THE ACCURACY OF VISUALIZED TREATMENT OBJECTIVES IN BIMAXILLARY PROTRUSION PATIENTS

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MChD thesis of Dr Desmond Murphy, submitted in partial fulfillment of the requirements for the degree of MChD, Department of Orthodontics, Faculty of Dentistry, University of the Western Cape. March 2008.
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DECLARATION

I ………………………………………………………. declare that this thesis entitled “The accuracy of Visualized Treatment Objectives in bimaxillary protrusion patients in the Western Cape Population” is my own original work and has not been submitted for a higher degree to any other institution. The sources I have quoted have been acknowledged by means of references.

Signature : …………………………..

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9. Lastly, but most importantly, to my family who sacrificed so much so that I might realize my goal. The sacrifice indeed has been worth it.

DEDICATION

This thesis is dedicated to:

my wife, Bonita, who proved to me that angels do indeed dwell amongst us. Your love, support, prayers and encouragement has pushed me over the finish line. I am honoured and privileged to call you my wife.

Proverbs 31 v 29: "Many daughters have done well, but you excelleth them all"

my beautiful children, Gabriella and Timothy. Although you may have been small, the sacrifices you made were indeed big. Thank you for always making me feel that I am the best dad in the whole world.

ABSTRACT

Introduction: A Visualized Treatment Objective (VTO) is a cephalometric tracing representing the changes that are expected (desired) during treatment. It is a procedure based primarily on cephalometrics, in which the expected or desired outcome after treatment can be predicted. Bimaxillary protrusion is a malocclusion characterized by protrusive and proclined upper and lower incisors and an increased procumbency of the lips. Although not commonly seen in Caucasians, it can be seen in almost every ethnic group. **Aims and Objectives:** The aim of this research project was to assess the accuracy of four different types of VTO's, [Steyn (1979), Jacobson and Sadowsky (1980), Ricketts (1982) and Holdaway (1984)], in predicting the final result of the incisor and soft tissue response to orthodontic treatment in bimaxillary protrusive patients. **Materials and methods:** A sample of forty five cases of patients in the age range of 12-16 years with bimaxillary protrusive characteristics were evaluated. Twenty-seven cephalometric landmarks were digitized on the pre and posttreatment cephalograms using the Quick Ceph© software package. Landmarks on the pretreatment cephalogram were used to construct the four VTO's. Eighteen pre- and post-treatment measurements were used to analyze the changes predicted by the four VTO's and the post-treatment cephalometric tracings. **Results:** None of the VTO's were able to predict with accuracy the final treatment outcome. Most of the VTO's could predict to some extent the final position of the incisors but were unable to correctly forecast the soft tissue response. The Ricketts and Steyn VTO came the closest to correctly predicting the incisor position as well as the soft tissue response. **Conclusion:** It was concluded from this study that the four VTO's could not predict the soft tissue response, and those VTO's which positioned the lower incisor first and then the soft tissue is draped accordingly (Ricketts and Steyn), fared slightly better in predicting the final outcome for both the soft tissue and dental tissue response. Present day VTO's cannot be applied, with any accuracy, to patients with bimaxillary protusion. Further studies are required to determine the soft tissue and hard tissue response in patients with bimaxillary protrusion, following orthodontic treatment.

CHAPTER 1

INTRODUCTION

According to Lewis (1948) the term "bimaxillary protrusion" was first used as early as 1897 by Calvin C. Case to define bimaxillary protrusion or bimaxillary dentoalveolar protrusion as it is sometimes referred to, as a condition characterized by protrusive and proclined upper and lower incisors and an increased procumbency of the lips. It is seen commonly in Americans of African descent and Asian populations, but it can occur in almost every ethnic or racial group (Fonseca and Klein 1978, Jacobs and Bell 1983, Keating 1985, Lew 1989, Farrow et al. 1993, Tan 1996, Bills et al 2005, Hussein and Abu Mois 2007). Bimaxillary dental protrusion is predominantly seen among black people but is also found to occur among whites (Keating 1985).

Bimaxillary prognathism, on the other hand, is a condition characterized by both skeletal bases, maxilla and mandible being prognathic (Bills et al 2000).

Tarisai and Nanda (2003) used the term bialveolar protrusion, when referring to bimaxillary protrusion and noted that it is a common occurrence in some ethnic groups because of the forward positioning of the teeth and its effect on the facial profile. They concluded that although bimaxillary protrusion might not be a common occurrence in the Caucsian population, it is natural in black people (Tarisai and Nanda 2003).

Chae (2007) used the term bi-alveolar protrusion to describe the condition of bimaxillary protrusion in the Asian population. He also stressed the increased procumbency of the lips and emphasised that patients sought treatment for the unaesthetic appearance of the lips.

The molar relationship in bimaxillary protrusion cases is usually normal and as such this occlusal pattern is often considered to be a sub-set of Class I malocclusion (Posen 1972).

Cephalometric studies of the skeletal and soft tissue relationships of Caucasian people with bimaxillary dental protrusion have revealed similarities with those of other ethnic groups exhibiting the same dentofacial morphology (Keating 1985).

Prediction has always been a part of science. The ability to predict allows certain laws or theories to be applied in specific situations. Baumrind (1991) suggested that the ability to predict assists the orthodontist psychologically in the treatment planning process by removing some of the art and adding a little more science.

Despite the listed advantages of Visualized Treatment Objectives (VTO's), limitations exist in their implementation. Inadequacies of VTO's include the following: the use of average growth increments in growth prediction, the use of existing morphological traits to predict future growth events, and the failure of present VTO analysis to exactly represent the final treatment outcome (Sample et al. 1998).

The aim of this study was to compare the accuracy of four VTO's in predicting the final outcome after orthodontic treatment, in patients with bimaxillary protrusion.

The literature review is presented in Chapter 2 and includes the aetiology, features as well as the treatment of patients with bimaxillary protrusion. The various growth studies and an extensive review of the four VTO are presented here together with the response of the hard and soft tissue response to treatment.

Chapter 3 explains the aims and objectives of this study in more detail as well as the method and materials used. The data measurements and statistical analyses are presented here together with the ethics statement.

The results of this study are presented in Chapter 4, with the discussion in Chapter 5. Finally recommendations and the conclusion of this study are presented in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

2.1. Aetiology

The aetiology of bimaxillary protrusion is considered to be multifactorial and consists of a genetic component as well as environmental factors, such as mouth breathing, tongue and lip habits, and tongue volume (Ballard 1963, Lamberton et al 1980).

Downs (1948) felt that because patients with bimaxillary protrusion have a normal molar relationship and a relatively normal overbite and overjet, he considered these cases to be in perfect harmony and balance with their physiognomy.

Savage (1963) conducted a study in the area surrounding Ngara in the West Lake Province of Tanganyika. His subjects were Hangaza, one of the Barundi groups. The dental tissues and skeletal structure of 459 children between the ages of 3 and 18 years were investigated. Regarding skeletal structure, nearly all the adolescents examined showed a typical profile: bimaxillary prognathism with a large Frankfort mandibular plane angle, an obtuse mandible angle, spacing of the teeth and bimaxillary dental protrusion.

Savage (1963) concluded that the maxillary prognathism observed is a genetic feature and that functional activity has little or no effect on it. Dental protrusion of the upper and lower anterior teeth and spacing of these teeth, according to him, was the result of the true bimaxillary protrusion, assisted by the powerful tongue, the growth of the obtuse angle mandible; and the texture of the lips which appears to be sufficient to hold the teeth in balance without retarding forward spacing and growth. He noted, at the time, that these types of orthodontic malformations are rarely seen in a comparable group of European children (Savage 1963).

Drummond (1968) in comparing white Americans with black Americans found that the black patients had a large, strong tongue and very loose flaccid lips that allowed the teeth to be in balance and harmony in a procumbent position. The position of the teeth and the thickness of the lips make the lower face appear very full (Drummond 1960).

Altemus (1968) compared cephalofacial relationships of white, black, Chinese, Japanese, Navajo Indian, and Australian aborigine groups. He concluded that the relative straightness of the facial profile is a compromise in the relationship of its component parts.

In previous studies Altemus (1960, 1963) concluded that, while the upper face profiles appeared similar, the area of the anterior teeth as well as the lips in black children were found to be more protrusive. When comparing his sample with the standards of whites in Burstone's research (1959), blacks demonstrated a protrusiveness of hard as well as soft tissues.

Posen (1972) measured the strength of the perioral musculature and found that this correlated with the position of the incisors. He observed that a change in the oral environment due to a more 'normal' tooth position was accompanied by a change in perioral musculature to more normal readings, especially in Class II division 2 incisor patterns. He found that a significant relationship exists between maximum strength and force of the lips and the final position and the angulation which the mandibular and maxillary incisor teeth assume after eruption (Posen 1972).

The high occurrence of bimaxillary protrusion among black people has led to the idea that tooth size may play a part in the aetiology of bimaxillary protrusion (Carter and Slattery 1988). The average mesiodistal tooth crown diameter has been shown to be greater in black people than among whites (Lavelle 1972). Keene (1979) reported that tooth size for the overall maxillary and mandibular dentition among black people was on average 8.4

per cent larger than for whites. The mesiodistal diameter of teeth was found to be greater in males than in females in both black and white people (Sanin and Savara 1971, Lavelle 1972).

McCann and Burden (1996) examined tooth size in a sample of thirty white Northern Irish people with a Angle Class I bimaxillary protrusion. The mesiodistal diameters of all permanent teeth, with the exception of the second and third molars, were measured. The tooth sizes were compared with a control group which consisted of thirty white subjects who had a variety of malocclusions, but who did not have bimaxillary protrusion. The results revealed that, on average, tooth size for the overall maxillary and mandibular dentition was 5.7 percent larger in the bimaxillary sample than in the control sample. The increase in tooth size affected all the teeth measured and not only specific teeth or groups of teeth (McCann and Burden 1996).

McCann and Burden (1996) concluded that although the adjacent soft tissues are likely to play a dominant role in the aetiology of bimaxillary dental protrusion, it is possible that the larger teeth found in patients with bimaxillary protrusion may contribute to the proclination of the incisors. They did, however, concede that the adjacent soft tissues are also likely to play a more dominant role in the aetiology of bimaxillary protrusion.

Ballard (1963) suggested that the crowding in these dental arches may contribute or exacerbate the proclination in cases of bimaxillary protrusion.

Othman and Harradine (2007) explored how many millimeters of tooth size discrepancy (TSD) would be clinically significant and what percentage of a representative orthodontic population had such a tooth size discrepancy. Their sample comprised 150 pretreatment study casts with fully erupted and complete permanent dentitions from first molar to first molar, which were selected randomly from 1100 consecutively treated white orthodontic patients. No mention is made of the breakdown of the sample or the number of patients with bimaxillary protrusion.

Othman and Harradine (2007) found that in the sample group 17.4% had anterior tooth-width ratios and 5.4% had total arch ratios greater than two standard deviations from Bolton's mean. For the anterior analysis, correction greater than ± 2 mm was required for 16% of patients in the upper arch or 9% in the lower arch. For the total arch analysis, the corresponding figures are 28% and 24%. They recommended that 2 mm of required tooth size correction is an appropriate threshold for clinical significance. They found that a significant percentage of patients have a TSD of this size (Othman and Harradine 2007).

Othman and Harradine (2007) concluded that it seems that tooth size plays a minor role, if any, in the aetiology of bimaxillary protrusion.

From the literature survey it is evident that further investigation into the aetiology of bimaxillary protrusion needs to be done before it will be possible to ascribe, with certainty, any role to tooth size as one of the factors which play a role in bimaxillary protrusion.

2.2. Features of bimaxillary protrusion

In 1978 Jacobson examined twenty-seven male and twenty-eight female adult craniums and mandibles of South African blacks in the Department of Anatomy of the University of the Witwatersrand. He compared them with twenty-three male and twenty-three female adult Caucasoids with excellent occlusion. He found that among the differences between the two groups was the forward position of the short maxilla relative to the anterior cranial base in the South African black sample. The forward location of point A has the effect of increasing the ANB angle, since the relative position of point B in both groups was much the same (Jacobson 1978).

