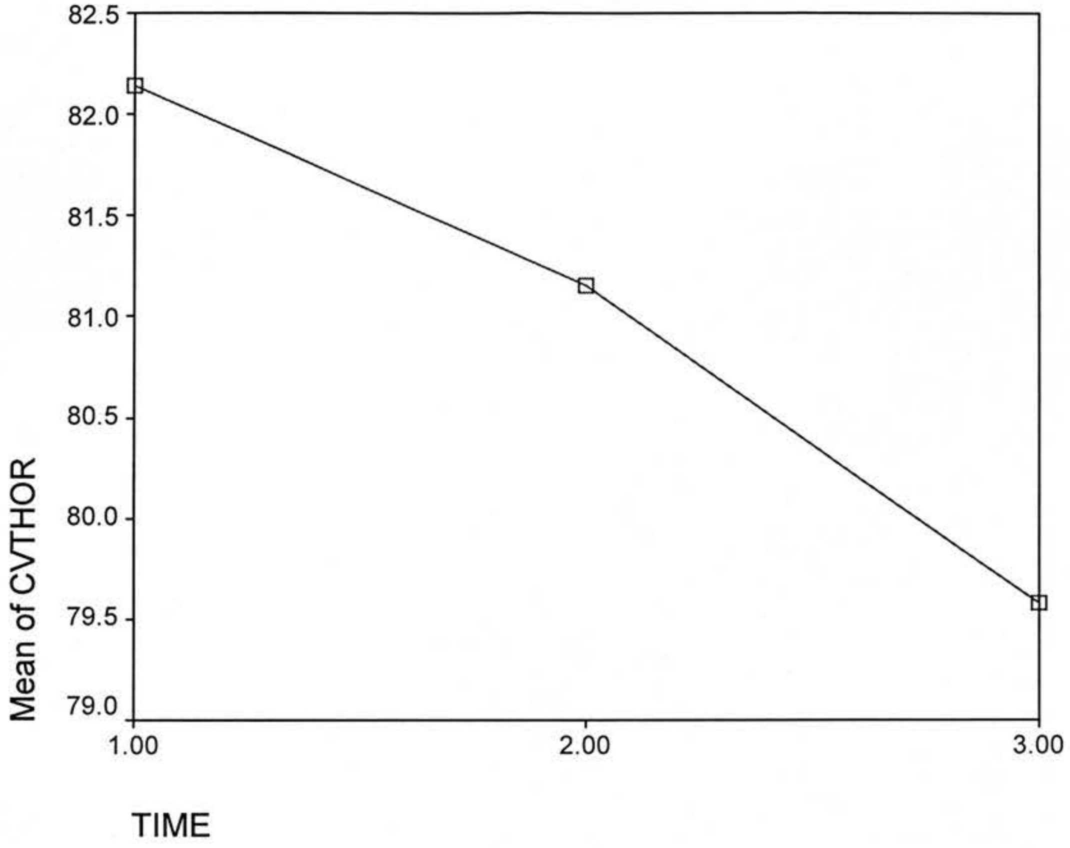
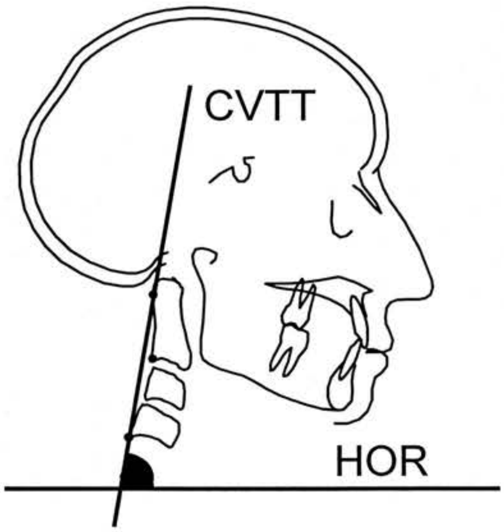


Figure 18: changes in angle CVT / HOR over the course of the study



CHAPTER 6: DISCUSSION

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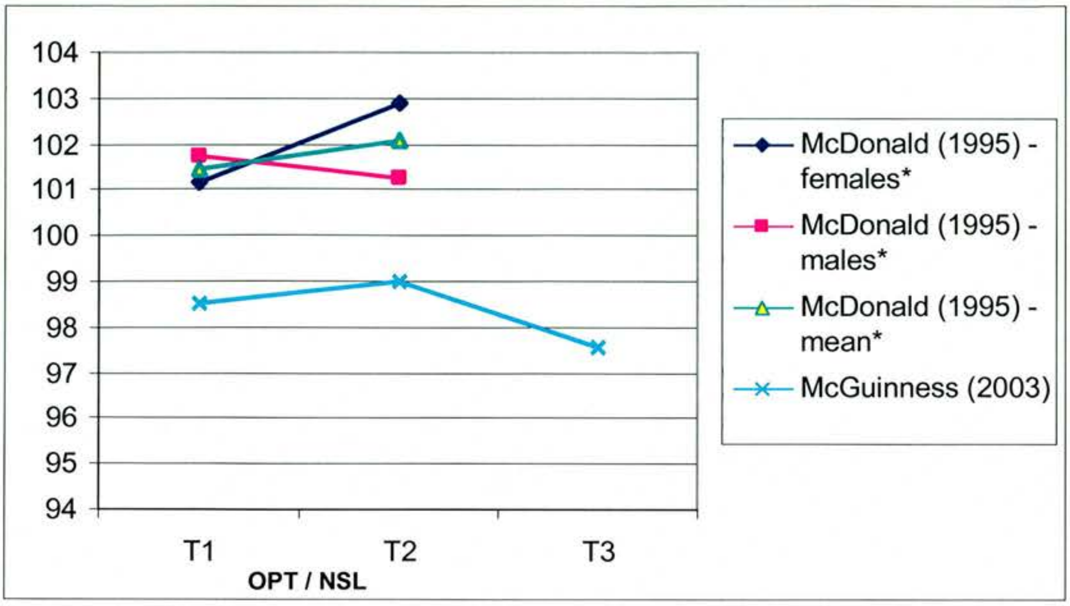
This study has shown that a number of statistically significant changes in cervico-horizontal and craniovertical angles take place subsequent to the change in mode of breathing initiated by rapid maxillary expansion. The clinical significance of one of these – the head elevation in relation to the true vertical, NSL / VER – is important, while the clinical significance of the changes in neck posture – OPT / HOR and CVT / HOR – may be important if it continues over time. These changes are similar to some of those found by McDonald (1995); the trends and directions are those that would be expected from a widening of the nasal airway, an improvement in nasal respiration, with a subsequent change in head posture, in accordance with Solow and Krieborg's (1977) hypothesis. A comparison of the results of this study and those of McDonald (1995) can be found in Table 17 and in Figures 19 – 23. When the values for the males and females are combined, the trends suggest a strong similarity to those found in this study.

The craniocervical angles, OPT / NSL and CVT / NSL both showed a very slight and statistically insignificant initial ***increase*** immediately after RME, which could be attributed to the bite opening effect of the RME splint on the occlusion. This finding also occurred in McDonald's (1995) study, but only for female anomaly subjects undergoing RME: all the male anomaly subjects showed exactly the opposite trend (Figures 19 and 20). This slight increase could also be explained by (a) an elevation of the nasion – sella line (NSL) due to the head flexing upwards, or (b) a decrease in the cervico – horizontal angles (OPT / HOR and CVT / HOR) which indeed, has occurred, with the angle NSL / VER remaining unchanged. As OPT / HOR and CVT / HOR both

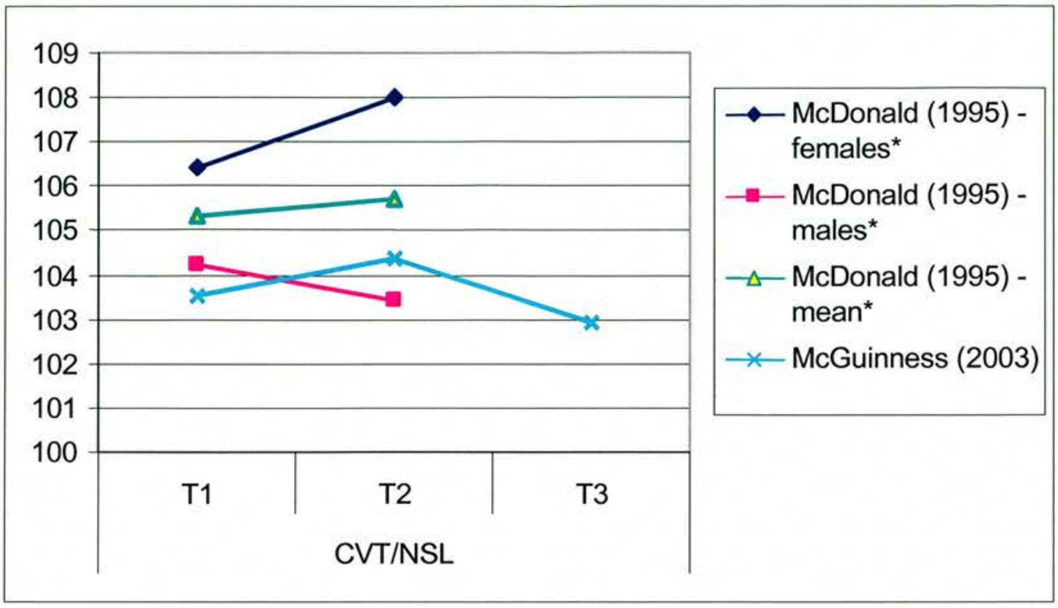
Table 17: Comparison of McDonald's (1995) results with the present study (all values in degrees)

	Control group (McDonald, 1995)	Anomaly group (McDonald, 1995) - pretreatment		Anomaly group (McDonald, 1995) - postexpansion		Test group (McGuinness, 2003) - pretreatment	Test group (McGuinness, 2003) - postreatment	
		Males	**Females**	**Males**	**Females**	T_1	T_2	T_3
OPT / NSL	98.85	101.72	101.18	101.24	102.91	98.54	98.98	97.54
CVT / NSL	103.86	104.22	106.42	103.41	108.03	103.51	104.37	102.94
NSL / VER	95.43	97.36	96.18	95.45	96.81	95.64	95.43	92.5
OPT / HOR	86.49	85.65	84.99	84.21	83.90	87.08	86.55	84.95
CVT / HOR	81.49	83.15	79.77	82.04	78.78	82.14	81.16	79.59