Unlike in the African American, the labial inclination of the upper incisors in the South African black population is not pronounced but is similar to the inclination observed in Caucasoids (Altemus 1960). As a result of the large ANB angle, the lower incisors in the South African black population, as in the African American group, are severely labially inclined. Ramus height in the South African black group is shorter than that of Caucasoids and appears to be related to the steep mandibular plane observed in the former population group (Jacobson 1978).

In a study by Keating (1985), thirty bimaxillary protrusion cases, which had four first premolars extracted were compared with thirty Class I malocclusion cases that, likewise, had similar extractions and treatment. The Class I malocclusion group acted as the control. Both groups were of the white population group. There was a significant and permanent increase in the interincisal angle in both groups [The bimaxillary group had an average interincisal angle of 115º versus the control group of 135º at pretreatment].

Keating (1985) used cephalometrics to determine the morphological features of bimaxillary protrusion, strictly in a Caucasian population. He reported that bimaxillary protrusion was associated with a shorter posterior cranial base, a longer and more prognathic maxilla, and a mild Class II skeletal pattern. He also showed that Caucasians with this condition displayed a smaller upper and posterior face height, diverging facial planes, and a procumbent soft tissue profile with a low lip line.

Keating (1985) found that patients in his study, with bimaxillary protrusion, demonstrated increased incisor proclination and protrusion, a vertical facial pattern, increased procumbency of the lips, a decreased nasolabial angle, and thin and elongated upper and lower anterior alveoli.

Cotton et al (1951) applied the Downs analysis to three ethnic groups namely African Americans, Chinese and Japanese. They found that the Chinese and the African Americans had reduced interincisal angles (120.8° and 123.0° respectively). The interincisal angle was also found to be reduced by Altemus (1960) for the Chinese and African Americans when compared to Caucasians.

Drummond (1968) undertook a study to determine cephalometric norms for the African American, using a sample of forty African American children. He found that the position of upper incisor was not markedly different to that of the Caucasians (Cotton 1951, Altemus 1960), but the lower incisor was more procumbent, leading to a reduced interincisal angle.

Kowalski et al (1974) examined cephalometric data obtained from the Veterans Administration Hospital in Ann Arbor, Michigan. Two groups of individuals were involved: The first group consisted of 244 Black adult males ranging in age from twenty to sixty years; the second consisted of 381 White males in the same age range. They applied the Steiner (1953) analysis to this data and found that the proclination of the lower incisor was much higher in black group. Not surprisingly, therefore, the interincisal angle was considerably higher in the white sample as shown in their previous study by Kowalski and Walker (1972).

In a study by Isiekwe (1989) to establish a standard norm for incisor angulation in a Nigerian population, 47 medical and dental students, 42 high school students, and 21 members of the Nigerian armed forces were examined, making a total of 110 persons. All persons were ethnic black of Nigerian ancestry and none had received any orthodontic treatment.

Their ages ranged from 11 to 26 years. Isiekwe concluded that the upper incisor angle to the Frankfort plane had a biological norm of between 119° and 127°, while the lower incisor angle (to the mandibular plane) was between 96° and 104°. The value for the interincisal angle was found to be between 108° and II6° (Isiekwe 1989).

Tarisai and Nanda (2003) assessed the dentoalveolar relationships in a “well-balanced” sample of adult black Zimbabweans. They claimed that their sample was a balanced one because it consisted of 25 men and 25 women between the ages of 18 to 38 years of age with Class I occlusions. Twelve angular and six linear measurements were analyzed. Statistically no significant differences were noted between the two genders.

The Zimbabwean sample had a low Frankfort-mandibular plane angle (19.6°± 5.5°) with a receding chin as shown by the negative Pog-NB measurement (-0.7 ± 1.5 mm). Both the maxilla (SNA = 88.5° ± 4.7°) and the mandible (SNB = 83.3° ± 4.4°) were prognathic, and the ANB difference was large (5.3° ± 2.7°) (Tarisai and Nanda 2003).

The maxillary incisors were more upright compared with those of white people (Steiner 1953), as measured by the angle of the maxillary incisor to NA line (20.6° ± 7.7°) which was lower than the average (22° ± 6°). The mandibular incisors were severely proclined (IMPA = 105.8° ± 6.0°, L1-Apog = 6.9° ± 2.7°, L1-NB = 37.6° ± 4.9°), and this proclination was considered to be compensatory to the prognathic maxilla (Tarisai and Nanda 2003).

It can therefore be concluded from the above studies that patients with bimaxillary protrusion may have a prognathic maxilla and short ramal height. The ANB angle is invariably increased. There also is an increased incisor proclination and protrusion as well as a vertical facial pattern, and an increase in the procumbency of the lips, which results in the typical bimaxillary profile (Cotton et al 1951, Jacobson 1978, Keating 1985, Keating 1986, Isiekwe 1989, Tarisai and Nanda 2003).

2.3. Treatment of bimaxillary protrusion

Patients with bimaxillary protrusion often are not happy with their soft tissue profile. These patients usually have dentoalveolar flaring of both the upper and lower anterior teeth.

Because of the negative perception of protrusive dentition and lips in some cultures, many patients with bimaxillary protrusion seek orthodontic care to decrease this procumbency (Langberg 2004, Bills 2005 et al, Chae 2007). Common treatment objectives for patients with severe bimaxillary protrusion are to reduce the facial convexity, improve lip competence, and relieve the crowding if present (Farrow et al 1993, Sarikaya et al 2002, Schacter and Schacter 2002, Chae 2007).

The treatment approach usually consists of extracting the four first premolars and retracting the anterior teeth with maximum anchorage mechanics. Maximum anchorage of the posterior teeth allows the anterior teeth to be retracted to the greatest extent. Excessive lingual retraction of the incisors may be needed to reach the objectives of treatment, and the extent of alveolar bone remodeling that occurs in response to this type of movement may vary with each patient. This retraction and retroclination of maxillary and mandibular incisors will hopefully result in a decrease in the soft tissue procumbency and convexity (Keating 1985, Farrow et al 1993, Diels et al 1995, Tan 1996, Sarikaya et al 2002, Celli et al, 2007, Chae 2007). Figures 1 and 2 demonstrate this reduction in procumbency after treatment (from Langberg and Todd 2004).

Lew (1989) looked at profile changes after the extraction of four first premolars and orthodontic treatment of bimaxillary protrusion in 32 Asian adults. He reported significant improvement in upper and lower incisor protrusion, nasolabial angle, upper and lower lip length, and upper and lower lip protrusion.

In some cases first permanent molars have to be extracted in addition to the premolars to provide enough space for the retraction of the incisors. Some cases may require orthognathic surgery, while a nonextraction approach can be more esthetic in patients with mild or moderate bimaxillary protrusion, as shown by Celli et al (2007).

Figure 1. Pretreatment photographs. Note the increased procumbency of the lips (Langberg and Todd 2004).

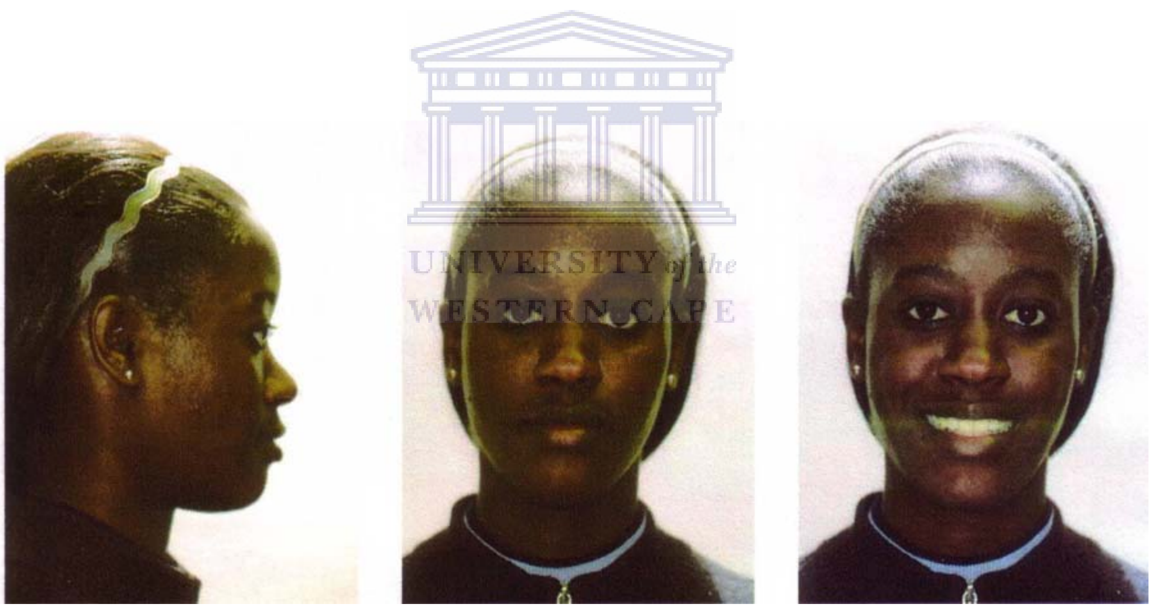


Figure 2. Post-treatment photographs. Note the softening of the profile as a result of the reduction in the procumbency of the lips (Langberg and Todd 2004).

Keating (1986) found that the inter-incisal angle, in the bimaxillary group, increased by 20º but that it relapsed post-treatment by 4º. The soft tissue procumbency also was reduced on average by 4º after treatment. The overbite appeared quite stable in both groups and stayed within normal limits throughout the treatment. Keating (1986) concluded that the extraction of four premolars in patients with bimaxillary protrusion is a viable option, although his results were only regarded as being statistically and not clinically significant. He did however note a decrease in the soft tissue procumbency.

Bills et al (2005) examined the success of treatment involving four premolar extractions in the treatment of patients (of 48 ethnically diverse patients) with bimaxillary protrusion. This study also showed that the extraction of four premolars can be extremely successful in reducing the dental and soft tissue procumbency seen in patients with bimaxillary protrusion, thus providing a stronger evidence-based rationale for this treatment modality (Bills et al 2005).

In conclusion, therefore, the most common treatment plan for patients with bimaxillary protrusion would therefore be the extraction of all four premolars with maximum anchorage utilization. This would ensure that the space created by the extractions being used for retracting the incisors with the lips following and thus leading to a reduction in their procumbency and resulting in a softening of the profile and improved aesthetics (Lamberton et al 1980, Holdaway 1983, 1984, Farrow et al 1993, Bills et al 2005).

2.4. Growth prediction

The number of adult patients visiting the orthodontic practices is increasing, with some practices reporting that adults make up as much as 40% of their patients (Khan and Horrocks 1991).

The majority of treatment, however, is still directed toward pre-adolescent and adolescent patients. Growth still has a significant effect on these individuals with regards to their occlusions, facial skeletons, and profiles. These changes are complex because each person has a unique growth pattern influenced by their genetic make-up (i.e., the biological or internal environment) as well as environmental factors such as function, disease, habits, and orthodontic treatment (Bishara 2000).

Being able to predict dentofacial growth is therefore not only essential, but extremely important to the profession of orthodontics. Herein lies the answer as to whether orthodontics is an art or a science. The prediction of growth is still largely a subjective aspect of clinical orthodontics.

Watson (1979) stated prediction as follows, “Although science starts with observations and the recording of data, it is basically concerned with finding patterns of facts and, in particular, with finding patterns that repeat. It is in the understanding of such patterns that we achieve the capacity to do one of the things that distinguish human beings from animals: to predict”.

Baumrind (1991) suggested that the ability to predict assists the orthodontist psychologically in the treatment planning process by removing some of the art and adding a little more science. The prediction of treatment outcomes has been difficult in orthodontic patients due to variations in growth, development, and treatment.

Because predicting facial growth would be of great benefit in planning orthodontic treatment, repeated efforts have been made to develop methods to do this from cephalometric radiographs. Successful prediction requires specifying the magnitude, the timing and the direction of growth, in the context of a baseline or reference point (Proffit 2007).

2.4.1. Craniofacial growth data

The craniofacial research data that has been used in growth predictions has been collected at great cost over a number of years. The collections of longitudinal growth records that have been accumulated are considered irreplaceable and it is nearly impossible to commence a new study of this magnitude, given the economic and ethical considerations (Hunter et al 1993, Proffit 2007). None of the studies below indicated whether their sample included patients with bimaxillary protrusion.

There are at least 12 sets of major longitudinal craniofacial growth record sets in the United States and Canada (Table 1). Nine of these include both standardized head films (cephalograms) and plaster casts of the teeth. The remaining three consist of standardized head films but lack plaster casts (Hunter et al 1993).

Below follows a brief overview of the listed craniofacial growth studies.

2.4.1.1. The Broadbent Bolton Growth Study

The Broadbent Bolton Study consists of mixed longitudinal records plus single visit data sets for a total of 5700 subjects. About 15% of these subjects have been seen 10 times or more, but 47% have been seen only once. Thus there are more than 850 longitudinal record sets (Hunter et al 1993, Proffit 2007). In addition to lateral head films, postero-anterior (PA) head films, and hand-wrist films are available. The study casts are trimmed, and there are height and weight records of the patients.

Many record sets have associated medical histories. The enlargement factor has been recorded on each film (Hunter et al 1993, Proffit 2007).

There are approximately equal numbers of male and female subjects, and the greatest concentration of records is in the 10 to 14-year age range.

Table 1. Alphabetical list of the twelve major Craniofacial Growth Studies (Hunter et al 1993)

1. The Broadbent Bolton Growth Study at Case Western Reserve University.
2. The Burlington Growth Study at the University of Toronto, Canada.
3. The Denver Growth Study now distributed between the University of Oklahoma and the University of Oregon.
4. The Fels Research Institute Study at Yellow Springs, Ohio.
5. The Forsyth Twin Study at the Forsyth Research Center, Boston.
6. The Iowa Child Welfare Study at the University of Iowa, Iowa City.
7. The Krogman Philadelphia Growth Study at the University of Pennsylvania.
8. The Mathews Implant Collection at the University of California, San Francisco.
9. The Meharry Growth Study at Meharry University, Nashville, Tenn.
10. The Michigan Growth Study at the Center for Human Growth, University of Michigan, Ann Arbor.
11. The Montreal Growth Study at the University of Montreal.
12. The Oregon Growth Study at the Child Study Center, Oregon Health Sciences University, Portland.

Fewer than 15% of subjects have received orthodontic treatment. The collection also contains a significant number of sibling and parent records. Approximately 90% of the original subjects are thought to be still living.

An active recall study is in place which is enhancing the limited initial recall begun in 1980 and this is adding to the age range of the long term series (Hunter et al 1993, Proffit 2007).

2.4.1.2. The Burlington Growth Study

The Burlington Growth Study is located at the Burlington, Ontario Orthodontic Research Centre at the University of Toronto. Its various longitudinal samples contain 1632 subjects in all. All samples are of the "diminishing" longitudinal type, so that the largest number of subjects is, for example, at age 4 years (for the annual series) and includes 167 male and 136 female subjects. These numbers diminish to 68 male and 57 female subjects at age 20 years, although there are over 100 subjects for each gender at 16 years of age (Hunter et al 1993, Proffit 2007).

The records for the serial experimental and control subjects include lateral head films (taken at rest, in occlusion, and with the mouth open), PA head films, 45° oblique, and hand-wrist films, photographs, study casts (with wax bites), height, weight, written treatment records (for the annual series only), and some medical histories. The enlargement factor is 9.8% at the midsagittal plane. All subjects are of Northern European white ancestry (Hunter et al 1993, Proffit 2007).

2.4.1.3. The Denver Child Growth Study

The Denver Child Growth Study is of the mixed longitudinal type. There may be as many as 100 subjects of each gender at each age, but the length of the individual record sets varies from 2 years to more than 20 years. Records for at least 60 male and 60 female subjects are available from 4 years to 30 years of age. The subjects are entirely of European white ancestry (Hunter et al 1993, Proffit 2007).

The collection contains lateral and PA head films and plaster casts of the dentition. The records were originally gathered in Denver but have been dispersed so that few, if any, are now available at their original location.

The majority of the remaining material is presently located at the University of Oklahoma under the jurisdiction of Ram S. Nanda (Hunter et al 1993, Proffit 2007).

2.4.1.4. The Fels Research Institute Growth Study

The Fels Growth Study records consist of over 9500 lateral cephalograms head films basically of the decreasing longitudinal type for more than 400 subjects. Wrist, knee, and foot films are also available, as are some lateral jaw films. Approximately 40 subjects have accompanying study cast records (Hunter et al 1993).

Enlargement factors have been recorded for the lateral skull films. A unique feature of the collection is that many subjects were first recorded at 3 months, with follow-up records every 6 months for 5 years. After age 6 years, the records were obtained at annual intervals (Hunter et al 1993).

Records collection for the sample was begun in 1952, with the earliest records gathered under the supervision of Drs Sontag and Reynolds. The sample is almost exclusively of European white ancestry with approximately 2% black subjects. Approximately 10% of the subjects have had orthodontic treatment. Lateral head films are available for approximately 100 pairs of parents, and more complete records are available for approximately 90 sets of siblings (Hunter et al 1993, Proffit 2007).

2.4.1.5. The Forsyth Growth Study

The Forsyth twin study consists of records for three samples of twins for whom complete records are available from ages 6 to 10 years, 10 to 16 years, and 6 to 16 years respectively. Records are also available from ages 4 to 18 years for a smaller number of twin pairs. In addition to lateral head films, the annual records include PA, lateral jaw and handwrist films, study casts, height, weight, and other anthropometric records. The enlargement factor for the lateral head films is constant at 6% at the midsagittal plane (Hunter et al 1993).

Orthodontic treatment was postponed as long as possible for study subjects and, once begun, the subsequent records were maintained apart from the study. In addition to the records of the twins themselves, there are approximately 200 sets of age-matched sibling records. There are also complete records (taken once) for 225 parents. The sample is entirely of European extraction. The record sets were gathered under the direction of CFA Moorrees (Hunter et al, 1993).

2.4.1.6. The Iowa Child Welfare Study

The Iowa Facial Growth Study is of the diminishing longitudinal type. The sample began with 20 male and 15 female 4-year-old subjects. These sample sizes diminish toward age 17 years; exact figures are not available for each age. Most subjects were recalled at age 25 years.

The Iowa Growth Study is a set of data collected by Drs Meredith and Higley at the University of Iowa starting in 1946. Cephalograms, study casts, and other records were obtained on the participants from ages 4 through 18 years. Another set of records was taken at adulthood around 25 years of age and a final set was taken at 45 years of age. In addition to lateral head films, PA head films are available. Orthodontically treated subjects are not included in the series. Once again all subjects are Caucasians and 97%

were of northern European ancestry. This population provided the material for the series of Iowa Facial Growth studies published during the last 50 years (Hunter et al 1993, Bishara 2000, Proffit 2007).

2.4.1.7. The Krogman Philadelphia Study

The Krogman Philadelphia Study contains lateral, PA head films, and wrist films for several samples of growing Philadelphia children. One mixed longitudinal sub-sample is a group of approximately 600 "healthy, normal, white" children from whom records are available at four to six time points. There is also a serial sample of approximately 150 black children for whom records collection started between the ages of 12 to 15 years and ended at the age of approximately 18 years. In addition, there are also records for some 410 sets of like-sexed twins, mainly of a cross-sectional nature and for approximately 1200 orthodontically treated patients. The records were originally gathered by Wilton M. Krogman.

Finally, there are an unknown number of record sets for subjects with cleft palate (Hunter et al 1993, Proffit 2007).

2.4.1.8. The Mathews Implant Collection

The Mathews Implant Collection contains lateral, frontal and 45° (left and right) cephalograms for 36 children. The sample is of the diminishing longitudinal type and was generated from early mixed dentition subjects presenting for orthodontic consultation at the Orthodontic Clinic between June 1967 and February 1972. The main special attribute of the sample is that metallic implants of the Björk type were placed for all subjects in the sample at the outset of observation. The subjects are exclusively of European white extraction. Approximately one third have received orthodontic treatment (Hunter et al 1993).

The images are presently located at the Craniofacial Research Instrumentation Lab, UCSF.

2.4.1.9. The Meharry Growth Study

The Meharry Black sample contains diminishing longitudinal records for approximately 160 American black subjects acquired during the age interval from ages 6 to 14 years. About 100 of these extend from age 5 years to age 20 years. Subjects were not enrolled after age 6 years. The sample includes records taken every 6 months to age 14 years and at annual intervals thereafter. In addition to lateral head films, there are PA head films, 45° oblique, hand-wrist, and mandibular and maxillary occlusal films. The upper and lower study casts were trimmed separately from each other. There are photographs, height and weight, and medical records (Hunter et al 1993).

There are a few individual records that can be added to the longitudinal data for cross-sectional purposes. The sample consists of approximately equal numbers of males and females. It contains 43 separate sibships with an average of slightly more than three siblings in each family. The sample is entirely of black ancestry (Hunter et al 1993).

2.4.2.0. The Michigan Growth Study

The Michigan sample is of the mixed longitudinal type. There are 99 male and 92 female subjects in the sample with an age range from 5 to 18 years. The main sample consists of lateral head films taken with the teeth in occlusion, PA head films, 45° obliques, hand-wrist films, and trimmed study casts. Weight and height records and some medical histories are available (Hunter et al 1993, Proffit 2007).

In addition, there are lateral head films, PA head films, casts, and height and weight records for about 10 sets of siblings and about 50 parents. The enlargement factor is 12.5% at the midsagittal plane. The treated cases have been grouped in a separate cohort so that the longitudinal sample, as described, is untreated (Hunter et al 1993, Proffit 2007).

The longitudinal sample has also been used as a cross-sectional sample. The male subjects constitute about 60% of the sample. There are several subjects of Asian origin, clearly identified. Otherwise, the sample is entirely of European extraction (Hunter et al 1993, Proffit 2007).

2.4.2.1. The Montreal Growth Study at Le Centre De Recherche sur la Croissance Humaine de l'Universite de Montreal

The Montreal Growth Study is a mixed longitudinal sample with two principle cohorts: (1) 6 to 15 years with at least 50 subjects for each gender at each age, and (2) 10 to 19 years with at least 30 males and 20 females at each age. Because of the overlap of cohorts, there are more than 100 subjects of each gender at each annual time point in the age interval between 10 and 14 years. The subjects were enrolled only at the age of 6 or 10 years. Up to age 16 years, the sample is approximately 55% male (Hunter et al 1993).

In addition to the lateral head films, there are PA head films, panoramic, and hand-wrist films. The study casts have been trimmed, and there are height and weight records. The enlargement factor for the lateral head films is 0.889. None of the subjects has had orthodontic treatment. By design, the sample consists entirely of third generation French-Canadian subjects who are of European ancestry. There are a few sibling records but no parent records in this collection (Hunter et al 1993).

The record sets were gathered under the direction of Arto Demirjian, who served as director. There is a computerized reference file for the data sets that includes gender, age, Angle classification, height, weight, bone age, dental age, and menarche (Hunter et al 1993).

2.4.2.2. The Oregon Health Sciences University Study

The Oregon Child Study contains records for 221 female and 188 male subjects for a total of 409 sets in a mixed longitudinal study from 3 to 18 years of age. The largest number of subjects at any age is 357 (at ages 12 and 13 years), comprising 204 females and 153 males. The lengths of individual records vary from 2 years to more than 30 years. Approximately one third of the records begin at 3 years, with the balance starting at all ages from 4 to 12 years. More than half the sample has records at 18 years, and there are 138 subjects at 21 years, with 20 subjects continuing to 27 years (Hunter et al 1993).