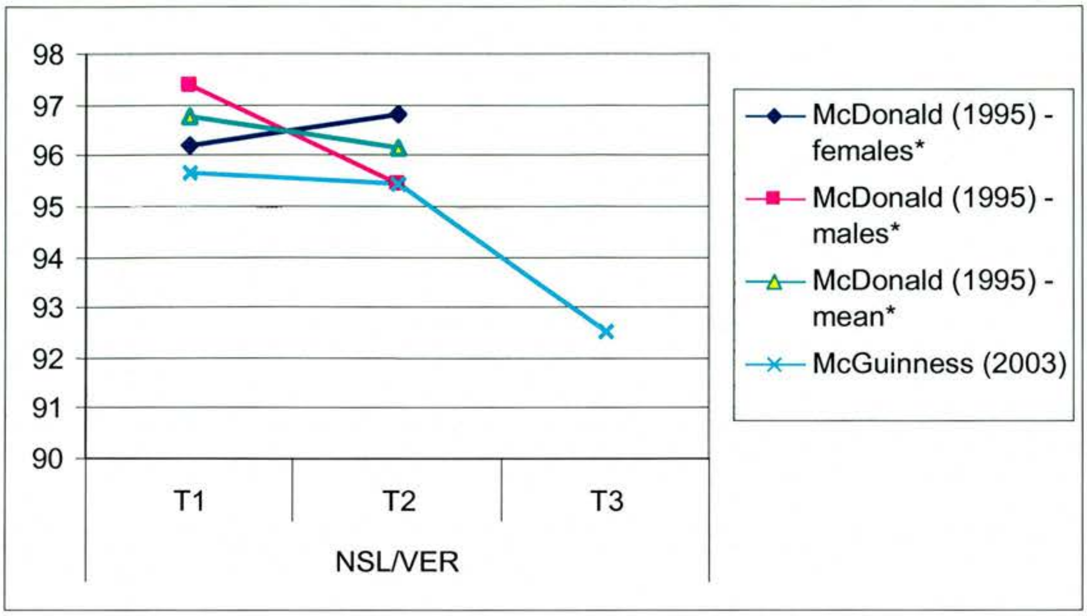
* = anomaly group

Figure 19: comparison of changes in angle OPT/NSL for McDonald (1995) and McGuinness (2003)



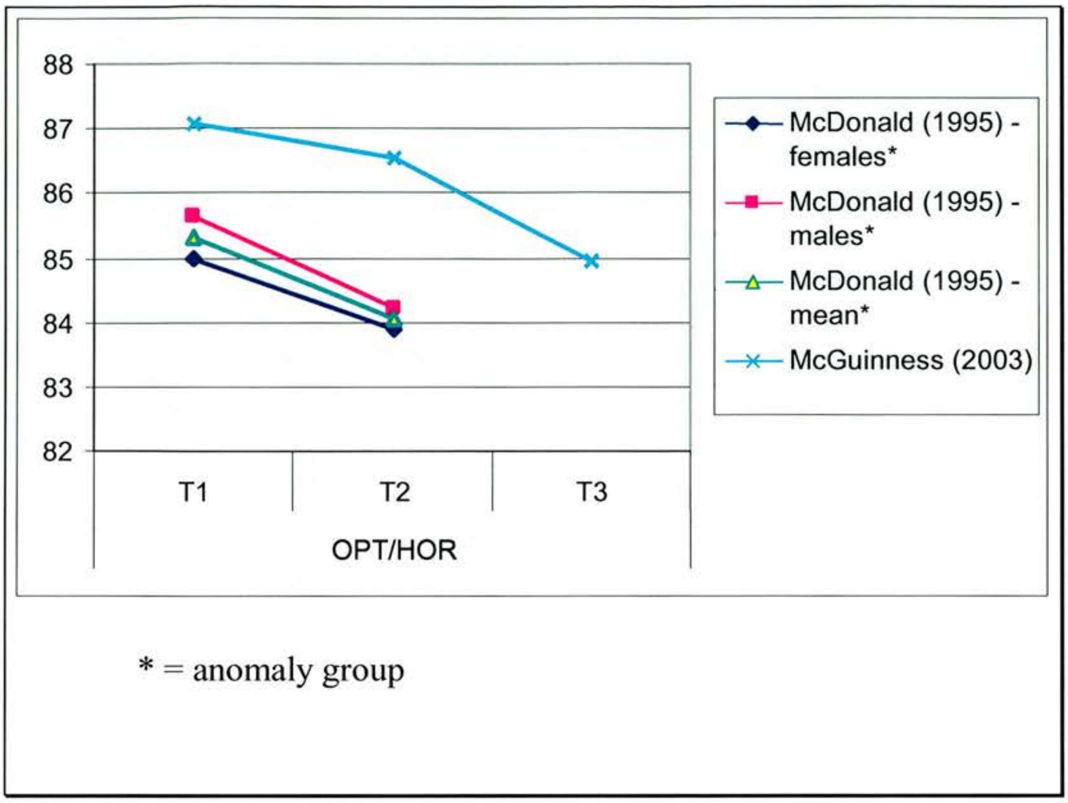
* = anomaly group

Figure 20: comparison of changes in angle CVT/NSL for McDonald (1995) and McGuinness (2003)