The sample has 55% to 57% females. At age 12 years, for example, there are 204 females and 153 males (including siblings, twins, and triplets). Looked at cross-sectionally, there are 300 to 357 subject records at each annual time point between 10 and 16 years, but there are only 252 subjects for whom there are longitudinal records from 10 to 16 years. These include 20 pairs of twins, accounting for 50 of the 252 subjects (Hunter et al 1993).

In addition to lateral head films, each record set includes wide open, PA, intraoral, and wrist films. The study casts are trimmed. There are photographs, height, weight, oral exam records, and treatment records, as well as medical histories. The enlargement factor for the lateral head films varies and is recorded on each film (Hunter et al 1993).

Of the 409 total subjects, 118 have had orthodontic treatment. There are numerous sibling records and no parent records. The sample is entirely of Northern European extraction (Hunter et al 1993).

2.4.2 Visualized Treatment Objective (VTO)

The amount and direction of facial growth have long been regarded as vital factors in determining the success or failure of orthodontic treatment in a large percentage of patients (Downs 1948, Björk and Skieller 1972). The ability to predict craniofacial growth accurately for individual cases will significantly reduce the difficulty of treatment planning in many instances (Burstone 1963, Ricketts 1957). This ability would be particularly useful when clinical experience suggests that the amount and direction of future facial growth are likely to be unpredictable, but are vital for the successful completion of the treatment plan (Tweed 1954).

Brodie (1946) popularized the idea that the individual's pattern of facial growth, when established at an age, does not change once it has been attained. It is obvious to note that if this were true, then the debate on being able to predict growth would be rendered unnecessary. There is, however now enough evidence in the literature to prove that an individual's growth pattern does change with regard to both amount and direction of growth (Nanda 1955, Björk and Skieller 1972).

In an attempt to better understand and predict craniofacial growth, different authors have used various cephalometric criteria and procedures such as serial cephalometric superimpositions (Tweed 1963) and mesh diagrams (Moorrees 1962). Ricketts (1972) used arcial growth evaluations while Johnston (1975) made use of grids. Popovich and Thompson (1977) used craniofacial templates in trying to account for the individual's current stage of development and to predict future changes by adding mean changes.

The failure to accurately predict growth at the time was to be expected. Ricketts (1962, 1972) recognized this shortcoming and realized the complexity of craniofacial growth prediction for the individual. He subsequently developed the computerized growth-prediction systems.

Ricketts (1962, 1972) advocated the use of computers to predict growth because of the time required to compare, organize, and sort data and then retrieve the information in a clinically useful form. He also stressed the need for individualizing measurements according to age, gender, ethnic type, and degree of maturation of each patient. The Ricketts approach to computerized growth prediction, which takes into account the initial individual facial pattern and then adds a variety of constants representing mean changes, has been available for several years as part of a commercial diagnostic service. However, few objective attempts have been made to validate the accuracy of his approach.

Greenberg and Johnston (1975) evaluated twenty untreated patients and reported that the commercial forecasts were no more accurate than estimates using the addition of constants derived from an independent sample.

Schulhof and Bagha (1975), after examining the longitudinal records of fifty untreated cases, concluded that refined computer methods which took into account individual facial patterns were not markedly more accurate in the 70 percent of patients in the normal range but might show considerable advantage in the 30 percent of patients with abnormal growth patterns, including long face patterns and Class III tendencies.

According to Thames et al (1985) any prediction system has to be able to predict the following:

1. The future size of a part.
2. The relationship of parts (the future facial pattern).
3. The timing of growth spurts (for example, the adolescent growth spurt).
4. The vectors of growth (for example, growth direction).
5. The velocity of growth (growth rate).
6. The effects of orthodontic therapy on any of the above predicted parameters.

The VTO can provide a graphic representation of the individual impact of the most probable pattern of growth and, by so doing, permit the clinician to visualize more readily the effect of various treatment alternatives. The VTO has also frequently been used as a "blueprint" from which a treatment sequence has been derived (Thames et al 1985).

Thames et al (1985) evaluated the accuracy of a commercially available forecasting system (Rocky Mountain Data System-RMDS), in predicting the effects of growth and orthodontic treatment. The pretreatment cephalograms and wax bites of mandibular casts of thirty-three (seventeen males, sixteen females of Northwest European origin), consecutively treated Class II patients with high mandibular plane angles were examined. All patients had already been treated on a non-extraction basis by a single practitioner using high-pull face-bow headgear (Thames et al 1985).

They concluded that the computer generated VTO was more accurate, when compared with the final result, in predicting the effects of growth and treatment on maxillary position and rotation, mandibular length, upper face height, and incisor positions. It was found to be inaccurate in predicting the effects of growth and treatment on maxillary length, mandibular rotation, lower anterior and posterior face heights, and the horizontal and vertical positions of the molars (Thames et al 1985).

The computer generated VTO was also found to be inaccurate in over 50% of the soft-tissue parameters, which included predicting the effects of growth on the size of the nose and the relative antero-posterior positions of the upper lip, lower lip, and soft tissue chin (Thames et al 1985).

A major difficulty with growth prediction based on average changes is that a patient may have neither the average amount nor direction of growth, and thus there is the possibility of significant error. The growth samples were composed mostly of children exhibiting a *normal* growth pattern. In clinical application, growth prediction is really needed for a child who has a skeletal malocclusion (Proffit 2007). His or her problem developed because of growth that deviated from the norm, and for such a child, deviant growth is likely to continue in the future. Which means that average increments and directions are unlikely to be correct. Our ability to predict facial growth, therefore, is poorest for the very patients in whom it would be most useful (Proffit 2007).

In 1971 Reed Holdaway (cited Bench 1971) was the first person to introduce the term, "visualized treatment objective" (VTO), to describe his predicted treatment result. He produced his VTO by taking a cephalogram, growing the individual skeletal framework on a tracing, building a soft-tissue profile, and then inserting the teeth in desired positions to achieve that profile, placing the upper incisor in the ideal position and then positioning the lower incisor according to that of the upper incisor.

Bench (1971) supported the use of cephalometric prediction, stating that the visualized treatment objective (VTO) allowed for selection of the most applicable treatment plan based on the individual's growth pattern.

Important in the application of the VTO was the attainment of ideal dental and soft tissue relationships.

The VTO's developed by Jacobson and Sadowsky (1980), Ricketts et al (1982) and Holdaway (1984) were initially developed for a Northern hemisphere population group and have subsequently been applied to other ethnic groups.

2.4.2.1 DESCRIPTION OF VTO's

a) Ricketts VTO

Ricketts (1957) had previously developed a similar method using cephalometric radiography in which craniofacial growth and orthodontic treatment effects were predicted. Ricketts' treatment prediction also allowed for a forecast of the integumental profile, which was based on the reaction of the skeletal elements and the teeth to orthodontic treatment. Ricketts (1957) claimed that his technique "appeared to be sensibly accurate in more than ninety percent of routine clinical cases to date."

In 1960, Ricketts stated that all treatment planning constituted some type of prediction. He suggested estimating the amount of change that should occur by predicting the possibilities of tooth movement and facial change. Ricketts called his method of prediction a "dynamic synthesis" in which craniofacial growth and tooth movement were predicted (Ricketts 1960) (Appendix B).

Ricketts et al (1982) and Bench (1971) used a different approach. They positioned the teeth, first the lower incisor in the corrected position, in the preconceived ideal relations and depended on the soft tissue to drape over these new tooth positions in a harmonious relation. They put it succinctly another way - "Begin with the end in mind."

b) Holdaway VTO

Holdaway (1983, 1984) took a different approach to cephalometric prediction. The goal of his "dynamic" cephalometric analysis and prediction was to establish a balanced facial profile with pleasing facial esthetics and to evaluate the orthodontic correction necessary to obtain the latter goals.

The main difference between Holdaway's VTO and other types was that Holdaway predicted the soft tissue profile first, then the positions of the maxillary incisors. Holdaway re-emphasized the importance of soft tissue analysis as he quantified certain soft tissue relationships in harmonious faces (Holdaway 1983, 1984) (Appendix C).

In contrast to Ricketts, Holdaway believed that the mandibular incisor could not be rigidly fixed to any anatomical landmark such as the A-Pogonion line (APo). Instead, the mandibular incisors should be placed relative to the maxillary incisors where adequate lip support had been established (Holdaway 1983, 1984).

c) Steyn VTO

Steyn (1979) devised his own VTO and described some norms for South African Caucasian patients. His VTO uses the S-N and Ba-Na planes and is gender specific. He allocated different increments of growth, in certain areas, for males and females (Appendix D). The lower incisor is positioned according to APo and then the upper incisor is positioned relative to this (Steyn 1979).

d) Jacobson and Sadowsky VTO

Jacobson and Sadowsky (1980) stated that the VTO is a dynamic cephalometric analysis which takes into account both growth and biomechanics, thus achieving its aim of being a Visualized Treatment Objective. It outlines a goal from the inception of treatment and may be usefully employed in monitoring growth and treatment progress. Devised a soft tissue template to help in constructing the soft tissue outline. As with the Holdaway VTO, the upper incisor is positioned after the soft tissue has been constructed (Jacobson and Sadowsky 1980) (Appendix E).

2.4.2.2 Differences between VTO's

There are essential differences with regards to the different VTO. These include the reference planes used, the amount of growth as well as the direction in certain areas. They also differ according to whether the teeth are positioned and then the soft tissue draped, or whether the soft tissue is first positioned with the teeth following it. Placement of the incisors is also a point that sets the various VTO apart. Should the lower incisor be placed first or should the lower incisor determine the position of the upper incisor and subsequently the soft tissue drape?

Although similar to the Holdaway VTO (1984), Jacobson and Sadowsky (1980) VTO reported three times the amount of the growth at Nasion than Holdaway (1984). Another difference is the introduction of the “lip contour template” that assists in the location of the H-line. Other differences include the use of the Basion-nasion reference line rather than the Sella-Nasion line (Jacobson and Sadowsky 1980).

2.4.2.3 Advantages of VTO’s

Several authors have discussed the advantages of VTO’s (Jacobson and Sadowsky 1980, Magness 1987, Sarver 1993 and Ackerman and Proffit 1995), and some of these can be summarized as follows:

(1) establishment of specific treatment goals, (2) formulation of a specific treatment plan to reach treatment goals, (3) assistance in determining if the ideal treatment result is attainable orthodontically or surgically, (4) assistance in making mid-treatment corrections, (5) enhancing communication between patients and clinicians, (6) allowing quantification of proposed movements to reduce the difficulties in planning facial response to different movements, and (7) allowing rapid comparisons of different treatment options before arriving at a final treatment plan.

2.4.2.4 Limitations of VTO's

Despite the listed advantages of VTO, limitations exist in their implementation. Several authors (Ricketts 1960, Johnston 1968, Jacobson and Sadowsky 1980, Holdaway 1984 and Sarver et al 1998) have described inadequacies of VTO, including:

(1) the use of average growth increments in growth prediction,
(2) the use of existing morphological traits to predict future growth events, and
(3) the fallibility of presenting VTO analysis as an exact representation of the treatment outcome. Most authors agree that the experience of the clinician also plays a large role in the accuracy of the VTO prediction (Ricketts 1960, Johnston 1968, Jacobson and Sadowsky 1980, Holdaway 1984 and Sarver et al 1998).

2.4.2.5 Reliability of Computer VTO's

Canglalosi et al (1995) examined the reliability of a commercially available computer prediction program (Quick Ceph II) using pretreatment and post-treatment cephalograms of 30 patients who were treated during an active period of growth. Canglalosi et al (1995) found that the computer came closer to the actual result in four of nine variables tested, while the manual method came closer in three variables.

The manual method of prediction was sufficient to give a reasonably good graphic representation of growth changes to create a VTO. They concluded that the computer offers the added advantages of quicker access to information and somewhat greater accuracy in producing the tracing, as well as its use in patient education (Canglalosi et al 1995).

Sample et al (1998) assessed the reliability of manual and computer-generated VTO when compared with the actual treatment results. Their sample consisted of 34 growing Class II patients. They found that both the manual and computer VTO methods were accurate when predicting skeletal changes that would occur during treatment.

Only slight differences were seen between the manual and computer VTO methods, with the computer being slightly more accurate with the soft tissue prediction. However, the differences between the two methods were not judged to be clinically significant. Overall, the prediction tracings were accurate to only a moderate degree, with marked individual variation evident throughout the sample. They concluded that the prediction of the final position of the incisor was always difficult even in non-extraction cases (Sample et al 1998).

Toepel-Sievers and Fisher-Brandies (1999) examined the validity of Ricketts computer-assited cephalometric growth prognosis VTO. Cephalograms of 180 patients, who were treated over a period of 2 and 5 years were analyzed. After the completion of active treatment the actual outcome was compared with the predictions. They found that the VTO yielded satisfactory results for the skeletal variables tested but were unsuccessful in predicting the dental relations, the of dentoskeletal relations or the soft-tissue configuration.

According to them the VTO is capable of giving a largely valid prognosis of skeletal growth tendencies, however, in view of the large number of parameters affected by therapeutic measures, the VTO prognosis must be expected to differ from the actual treatment outcome (Toepel-Sievers and Fisher-Brandies 1999).

Le et al (1998) evaluated the accuracy of computerized video imaging in predicting the soft tissue outcome of extracting four premolars, like in our study. However their sample consisted of adult patients (while other samples concentrated on actively growing patients). They concluded that both the VTO and video images were accurate enough to be used for patient- education and communication, as well as for diagnosis and treatment planning.

While lay people found that the predicted video images adequately resembled the actual outcomes, orthodontists were more critical, particularly of the lower lip area where variable soft tissue responses to treatment were noted (Le et al 1998). It should be re-iterated that their sample consisted of adult patients with growth playing a minor role in the overall outcome. Lu et al (2003) evaluated the accuracy of the outcome in soft tissue prediction through the use of a computer imaging system after bimaxillary orthognathic surgery. The computer-generated soft tissue image and the actual post-surgical profile were compared. The accuracy of this computer-generated profile image was then evaluated.

Although they did not evaluate the effect of orthodontic treatment, Lu et al's (2003) results are never the less interesting as they indicated that the nasal tip, soft tissue A point, and upper lip presented the least errors in predictions in the sagittal plane. The nasal tip had higher prediction reliability. As in our study lower lip prediction was found to be the least accurate region and tended to be located anterior to the actual position. In the vertical plane, most of the predictions revealed higher accuracy than those in the sagittal plane (Lu et al 2003).

Lu et al (2003) concluded that the computer-generated image prediction was suitable for patient education and communication. However, efforts are still needed to improve the accuracy and reliability of the prediction program and to include the consideration of changes in soft tissue tension and muscle strain. The accuracy of this system in soft tissue prediction should therefore be carefully interpreted (Lu et al 2003).

2.4.3 Hard and soft tissue response to treatment

Controversy still continues today over the relationships of the hard and soft tissues. Riedel (1957) stressed that the soft-tissue profile is closely related to the skeletal and dental structures. Subtelny (1959) indicated that not all parts of the soft-tissue profile directly follow the underlying skeletal profile.

Burstone (1959) suggested that a direct relationship may not always exist because of the variation in the thickness of the soft tissue covering the skeletal face while Stoner et al (1956) concluded that the recontouring of the lips seemed to occur because of the gross movement of the incisor teeth. Neger (1959) on the other hand stated that a proportionate change or improvement in the soft-tissue profile does not necessarily accompany extensive dentition changes. Wylie (1955) concluded that modification of the facial profile by orthodontic means does not depend on the inclination of anterior teeth.

Subtelny (1959) studied 15 male and 15 female subjects until the age of approximately 15 years. He reported that the correlation between the hard and soft tissue growth is not strictly linear. He noted that the vertical relationship of the incisal edge of the maxillary central incisors to the tip of the upper lip is constant after the age of 9 years. He also added that soft tissue growth is quite independent of underlying skeletal tissues. He found that the soft-tissue thickness overlying bony point A in three periods, from 9 to 18 years of age, increased by an average of slightly more than 1mm in boys and slightly less than 1mm in girls.

Bloom (1961) concluded from his study that it is still possible to predict the perioral soft-tissue changes in relation to the expected amount of anterior tooth movement.

Previous longitudinal studies (Burstone 1958, Subtelny 1959, Vig and Cohen 1979 and Bishara et al1985,) have shown that the lips increase in thickness from 7 to 20 years of age, more so in boys than in girls. The lower lip grows to a significantly greater extent than the upper lip, and the lips grow to a greater extent than the anterior skeletal facial height. Most of the reported growth changes suggest gender dimorphism.

The change in the soft tissue profile caused by tooth movement has distinct characteristics which cannot be calculated or easily described in a formula. Facial soft tissue configuration may be as variable as malocclusion itself. Nevertheless, a prediction of post-orthodontic profile change is still possible. To properly predict post-treatment change, each individual case must be studied carefully for soft tissue movement patterns (Yogosawa 1990).

Halazonetis (2007) examined the variability in shape of the soft-tissue profile outline and found that this was mainly concerned with the protrusion of the nose and chin relative to lip protrusion, convexity of the face, and lower lip shape.

He also found that relative nose and chin protrusion increased with age, similarly for both genders. Shape dimorphism was found between the sexes, both before and after the age of 12 years. However, sex differences in shape were small and that age changes in shape appeared to be more significant (Halazontis 2007).

2.4.4 Profile changes

The relationship between orthodontic tooth movement and changes in the soft-tissue profile draping around the mouth is still today not clear. Altering the dentoskeletal framework by orthodontic therapy may produce desirable or undesirable changes in the soft-tissue contours (Bloom 1961).

The orthodontist is often confronted with the need to predict soft-tissue profile changes that may result from orthodontic treatment. A problem arises because the contribution of many of the factors influencing the soft-tissue profile is still not fully understood. The complexity of the problem is increased in growing patients in whom the post-treatment soft-tissue profile is the result of both growth and orthodontic treatment (Talass et al 1987).

During treatment it is possible to produce changes in tooth position, skeletal relation, and the soft tissue profile of an individual. These changes in the soft tissue profile, due to alterations implemented by treatment and concomitant growth, are among the most obvious overt changes that the orthodontist is given credit for, or is held liable for by the patient and family (Chaconas and Bartroff 1975).

Case (1921, cited Chaconas and Bartroff 1975) was one of the early pioneers in facial aesthetics. He declared that facial outline should be an important guide in determining treatment objectives and procedures. He advocated extraction in some cases of bimaxillary protrusion to retract the procumbent lips. Case was aware of the soft tissue and he pointed out that the facial type did not have a certain accompanying malocclusion. Therefore, one should not depend on the profile for a complete diagnosis (Chaconas and Bartroff 1975).

The soft tissue profiles of patients with bimaxillary protrusion may not be considered aesthetically pleasing. These patients characteristically have dentoalveolar flaring of the maxillary and mandibular anterior teeth, with resultant protrusion of the lips and convexity of the face. To reduce the facial convexity and allow retraction of the anterior teeth to a more pleasing and possibly a more stable position, the treatment of choice includes extracting the four first premolars (Farrow et al 1993).

Sushner (1977) studied 100 lateral photographs of attractive blacks. He compared the Steiner, Holdaway, and Ricketts standards with the black profile. He concluded that the black soft tissue profile was significantly more protrusive than white profiles and that evaluation of black profiles should be made without the imposition of white standards. He established black norms by using Steiner, Holdaway, and Ricketts aesthetic lines (Sushner (1977). Connor (1985) confirmed that the black soft tissue profile was more protrusive and differed significantly from white norms.

2.4.5 Lip posture and lip length

Burstone (1959) felt that much variation exists between individuals in regard to soft tissue thickness, length, and posture overlying the hard tissue foundation of the human face. He found, in his study of lip posture, that there was no support for the hypothesis that lip posture followed the posture of the underlying teeth. On the contrary, Burstone (1959) suggested that lip posture may be the aetiologic factor causing a mal-relationship of the teeth. As there was no significant correlation between lip profile and tooth position, he advocated that lip posture should be a primary factor in treatment planning. Lip length and posture are different for each individual and therefore affect and are affected differently (Burstone 1959).

It is especially important to study the relaxed lip posture due to its accuracy in determining post-treatment posture as Burstone (1967) has described. Therefore, for clinical application, understanding the basic soft tissue treatment response and pre-operative relaxed lip posture offers a framework for the prediction of post-orthodontic facial profile change (Yogosawa 1990).

Vig and Cohen (1979) conducted a serial cephalometric study to evaluate vertical growth of the lips. They concluded that the lower lip was shown to grow significantly more than the upper lip, in both absolute and proportional terms. The upper and lower lips together grow to a significantly greater extent in absolute terms than the anterior lower face height. It is of interest to note that the age interval during which the most marked changes occur in lip separation and in the relationship of the lower lip to the upper incisors is between 9 and 13 years (Vig and Cohen 1979).

Mamandras (1984) studied the growth of lips longitudinally in twenty-eight persons from 8 to 18 years of age. The findings of his investigation indicate that the lip area increases in size with advancement of age from 8 to 16 years. During this period the most marked increase occurred between the ages of 12 and 14 years. The mean percentage increase of the maxillary and mandibular lip areas from age 8 to age 18 years was 59.0 and 57.9 for the males and 27.1 and 39.7 for the females (Mamandras 1984).

The work of Nanda et al (1990) studied soft tissue growth in harmonious facial patterns. Gender dimorphism was reported by the authors in most soft-tissue growth changes, especially concerning timing and rates of growth. Girls were found to essentially stop growing at 15, but boys continued even after 18 years.

Prahl-Andersen et al (1995) concluded that the upper lip is higher in girls than in boys, in relation to the maxillary incisor, whereas the lower lip is more protruded in boys than in girls. These findings are similar to the study done by Halazonetis (2007), regarding both the position of the lower lip and the higher vertical position of the upper lip and the overall gender dimorphism of the soft tissue.

2.4.6 Soft tissue chin

Subtelny (1959) attempted to longitudinally evaluate growth of the soft tissue in relation to the underlying skeleton. He obtained from the Broadbent Bolton collection serial cephalometric records of thirty patients from 3 months to 18 years of age. All of the subjects had normal skeletal profiles meaning that there was no abnormal protrusion or retrusion of facial structures.

He found that, as a result of growth, both the skeletal and integumental chin assumes a more forward relationship to the cranium. The integumental chin was closely related to the degree of prognathism of the underlying skeletal framework. The bony facial profile becomes less convex with age, but the total soft tissue profile (including the nose) increases in convexity with progression of growth (Subtelny 1959).

The soft tissue profile, excluding the nose, tends to remain relatively stable in its degree of convexity. In this respect, soft tissue changes are not analogous to those exhibited by the skeletal profile. Changes take place in the thickness of soft tissue covering the bony profile with a proportionally greater increase in the thickness of soft tissue covering the maxillary region than is found in the areas of nasion and pogonion (Subtelny 1959).

2.4.7 The nose

The nose continues to grow downward and forward from 1 to 18 years of age and is responsible for the total soft tissue profile increase in convexity with age. Both lips show a fairly constant vertical and anteroposterior relationship to the anterior teeth as well as to the underlying alveolar process. Subtelny's results indicate that all parts of the soft tissue profile do not directly follow the underlying skeletal profile (Subtelny 1959).

Behrents (1985) observed that the tip of the nose moved forward and downward more than either subnasale, point A, or the upper lip. This differential movement made the nose appear more prominent. The tip of the nose and stomion moved vertically, but the upper lip lengthened more (moving downward more than forward).