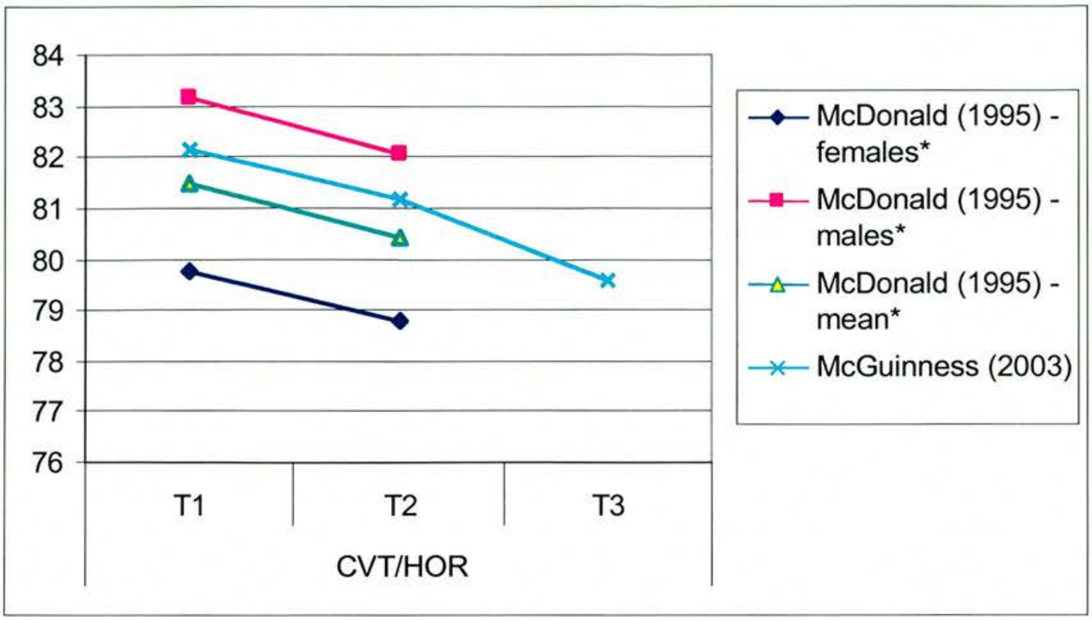
* = anomaly group

Figure 21: comparison of changes in angle NSL/VER for McDonald (1995) and McGuinness (2003)



* = anomaly group

Figure 22: comparison of changes in angle OPT/HOR for McDonald (1995) and McGuinness (2003)



* = anomaly group

Figure 23: comparison of changes in angle CVT/HOR for McDonald (1995) and McGuinness (2003)

decreased and continued to decrease at one year post-expansion, this suggests that the neck extends forwards as a result of RME. The initial change in OPT / NSL and CVT / NSL may be a relative increase, mediated by OPT / HOR and CVT / HOR changes. The actual decrease in NSL / VER in the immediate post-expansion period is very small indeed (almost negligible), so this hypothesis is tenable.

The cranio-vertical angle NSL / VER, after a very slight decrease of 0.21° immediately post-expansion, exhibits a larger, statistically and clinically significant decrease of up to 3.14° a year later. In the anomaly sample that underwent RME studied by McDonald (1995) there was an ***increase*** in the NSL / VER angle of 0.63° for males and ***decrease*** in this angle of 1.91° for females. It should be borne in mind that these latter figures were observed shortly after completion of expansion (Table 17 and Figure 21)

The angles OPT / NSL, CVT / NSL, and OPT / CVT showed no statistically or clinically significant changes over the course of the present study, though the trend suggests that these angulations may continue to change with time and may become statistically or clinically significant in the future.

Overall, the changes in the craniocervical angles (OPT / NSL and CVT / NSL) were towards a decrease, but were much smaller than the decrease observed for the cranio-vertical angle (NSL / VER) and the craniohorizontal angles (OPT / HOR and CVT / HOR). These changes showed that all six angles (apart from OPT / CVT) decreased one year after RME, with the greatest changes taking place between T_2 and T_3, the period between the end of initial expansion and the follow-up period of one year after expansion. This suggests that it could take some time for the physiological chain of events that governs the relationship between the airway patency and the morphological changes proposed by Solow and Krieborg (1977) to occur, which is in agreement with the work of Linder-Aronson (1970, 1974, 1975). Three of these angles – NSL / VER, OPT / HOR and CVT / HOR – show statistically significant changes which can be ascribed to the change in breathing mode caused by RME.

In the case of NSL / VER, the change in this angle would tend reflect the increased airway patency as a result of rapid maxillary expansion (though ideally this should be tested using rhinomanometry), and is the most important change found in this study. The relationship of the head to the true vertical would tend to drop, and this has happened in the case of NSL / VER by an average of 3.14° ($p = 0.005$). This is a highly significant change and it is probable that this is likely to continue during the succeeding years.

It is interesting to note that changes have taken place in all of the angulations studied – the neck has extended forward as shown by the angles OPT / HOR and CVT / HOR, and the head itself has dropped very slightly in relation to the cervical spine, as shown by the cervico-horizontal angles OPT / NSL and CVT / NSL. The cervico-horizontal angles seem to be important in mediating large changes in the cranio-cervical angles (OPT /NSL and CVT / NSL) and show the same relationship to craniocervical development as the cranio-cervical angles, but with the opposite sign, due to the construction of the angles (Solow and Sandham, 2002). If significant change has taken place in the cervico-horizontal angles, then one would expect the same to happen in the cranio-cervical angles, but over the course of this study no significant change in these latter angles has taken place. It is likely that a delayed effect mechanism is in operation here, and it would be useful to recall the patients at a later date to see if such significant change has taken place.