Chaconas (1969) evaluated, on a longitudinal basis, hard and soft tissue nasal growth and its relationship to total face morphology. He found that, regardless of dental classification, with growth the convexity of the soft tissue profile increased markedly when the nose was included in the evaluation. His results in this area thus coincided with that of Subtelny's findings. In a later study by Chaconas and Bartroff (1975), they concluded that it is now possible to predict soft tissue facial form for an individual, given the profile configuration of that person at an earlier age.

In 1998 Bishara et al described the changes in soft tissue that occurs as a result of orthodontic treatment. They also looked at profile changes that occur with growth and orthodontic treatment. Their subjects consisted of 20 males and 15 females between 5 and 45 years of age.

Their findings showed that growth changes in both males and females were similar in both magnitude and direction. The timing of the greatest changes in the soft tissue profile occurred earlier in females (10 to 15 years) than in males (15 to

25 years). Soft tissue convexity, excluding the nose, showed very little change between 5 and 45 years. Both the upper and lower lips became significantly more retruded in relation to the esthetic line between 15 and 25 years of age in both males and females. This trend also occured between 25 and 45 years of age. They also found that the Holdaway soft tissue angle (H-angle) decreases progressively between 5 and 45 years of age (Bishara et al 1998).

Bishara et al (1998) concluded that it is important for clinicians to be aware of these changes when planning the orthodontic treatment of the still growing adolescent patients because the changes might influence the extraction/nonextraction decision.

2.4.8 Treatment and soft tissue response

Tan (1996) studied the changes in soft tissue and skeletal profiles following orthodontic correction of bimaxillary protrusion in 50 Chinese adult patients. Treatment involved extractions of four premolars. Treatment resulted in a more harmonious soft tissue profile; with a reduction in the nasolabial angle. They also found a 2.75- and 2.09-mm reduction in upper and lower lip protrusions, respectively, and a 3.41mm decrease in interlabial gap.

Effects on dental relationships included a 0.90-mm reduction in incisal show, a reduction of overbite, and an improvement in the inclination of maxillary and mandibular incisors. It was concluded that orthodontic correction of bimaxillary protrusion achieved favorable soft tissue changes without causing undesirable effects on the underlying hard tissues (Tan 1996).

Hershey (1972) examined thirty-six female patients, studying the response of the perioral soft tissue to incisor tooth retraction. His sample consisted of thirty two cases which were treated with the removal of four first premolars and the remainder were treated by a non-extraction approach.

As the amount of incisor retraction increased, the reduction of lip prominence to adjacent sulcus also increased. Increased amounts of tooth movement tended to produce relatively less prominent lip contour. Increasing the magnitude of upper incisor retraction decreased the strength of the correlation between tooth movement and lip response. The response of the soft-tissue profile to incisor tooth retraction showed no significant differences between Class I and Class II subjects. The sample consisted of subjects who were sixteen at the start of treatment, so as to minimize the effect of growth (Hershey 1972).

Talass et al (1987) found from their study of 133 white female subjects that generally growth was associated with only minimal changes in the soft-tissue profile in a period not exceeding 36 months. They found three clinically significant soft-tissue changes that occurred in response to orthodontic treatment. These included a mean upper incisor retraction of 6.7 mm were the upper lip was retracted, increase in the lower lip length and an increase in the nasolabial angle. In general, changes in the lower lip in response to orthodontic tooth movement were more predictable than those of the upper lip. The low degree of predictability associated with the upper lip response to orthodontic tooth movement may be caused by the complex anatomy and/or dynamics of the upper lip, which they believed could not be evaluated by the available cephalometric techniques at the time (Talass et al 1987).

Other soft-tissue changes, which were of little clinical significance, included the retraction of the lower lip, the reduction of the interlabial gap, and the increase in the thickness of both the upper and lower lips, the increase in the soft-tissue lower facial height and the lower soft-tissue component, which is the distance between lower stomion and soft-tissue menton. The length of the upper lip did not increase with either growth or orthodontic treatment (Talass et al 1987).

2.4.9 Incisor position

It is widely accepted that the position of the lower incisors is of clinical importance in treatment planning. Many clinicians feel that lower incisor position is influenced more by soft tissue than skeletal factors, however, it is still unclear whether moving the lower incisors into more ‘normal' relationships will bring about a favourable change in soft tissue pattern (Mills 1986).

The problems of relying on cephalometric points and planes distant from the area of interest, e.g. SN line, Frankfort plane, have been highlighted by Björk (1955). He showed S (Sella tursica) and N (Nasion) points can undergo considerable movement with growth independent of other cranial structures.

Hussels and Nanda (1984) have detailed factors which affect the accuracy of the ANB angle skeletal assessment, and it would seem that this is a relatively poor measure of anteroposterior discrepancy. The validity of lower incisor prognosis measurements involving S and N points. and ANB angle, is therefore questionable.

Tracing and superimposition errors have also been well documented (e.g. Gravely and Benzies 1974) and can be responsible for reduction in accuracy of formula based assessments.

Hixon (1972) has warned against the trend of applying increasingly complicated cephalometric measurements to a biological system; this is relevant to lower incisor position, where individual variation and the uncertain effects of growth and treatment can render the most elaborate analysis worthless.

Williams (1986) found that the A-Po line is probably the most useful adjunct to treatment planning; unlike many other reference lines it is closely related to the structures influencing lower incisor position and the modifying effects of treatment and growth can be clearly visualized. Moreover it is uncomplicated by the need for extensive analysis or accurate measurement. It would seem wise, however, to adopt a cautious approach in the light of Mills' work and avoid planning an excessive movement of the lower incisors (Mills 1986).

Park and Burstone (1986) evaluated thirty adolescent patients who were successfully treated to a cephalometric standard with lower incisors positioned approximately 1.5 mm anterior to the point of A-Po line. Large variation was found in the amount of lip protrusion even though the goal of incisor positioning was achieved. They concluded that facial aesthetics requires consideration of soft tissue factors in addition to hard-tissue structures (Park and Burstone 1986).

2.50 Incisor reposition and upper lip changes

Ricketts (1960a) reported that the lips would increase in thickness 1 mm for every 3 mm of incisor retraction. He indicated that the upper lip would return to its original thickness after treatment. Ricketts (1970) found that there was no significant relationship between retraction of upper incisors and anteroposterior lower lip changes after treatment.

Anderson et al (1973) found that the soft-tissue thickness of the upper lip increased during treatment at the same time the incisor was being retracted. Their sample consisted of seventy patients treated orthodontically at the University of Washington and in the private practice of Dr Reidel. No mention was included of the gender or age of the patients. They reported that during and after retention, upper lip thickness decreased, but not to its original dimension. They found that the thickness of the lower lip was not affected by orthodontic treatment (Anderson et al 1973).

They also found that the soft tissues of the facial profile were closely related and dependent on the underlying dentoskeletal framework. Orthodontic treatment resulted in a reduction of dentofacial protrusion with both upper and lower lips becoming less procumbent during treatment. This alteration in position was due to the lingual movement of maxillary and mandibular incisors. It was also noted that the soft tissue profile continued to flatten with additional nasal and chin growth during maturation following treatment (Anderson et al 1973).

The thickness of the upper lip increased considerably during treatment and this change was related to maxillary incisor retraction (1.0 mm lip thickening for every 1.5 mm of maxillary incisor retraction). During and after retention this lip thickness decreased, but not back to the original dimension.

They also found that a significant increase remained ten years post-retention. It was noted that the thickness of the lower lip was not affected by orthodontic treatment. Males showed significantly more growth than females in soft tissues of the nose, base of the upper lip and chin (Anderson et al 1973).

They concluded that Holdaway's H line seemed to be the most practical approach to soft tissue analysis.

Garner (1974) in a study of black subjects, concluded that the extent of lip change was unpredictable, when referring to white norms in the sagittal dimension. Clinically the relative length of the upper lip and the position of the tip of the incisal edge of the maxillary incisors have been a significant part of treatment planning.

In a study by Jacobs (1978), a total of 20 white patients (Class II, Division 1 requiring four first premolar extractions) were studied to evaluate vertical lip changes after maxillary incisor retraction. A high correlation was found between closure of the interlabial gap and the retraction of maxillary incisors. He stated that the interlabial gap closes vertically at a ratio of 1 mm for every 2 mm of horizontal retraction of maxillary incisors (Jacobs 1978).

Park et al (1989) evaluated vertical changes of the lips in North American black patients after four first premolar extractions. Age range of patients at the beginning of treatment was 10 years 6 months to 16 years 1 month for girls and 9 years 6 months to 13 years 10 months for boys. Ten of the patients were classified as skeletal Class I with bimaxillary dental protrusion; five of the patients were skeletal Class II with a Class II Division 1 dental relationship.

Their findings indicated that retraction of the maxillary incisors correlated with an increase in upper lip depth, an increase in interlabial gap, and an increase in the inferomentolabial angle. The increase in interlabial vertical dimension correlated with an increase in the horizontal dimension of the upper lip relative to upper incisor retraction. This increase in interlabial vertical dimension relative to upper incisor retraction differed significantly from the results of the study by Jacobs (1978) on a sample of white patients treated with four first-premolar extractions (Park et al 1989).

Dental and skeletal tissue changes in the perioral region can affect the lip, nose, and chin areas (Subtelny 1959, Burstone 1959). These dental and skeletal tissue changes can be produced by surgery, growth, orthopedic forces, and orthodontic movement of the teeth. Changing the inclination and position of the teeth, either by protraction or retraction, directly influences the overlying soft tissue, particularly the lips (Bloom 1961, Wisth 1974, Rains and Nanda 1982).

Prediction of upper lip movement in response to tooth movement has usually been expressed as the ratio of maxillary incisor retraction to upper lip retraction, but this ratio has varied according to gender, treatment modality, and ethnicity (Rudee 1964, Hershey 1972, Wisth 1974, Rains and Nanda 1982, Talass et al 1987, Yogasawa 1990) (Table 2).

Bloom (1960) examined perioral changes associated with incisor retraction by using linear regression analysis. Although no ratio was discussed, he reported a high positive correlation (r = 87) between the two.

Rudee (1964) reported that a 2.9:1 ratio existed between maxillary incisor retraction and upper lip repositioning. Oliver (1982) showed a statistically significant correlation between incisor retraction and lip repositioning in individuals with thin, highly strained lips. As lip thicknesses increased and strains decreased, the correlations fell to non significant levels. Hershey (1972) presented his findings on the effects of incisor retraction on the soft tissue profile.

As the magnitude of the incisor retraction increased, the correlation between soft and hard tissues decreased. Wisth (1974) showed that, when incisors were retracted 3 to 4 mm, a 2:1 ratio existed between incisor and lip retraction. When there was 8 to 10 mm of incisor retraction, a 6:2.5 ratio existed, but neither of these ratios was statistically significant. His results showed the great variability that exists between incisor retraction and lip response that serves to indicate that prediction of soft tissue changes in an individual case is difficult.

Subtelny (1959) studied the effect of gender and maturation of the soft tissues of individuals with maxillary incisor and lip retraction. He noted that from 9 to 18 years of age, the thickness of the upper lip increased 3.5 mm in males and 2.9 mm in females over point A.

Kokodynski et al (1997) reviewed the literature with regards to incisor retraction and profile changes and found considerable controversy remains with regards to the effects of incisor retraction on lip retraction. They concluded that studies all suffer from certain limitations. Among these limitations are the roles gender and maturation play; the effects of thickness, strain, and length of the upper lip; the way in which reference plane measurements are taken; and the ability to define points reliably on each cephalometric radiograph.

They therefore undertook a study to determine whether a correlation exists between maxillary incisor and upper lip retraction and whether there is a statistically significant ratio between maxillary incisor retraction and lip retraction that would aid in predicting soft tissue changes in non growing patients (Kokodynski et al 1997).