The neck extension that has taken place (i.e. in the angles OPT / HOR and CVT / HOR) is an interesting finding. These two angles show similar trends to those of McDonald's (1995) study (Table 17 and Figures 22 and 23). This type of ***forward*** neck posture is associated with patients with smaller nasopharyngeal dimensions (Solow et al, 1984), and obstructive sleep apnoea (OSA) (Solow et al, 1993; Solow et al, 1996). Achilleos et al (2000a) showed in surgical mandibular advancement that the angles OPT / HOR and CVT / HOR both ***increased*** (i.e. the neck became more flexed and upright), and the average pharyngeal airway space had increased in the sagittal dimension. Robertson (2002) also in a study of mandibular advancement surgery for obstructive sleep apnoea, found a decrease in the angle NSL / VER from 99.7° to 93.0°, a decrease of 6.7°, which would be consistent with an increased airway patency. Achilleos (200b) in a study of patients who had mandibular setback surgery, showed that the angles OPT / NSL and CVT / NSL had both increased significantly, while the airway space had decreased, indicating cervical hyperflexion at follow-up. No significant changes were found in the cervico-horizontal angle studied, CVT / HOR. In the present study, the nasal airway has become more patent, but the angulations OPT / HOR and CVT / HOR have ***decreased***, rather than increased: the pharyngeal airway dimensions have not been affected, as would occur in mandibular surgery, and this finding may reflect a change that is associated with nasal airway resistance alone, rather than pharyngeal airway resistance.

The effect of RME on the cervico-horizontal angles, OPT / HOR and CVT / HOR, appears to be somewhat more immediate than that on the angle NSL / VER, and this finding is significant in view of the fact that the structures that form the neck are more remote from the site of nasal airway expansion.

A possible explanation for this forward neck posture with improved breathing mode after RME may be as follows: forward or extended neck posture is associated with OSA (Solow et al, 1993; Solow et al, 1996), and with narrower nasopharyngeal dimensions, while flexed or backward neck posture is associated with wider nasopharyngeal dimension (Solow et al, 1984). If, as in the present study, airway patency has improved at the nasal level, and the nasal dimensions have increased, while the pharyngeal dimensions remain the same, this may result in an increase in airway resistance at the pharyngeal level. In order to compensate for this, either the head can elevate (Hellsing, 1989), or the neck extends forwards, and both of these actions widen the most caudal part of the pharyngeal airway: an observation noted by Solow et al (1993, 1996) in patients with obstructive sleep apnoea (Figure 19). Paradoxically, it would seem to suggest that a minor state somewhat similar to OSA is created by rapid maxillary expansion at the lower levels of the airway, and the neck extends forward to compensate, decreasing the angles OPT / HOR and CVT / HOR. This suggests that a state of "dynamic equilibrium" may exist between the two

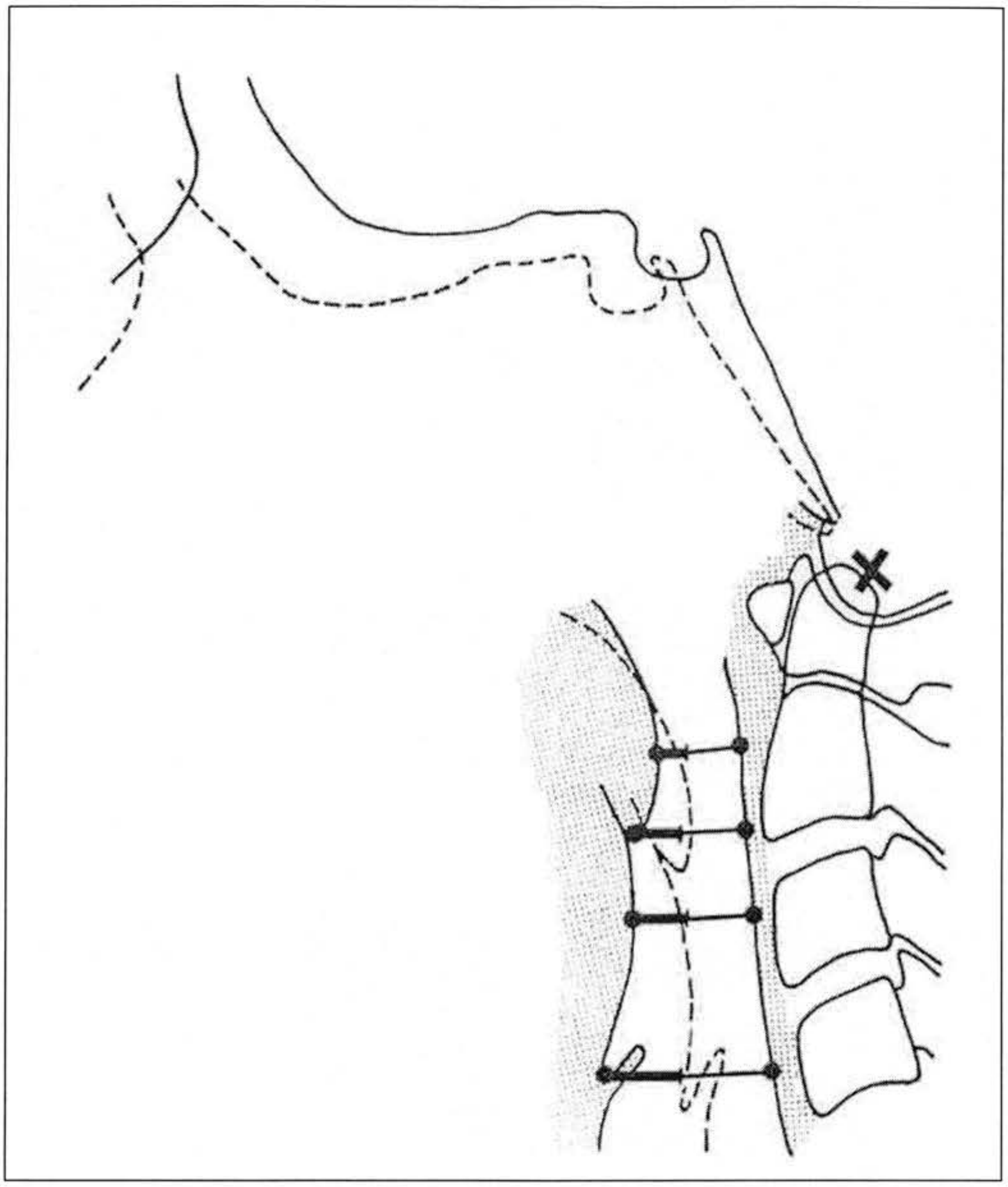


Figure 19: Effects of head elevation or neck proclination on nasopharyngeal dimensions (from Solow et al, 1996)