They concluded that maxillary incisor retraction and associated upper lip changes were studied in 30 male and 30 female post adolescent orthodontic patients (all white). Although a ratio for predictive purposes was determined for each of these groups, their absolute value is questionable because no apparent pattern exists between them. It was found that as lip thickness increased and lip strain decreased, correlation coefficients fell to non-significance, making it more difficult to predict upper lip change resulting from maxillary incisor retraction in these individuals (Kokodynski et al 1997).

The upper lip changes both horizontally and vertically with incisor retraction, but these changes are incompletely explained by lip thickness, lip tonicity, initial incisor inclination, lip length, and lower lip proximity (Brock et al 2005).

Table 2. Summary of existing literature on horizontal upper lip response to incisor retraction (Brock et al 2005).

Race/Ethnicity	*Movement*	*Landmarks*	*Study*	*T1 age (years)*	*N*
NR	2:1	Ia:Ls	Rudee	6-22	85
White	3:1 (female)	Ia:Ls	Hershey	>16	36
Black	3.7:1 (combined) 2:1 (female only)	Is:Ls	Garner	11-15	16
NR	2:1 (nonetraction) 3:1 (extraction)	Is:Ls	Wisth	11-12	60 (male)
White	1.6:1 (female)	Ia:Ls	Rains	15-23	30
White	1.6:1 (female)	Is:Ls	Talass	10-18+	80
Asian	2.5:1 (female)	Is:Ls	Yogosawa	Adult	20
Asian	2.1:1 (combined)		Lew	22 (mean)	16
Black	3.2:1 (female) 2.8:1 (male)	Is:Ls	Diels	10-17	60
Black	1.6:1 (female)	Ia:Ls	Caplan	15-34	28
White	1.5:1 (female) 1.6:1 (male)	Is:Ls	Kokodynski	>16	60

Ethnic differences in soft tissue composition and morphology could also influence upper lip response to incisor retraction. Cephalometric data for a black population group show significant differences between normal hard and soft tissue values compared with white subjects (Altemus 1960, Kowalski and Walker 1972, Kowalski et al 1974).

As shown previously blacks have greater incisor inclination and a more protrusive soft tissue profile (Kowalski and Walker 1972, Alexander and Hitchcock 1978)

Brock et al (2005) examined whether there are ethnic differences in the upper lip response to incisor retraction. They used 88 post-pubertal female patients (44 black and 44 white) as their sample which were matched by age and the amount of incisor retraction at incisor superius. Their results showed that although significant pretreatment differences existed between the groups in some cephalometric measurements, analysis of the treatment changes demonstrated significant differences only in incisor inclination (Brock et al 2005).

They concluded that the hard and soft tissue treatment changes of the black group were more downward and those of the white group were inclined to be in a backward direction. Ethnic differences exist in the soft tissue response to hard tissue changes in the upper lip, and at subnasale and the superior labial sulcus: however, these response differences at superior labial sulcus can be explained by ethnic differences in initial lip thickness and incisor inclination; they are not due in and of themselves to ethnicity (Brock et al 2005).

The change at prosthion corresponded with the response of the upper lip at labrale superiorus to incisor retraction. Ethnicity did not improve the predictability of the response. When incisor retraction was performed, the final, horizontal, upper lip position could be accurately and reliably predicted (Brock et al 2005).

From the literature it can be concluded that predicting the soft tissue and hard tissue response in the growing patient following treatment will not be easy. Factors such as those relating to the patient, growth, soft tissue composition, amount of incisor retraction as well as those pertaining to treatment, such as mechanics and various techniques all conspire to make this part of orthodontics both interesting and difficult.

Generally it is easier to predict the hard tissue response as well, to a degree, the responses of the nose, chin and upper lip. It seems far more difficult to predict the response of the lower lip. There is paucity in the literature with regards to the response of the soft tissue in bimaxillary protrusive patients.

CHAPTER 3

METHOD AND MATERIALS

3.1. Aim and objectives

The aim of this research project was to assess the accuracy of four different types of VTO in predicting the final result of orthodontic treatment in bimaxillary protrusive patients.

The objectives were to determine whether:

(1) the VTO can accurately predict the final result;
(2) present VTO's are applicable to bimaxillary patients;
(3) the soft tissue response can be predicted;
(4) the dental response can be predicted;
(5) a specific VTO is better suited to the bimaxillary patient.

In this study the VTO's were be used to predict the final treatment result, based upon the pre-treatment cephalogram and pretreatment study models. The study models were used to calculate the amount of crowding or excess space present. This value was then factored into the VTO's.

3.2. Research sample

A retrospective study was structured to analyze the records of forty-five cases (28 females and 17 males) with bimaxillary protrusion who had undergone orthodontic treatment after extraction of four first premolars. The cephalometric analysis according to Keating (1986) was used to confirm the diagnosis of bimaxillary protrusion.

Cephalometric criteria:

(a) An inter-incisal angle less than 125°.
(b) An upper incisor axis to maxillary plane greater than 115°.
(c) A lower incisor axis to mandibular plane (Downs 1948) greater than 99°.

Patient selection criteria:

1. Patients who were treated by the same operator;
2. Patients for whom complete pre- and post-treatment records are available with initial and final cephalograms taken with the same x-ray machine;
3. Patients in the age range of 12-16 years at the start of treatment;
4. Patients with no congenitally missing teeth;
5.

Exclusion criteria:

Nonextraction cases and cases where other premolar extraction sequences (other than four first premolars) were done, orthognathic surgery cases and patients with cleft lip and palate defects or craniofacial dysmorphology.

3.3 Cephalometric landmarks and measurements used in this study

Pre and post-treatment cephalograms were used from patients who met the inclusion criteria. Pre-treatment study casts were used to determine the amount of dental crowding or spacing present. These values were later factored into the VTO. Cephalometric landmarks which were used in this study are depicted in Table 3 and Figure 3.

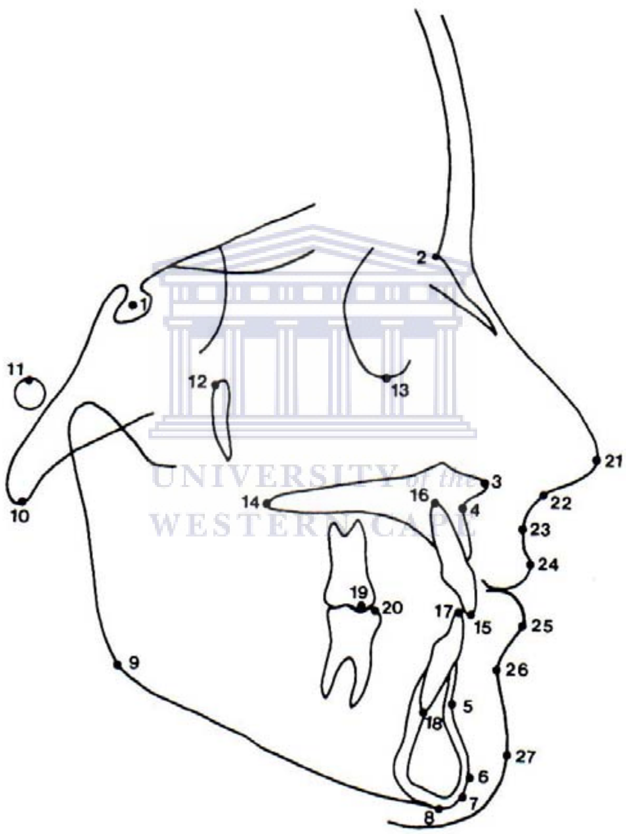


Figure 3. Cephalometric points digitized

Legend. **1 = Sella, 2 = Nasion, 3 = Anterior nasal spine, 4 = Point A, 5 = Point B, 6 = Pogonion, 7 = Gnathion, 8 = Menton, 9 = Gonion, 10 = Basion, 11 = Porion, 12 = Ptm, 13 = Orbitale, 14 = Posterior nasal spine, 15 = Incisor (upper), 16 = Maxillary incisor apex, 17 = Incisor (lower), 18 = Mandibular incisor apex, 19 = Mesial cusp of upper 6, 20 = Mesial cusp of lower 6, 21 = Pronasale, 22 = Subnasale, 23 = Superior labial sulcus, 24 = Labrale superius, 25 = stomion superius, 26 = inferior labial sulcus, 27 = soft-tissue pogonion.**

Table 3. Digitized points used in the study

1) **Sella (S)** - *The centre of the sella turcica, determined by inspection*

2) **Nasion (N)** - *The most anterior part of the fronto-nasal suture as seen in the lateral skull radiograph*

3) ***Anterior Nasal Spine (ANS)*** *– The anterior tip of the sharp bony process of the maxilla at the lower margin of the anterior nasal opening*

4) ***Point A*** *- Also known as subspinale, the most posterior midline point in the concavity between anterior nasal spine and the prosthion (the most inferior point on the alveolar process overlying the maxillary incisors)*

5) ***Point B*** *- Also known as supramentale, the most posterior midline point [in the concavityt on the mandible] between the most superior point on the alveolar process overlying the lower incisors (infradentale) and pogonion*

6) ***Pogonion (Pog)*** *- The most anterior point on the chin*

7) ***Gnathion (Gn)*** - A point located by taking the midpoint between the anterior (pogonion) and inferior (menton) points of the bony chin

8) ***Menton (M)*** *- The lowest point on the symphyseal shadow of the mandible seen on the lateral cephalogram*

9) ***Gonion (Go)*** *- A point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and inferior border of the mandible*

10) ***Basion*** *-The lowest point on the anterior rim of foramen magnum*

11) ***Porion (Po)*** *- The uppermost point of the bony external auditory meatus*

12) **Ptm –** The contour of the pterygommaxillary fissure formed anteriorly by the retromolar tuberosity of the maxilla and posteriorly by the anterior curve of the pterygoid process of the sphenoid bone

13) ***Orbitale (O)*** *- The lowest point of the infra-orbital margin. Where two orbitalia were visible a point mid-way between the two was used*

14) ***Posterior Nasal Spine (PNS)*** *- Posterior spine of the palatine bone constituting the hard palate.*

15) ***Incisor (upper)*** *- The tip of the crown of the most anterior upper central incisor*

16) ***Maxillary incisor apex*** *- The tip of the root of the most anterior maxillary central incisor*

17) ***Incisor (lower)*** *- The tip of the crown of the most anterior lower central incisor.*

18) ***Mandibular incisor apex*** *- The tip of the root of the most anterior mandibular central incisor.*

19) ***Mesial cusp of upper 6*** *- The mesial cusp of the upper first molar*

20) ***Mesial cusp of upper 6*** *- The mesial cusp of the lower first molar*

21) ***Pronasale*** - The most prominent or anterior point of the nose (tip of the nose)

22) ***Subnasale*** - The point at which the columella (nasal septum) merges with the upper lip in the midsagittal plane

23) ***Superior labial sulcus*** - The point of greatest concavity in the midline of the upper lip ibetween subnasale and labrale superius

24) ***Labrale superius*** - A point indicating the mucocutaneous border of the upper lip. The most anterior point of the upper lip (usually)

25) ***Stomion superius*** -. The lower- most point on the vermilion of the upper lip

26) ***Inferior labial sulcus*** -. The point of greatest concavity in the midline of the lower lip between labrale inferius and soft-tissue pogonion. Also known as labiomental sulcus (SI)

27) ***Soft tissue pogonion*** - The most prominent or anterior point on the chin in the midsagittal plane

The following eleven soft tissue and seven hard tissue relationships were evaluated:

a) Soft-tissue changes: The soft tissue response was evaluated using the Holdaway soft-tissue analysis (1984), which uses the Sella-Nasion (S-N) plane as its reference (Figures 4-11).

1) **Soft-tissue facial angle** (Figure 4).
A measurement of 90 to 92 degrees is ideal, with an acceptable range of ± 7 degrees (Holdaway 1983).

2) **Superior sulcus depth** (Figure 5).
A range of 1 to 4mm is acceptable in certain types of faces, with 3mm being ideal (Holdaway 1983).