This results in in widening of the most caudal portions of the nasopharyngeal airway. "X" is the location of the atlanto-occipital joint around which rotation occurs. Heavy lines represent the structures after widening, dotted lines represent structures before widening.

components of the upper airway – the nasal component and the pharyngeal component. When one component changes to allow more air to be inhaled, it results in a slightly increased airway resistance at the lower level. In order to re-establish the state of equilibrium between the two components, the neck extends forwards, widening the most caudal dimensions of the pharyngeal airway as a result, the centre of rotation being at the atlanto-occipital joint of the cervical spine (Solow et al, 1996). This state of dynamic equilibrium integrates with the cycle of events described by Solow and Krieborg's (1977) hypothesis, and an adaption of this can be seen in figure 20.

In the present study, the relationship of the head to the true vertical, NSL / VER, has also declined. This may be mediated ultimately by the relationship of the nasion-sella line, (NSL) to the cervical tangent lines, OPT and CVT (see above). What long-term effects these will have on the subsequent development of the craniofacial skeleton remain to be seen, but they are likely to correspond with the work of Linder-Aronson. Solow and Tallgren (1976) found that the greatest correlations between craniofacial angulations and development were those between the craniocervical angles and NHP, while craniovertical and cervico-horizontal angles had little effect. However, as has been stated by Solow and Sandham (2002) the cranio-horizontal angles may mediate large changes in the cranio-cervical angles, and this relationship is one that should be explored further. However, the angulation of the neck to the horizontal has definitely changed over the course of this study, and as the results are statistically significant at one year after RME, a follow up study would be useful to establish if continuing change takes place and if so, whether or not it would have an effect on craniofacial development.

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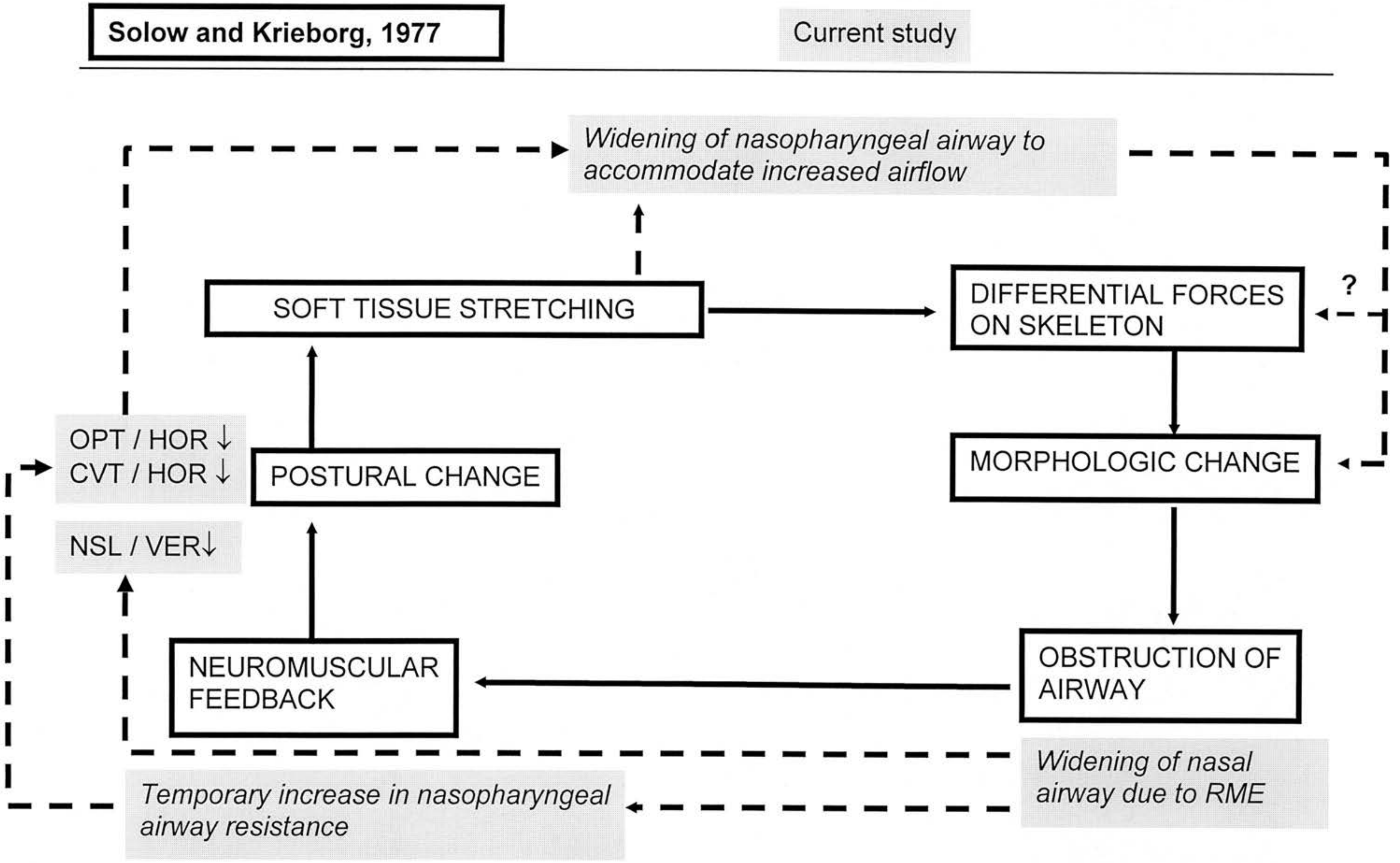

Figure 20: modification of Solow and Krieborg's (1977) hypothesis to explain the results of this study

Other factors that may influence head posture are discussed by Wenzel et al (1989a), in a study of patients who had mandibular setback surgery for mandibular prognathism, both OPT / NSL and CVT / NSL increased by an average of 2.7°. The nasopharyngeal airway size ***decreased*** following surgery, but the authors considered that a decrease in airway size on radiographs is not necessarily followed by an increase in airway resistance, and the degree of mandibular setback in many cases was only of the order of a few millimetres. Wenzel and her co-workers proposed that psychosocial factors such as improved self-confidence might have stimulated patients into raising their head, thereby reinforcing the changes in head posture arising from the biological changes.

While this present study did not attempt to quantify nasal airway resistance or patency using rhinomanometric or other methods, the results for the head elevation (NSL / VER) are as would be expected from the increase in nasal permeability, while the results for the cervico-horizontal angles (OPT / HOR and CVT / HOR) appear to reflect the work of Huggare and Laine-Alava (1997) and Solow et al (1993, 1996). An decreased nasal airway resistance may induce a change in total airway resistance, resulting in greater pharyngeal airway resistance, a state seen in obstructive sleep apnoea. The result is that the neck tends to incline forwards, as this manoeuvre widens the airway at the pharyngeal level.

CRITICISMS OF THIS STUDY

(a) Ideally a concurrent control group of similar patients would have been useful, as opposed to a historical control group.

(b) Electronic digitisation would be preferable to hand-tracing from the point of view of method errors.

(c) Randomisation of the test group would give a more scientifically sound methodology.

(d) Power calculations would allow both the size of the ideal test group and the calculation of the degree of clinical significance required.

(e) Equal numbers of males and females would be ideal, in both the test and the control group.

CONCLUSIONS

CONCLUSIONS

1. Rapid maxillary expansion was found in this study to have no immediate significant effect on the relationship of the head to the true vertical, the cervical column, or the horizontal, as measured on cephalometric radiographs in the natural head position.

2. One year after expansion, a statistically and clinically significant reduction in the relationship of the nasion-sella line to the true vertical (NSL / VER) from 95.64° to 92.5°, a difference of 3.14°, ($p < 0.01$) was found. This finding indicates a drop in head elevation and is consistent with improved nasal respiration.

3. The relationship of the cervical column to the horizontal (OPT / HOR and CVT / HOR) also changed significantly one year after rapid maxillary expansion. OPT / HOR reduced from 87.08° to 84.95°, a difference of 2.13° ($p < 0.05$), while CVT / HOR reduced from 82.14° to 79.59°, a reduction of 2.55° ($p < 0.05$). The net result was a more forward inclination of the cervical spine.

4. A more forward inclination of the cervical spine has been shown by Hellsing (1989) to increase the cross-sectional area of the pharyngeal airway, while Solow et al (1993, 1996) showed that patients with obstructive sleep apnoea tended to have much more forward inclination of the cervical spine to augment airway capacity. The increased forward

inclination of the cervical spine seen in patients one year after RME in the present study suggests that the increase in nasal permeability and consequent increased nasal airflow may result in a temporary increase in pharyngeal airway resistance. In order to compensate for this, the neck inclines forward to increase the cross-sectional area of the pharynx.

5. The clinical significance of this study is that RME causes a reduction in nasal airway resistance, which in turn results in a reduction in head elevation which is likely to have an effect on soft tissue stretching. Such a change would be beneficial for a patient who suffers from nasal airway obstruction and who has a higher facial vertical dimension as a result. By changing the mode of breathing early in adolescence, a tendency towards normalisation of the craniofacial dimensions can occur with growth. The change in neck inclination may be of clinical significance in a follow-up study.

SUGGESTIONS FOR FUTURE INVESTIGATIONS

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Craniofacial growth and development in the teenage years is an ongoing phenomenon, and long-term studies in this area are lacking. Longitudinal cephalometric studies of untreated normals have been done in the past, but follow-up studies of patients who have undergone rapid maxillary expansion are rare, and the number of investigations of natural head position after such treatment are limited (McDonald, 1995).

Ideally all such studies should be done as randomised controlled clinical trials, but the cost, time and effort involved in such studies are often prohibitive. Studies of the type outlined here are useful in that they supply a good deal of useful evidence to support a hypothesis, and also as a useful addition to previous research. The study also reflects the real situation in many clinical departments, where very high numbers of patients are seen and often it is not possible to select the "ideal" patients for the ideal study.

It is proposed to recall the patients in this study some years after the initial maxillary expansion and to repeat the cephalometric radiographs at that stage. It will be instructive to see if any of the cephalometric variables that showed insignificant change over the course of the present study undergo significant change in the post-treatment period, and also to see if the variables that did show significant change continue to do so. If this process continues, this would imply that rapid maxillary expansion has a significant effect on overall lower and midfacial development, airway patency and natural head posture, throughout the period of generalised growth in the teenage years. The implant studies of Krebs (1964) and the more recent work of Cross and McDonald

(2000), Cameron et al (2002), and Baccetti et al (2001) who found long term stable increases in nasal width after rapid expansion, and by implication, continued decreased nasal resistance, would suggest that this hypothesis is a tenable one. The effects of relapse in the skeletal dimension or the dental dimension could also be assessed at this stage.

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APPENDIX

APPENDIX 1

TABLE 18: CEPHALOMETRIC VALUES DERIVED FROM DIFFERENT STUDIES

	OPT / NSL	CVT / NSL	NSL / VER	OPT / HOR	CVT / HOR	OPT / CVT
Bjerin (1957)						
Sitting / mirror			96.2			
Standing / mirror			94.3			
Moorees and Kean (1958)						
Sitting / mirror (females)			94.7			
			95.3			
Carlsoo and Leijon (1960)[1]						
Sitting / no ref (males)			93.0			
Sitting / no ref (females)			96.9			
Fromm and Lundberg (1970)						
Sitting / no ref (males)			99.8			
Sitting / no ref (females)			102.4			
Solow and Tallgren (1971, 1977)	92.18	97.72	92.59	90.41	84.87	
Siersbaek-Nielson and Solow (1982)	96.28	100.72	98.42	92.14	87.69	4.45
Tallgren and Solow (1984)						
Edentulous patients, time 1	88.19	96.06	99.01	100.82	92.95	7.87
Edentulous patients, time 2	93.36	102.16	100.21	96.86	88.06	8.8
Solow et al (1984)	94.04	98.27	98.55	94.51	90.28	
Huggare et al (1986)[2]	-	-	96.9	95.7	91.9	
Solow and Siersbaek-Nielson (1986)	95.06	99.83	98.4	93.34	88.57	

	OPT / NSL	CVT / NSL	NSL / VER	OPT / HOR	CVT / HOR	OPT / CVT
Huggare (1987)[3]						
Girls	92.2		94.7	92.7		
Boys	89.1		94.2	96.1		
Tallgren and Solow (1987)	-	-	99.6	96.9	92.7	
Sandham (1988)	91.51	95.77	92.665	91.165	86.9	4.28
Thuer et al (1989)[4]						
Girls		100.8			86.3	
Boys		96.2			89.6	
Wenzel et al (1989)						
Mandibular setback *Pre-surgical*						
Osteosynthesis group	89.9	96.8				
Non-osteosynthesis group	90.4	97.0				
Post-surgical (1 year)						
Osteosyntheis group	92.6	99.0				
Non-osteosynthesis group	93.5	100.0				
Hellsing and Hagberg (1990)[5]						
Adults	96.8					
Phillips et al (1991)						
Orthognathic patients, pre-surgical	109.02	109.78	98.4	79.38	78.24	1.2
Siersbaek-Nielson and Solow (1992)	96.28	100.72	98.42	92.14	87.69	
Huggare (1993)						
Standing	93.0		98.3	95.3		
Sitting	92.9		98.6	95.7		
Solow et al (1993)						
(patients with OSA)	104.1	108.0	95.1	81.0	77.2	

	OPT / NSL	CVT / NSL	NSL / VER	OPT / HOR	CVT / HOR	OPT / CVT
McDonald (1995)						
Control group	98.85	103.86	95.34	86.49	81.47	5.01
Anomaly group (pre-RME)	101.41	105.47	96.69	85.28	81.23	
Anomaly group (post-RME – males)	101.24	103.41	95.45	84.21	82.04	
Anomaly group (post-RME – females)	102.91	108.03	96.81	83.90	78.78	
Huggare and Laine-Alava (1997)	93.0		97.1	95.0		
Ozbek et al (1998)						
Snorers	101.8	107.0	99.3	93.0	98.2	
(patients with OSA) *Mild OSA*	103.1	108.2	101.3	91.8	97.1	
Mod OSA	103.3	109.4	101.5	92.4	98.4	
Severe OSA	108.4	113.1	102.4	97.1	101.7	
Solow and Sonnesen (1998)	94.6	98.9	96.3	91.6	87.4	4.3
Zuniga et al (2000)[6]						
Cleft patients			97.71		77.89	
Controls			100.59		90.03	
Leitao and Nanda (2000)[7]	98.87		81.81			
Zepa et al (2000)						
Males	93.92	99.7	94.65			-5.78
Females	91.87	98.79	94.19			-6.91
Achilleos et al (2000a) **Mandibular advancement for retrognathism**						
Presurgical	97.33	102.4	86.51	84.62	79.78	5.26
6 months post-surgery	95.97	100.59	84.51	83.86	79.12	4.49
3 years post-surgery	96.27	101.05	82.71	91.22	86.42	4.78

	OPT / NSL	CVT / NSL	NSL / VER	OPT / HOR	CVT / HOR	OPT / CVT
Achilleos et al (2000b) **Mandibular setback for prognathism**						
Presurgical	90.78	95.48	86.38		85.31	4.69
6 months post-surgery	93.10	97.16	88.03		84.43	4.05
3 years post-surgery	94.27	98.68	87.14		84.97	4.40
Robertson (2002) **Mandibular advancement for OSA**						
Presurgical			99.7			
Postsurgical (6 months)			93.0			
Present study						
Pretreatment values	98.54	103.51	95.64	87.08	82.14	4.97
Immediate post-expansion values	98.98	104.37	95.43	86.55	81.16	5.40
1 year post-expansion values	97.54	102.94	92.50	84.95	79.59	5.40

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