3) **Soft-tissue subnasale to H-line** (Figure 6).
Here the ideal is 5mm with a range of 3 to 7mm (Holdaway 1983).

4) **Skeletal profile convexity** (Figure 7).
Although this is a skeletal measurement, Holdaway (1984) lists this under soft tissue values as it has a great bearing on the soft tissue profile convexity. Here the range is 2±2mm. This is a measurement from point A to the hard-tissue line Na-Pog or facial plane (Downs 1948, Ricketts 1957, Holdaway 1983).

5) **Basic upper lip thickness** (Figure 8)
This is near the base of the alveolar process, measured about 3mm below point A (Holdaway 1983).

6) **Upper lip strain measurement**
The usual thickness at the vermilion border level is 13 to 14mm (Holdaway 1983).

7) **H- angle** (Figure 9).

This is an angular measurement of the H line to the soft-tissue N-Pog line or soft-tissue facial plane. Ten degrees is ideal when the convexity measurement is 0mm (Holdaway 1983).

8) **Lower lip to H-line** (Figure 10).

The ideal position of the lower lip to the H line is 0 to 0.5mm (Holdaway 1983).

9) **Inferior sulcus to the H-line**.

The contour in the inferior sulcus area should fall into harmonious lines with the superior sulcus form (Holdaway 1983).

10) **Soft-tissue chin thickness** (10 to 12mm on average).

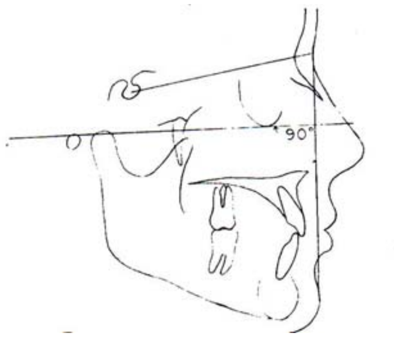
This is recorded as a horizontal measurement and should on average be between 10 to 12mm (Holdaway 1983).

11) **Ricketts E-line** (Figure 11)

Lower Lip to E- Line

The norm is -2 mm±2 mm at age 9 (Ricketts 1957).

b) Dento-alveolar changes: The changes in the positions of the upper and lower incisors were evaluated by measuring the upper incisor to the palatal plane and the interincisal angle (Keating 1986), as well as the lower incisor to mandibular plane (IMPA)(Tweed 1954) and Steiner's (1953) linear and angular values for upper and lower incisors.



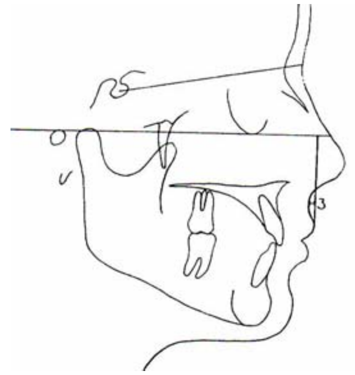
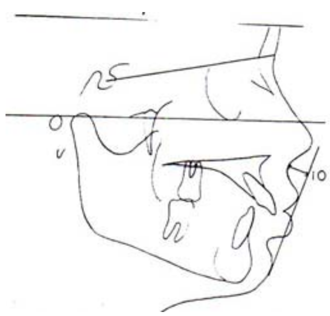


Figure 4. Soft-tissue facial angle (Holdaway 1984)

Figure 5. Superior sulcus depth (Holaway 1984)



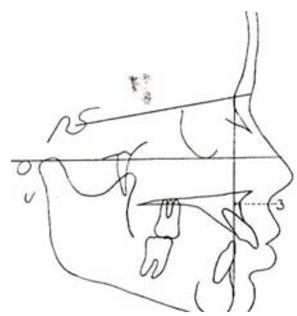
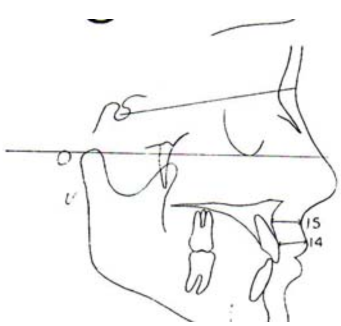


Figure 6. Soft-tissue subnasale to H- line (Holdaway 1984)

Figure 7. Skeletal profile convexity (Holdaway 1984)



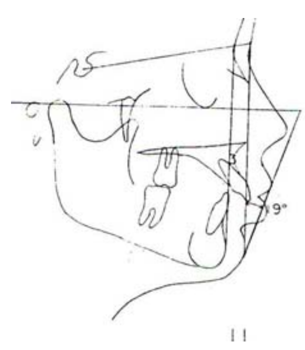


Figure 8. Upper lip thickness and lip tension (Holdaway 1984)

Figure 9. H- angle (Holdaway 1984)

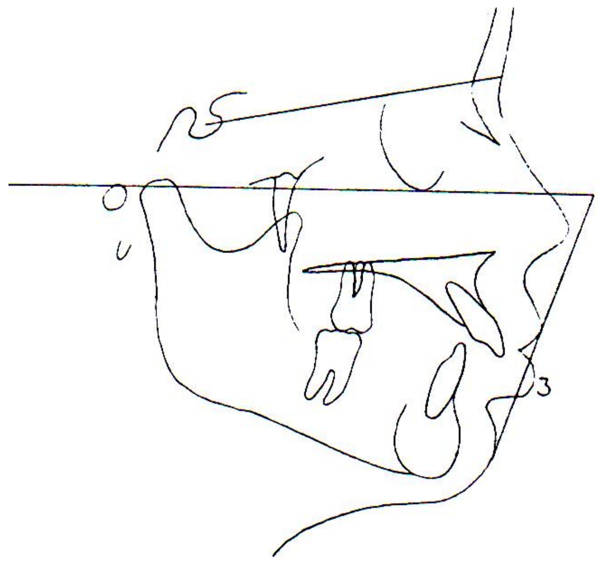


Figure 10. Lower lip H line (Holdaway 1984)

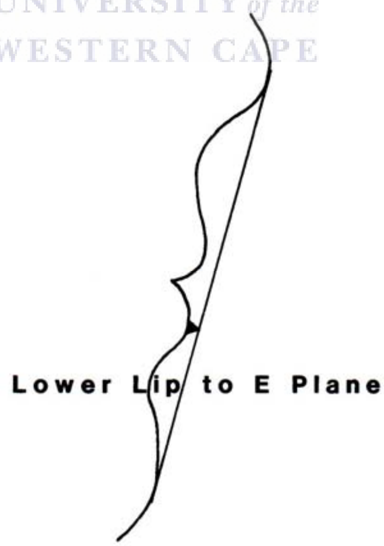


Figure 11. Lower lip to E-line. Lip position depends on nose and chin size as well as movement of anterior teeth (Ricketts 1982)

3.4 Data measurement

The cephalograms were digitized using the Quick Ceph Imaging© software package (Quick Ceph Systems, San Diego, California, 1998) developed by Günter W Blaseio.

The digitizing apparatus consisted of a computer, a video camera and the Quick Ceph Imaging© software package (Figure 12). Before digitizing each cephalogram, the machine was calibrated to ensure that the ratio between the cephalogram and the computer captured image was in a ratio of 1:1. The pre- and post-treatment cephalograms were prepared and digitized by one operator (DM).

Once the cephalograms were digitized using the points shown in Figure 3, the results were then entered into the data capture form. The pre-treatment cephalogram was used to construct the four VTO's, namely those developed by Steyn (1979), Jacobson and Sadowsky (1980), Ricketts (1982) and Holdaway (1984) (Appendix B-E, Figures 13-15). These results were then also entered onto the data capture form (Appendix A).

The four (4) VTO were then severally superimposed onto the post-treatment digitized cephalogram making it possible to determine the accuracy of each VTO by comparing predetermined points on the VTO to the same points on the post-treatment cephalogram tracing.

Figure 12. Digitizing apparatus consisting of a computer, a video camera and the Quick Ceph Imaging© software package.

Eleven linear and seven angular measurements were selected for quantitative cephalometric evaluation.

Statistical analysis using descriptive and analytical statistical methods was used to evaluate the differences between the VTO predicted change and the actual change obtained. Statistical significance was established at P < 0.1.

3.5 Statistical analysis of the data

The data was captured on an Excel spread sheet (Table 4) and managed by the statistician using Microsoft Office Excel 2003 and the NCSS 2001 statistical package. The Wilcoxon Signed Rank Tests were used to test for significant differences between the predicted changes of the four VTO and the actual change measured on the post-treatment cephalograms. This method was preferred to the Student t-test because of the sample size and the possibility of distributional difficulties which may arise when using the Student t-test. The post-treatment values were subtracted from the predicted values. This indicated how close the VTO prediction was to the final treatment outcome. A positive value (difference) indicated overestimation on the part of the VTO, a negative value (difference) indicated underestimation by the VTO prediction. The closer the two values were (postreatment and VTO), the more reliable or accurate the VTO.

3.6 Intra-examiner variability

The reproducibility of the digitized cephalograms and VTO were determined from duplicate measurements of five randomly selected cases from the total sample, which were re-digitized and compared with the corresponding digitized cephalogram and VTO previously done. This was done to determine the intra-examiner variability. The differences between the first and second measurements were computed and the occurrence of a systematic difference was determined. Errors in landmark identification (tracing error) and digitization were evaluated statistically and a high degree of intra-examiner reliability was found.

3.7 Ethics statement

The confidentiality and anonymity of patients was guaranteed at all times.

Table 4. Example of a Data capture form
Excel spread sheet of patient UWC3

PATIENT NUMBER: UWC3 **DATE: 03.12.07**
GENDER: Female
BIRTH DATE: 02.09.88
START DATE: 30.09.02
END DATE: 25.11.04
SPACE SHORTAGE: 12.4 mm(upper)
7.6 mm (lower)

Soft Tissue Changes	**Pre-Treatment**	**Post-treatment**	**Steyn**	**Jacobson**	**Ricketts**	**Holdaway**
Facial angle (º)	97.3	93.2	92.6	94.2	93.8	93.7
S.Sulcus depth	5.8	4.1	3.7	3.9	4.9	4.4
Soft tissue subnasale (mm)	11.2	6.9	6.1	6.5	7.3	6.2
Convexity (mm)	1.9	-1.2	0.3	0.9	0.3	1.8
Upper lip thickness (mm)	16.6	19.3	18.8	21.1	19.7	19.7
Upper lip strain (mm)	2.6	1.1	1.9	0.8	1.4	0.2
H-angle (º)	**17.9**	**12.1**	**14.5**	**11.1**	**16.3**	**13.4**
Lower lip to H-line (mm)	3.9	1.9	2.8	2.3	2.4	0
Inferior sulcus (mm)	2.2	3.8	4.6	3.1	4.2	3.3
Chin thickness (mm)	16.8	14.2	13.9	13.1	14.5	14.8
E-line (mm)	4.1	0.3	0.5	-1.1	0	-2.9
Dental Changes						
Inter-incisal angle (º)	108.2	134.1	129.9	130.4	132.7	129.6
U1/Palatal plane (º)	116.4	105.1	103.2	104.7	103.9	104.8
L1/Mand. Plane (º)	101.1	87.3	88.4	89.9	91.3	88.2
U1/NA (º)	30.3	22.2	23.1	22.4	22.1	21.8
U1/NA (mm)	9.8.	4.7	5.2	4.1	5.3	4.2
L1/NB (º)	40.1	25.7	26.4	27.1	26.1	28.2
L1/NB (mm)	13.1	7.9	7.5	6.8	7.3	5.7

CHAPTER 4

RESULTS

Wilcoxon Signed Rank Tests were used to test for significant differences between the predicted changes of the four VTO and the actual change measured on the post-treatment cephalograms.

4.1. SOFT TISSUE CHANGES

To illustrate how the Wilcoxon Signed Rank Tests were done for each measurement, the calculations for the Soft tissue Facial angle are shown in detail. The results of the analyses for the other variables are presented in summarized form, but the same method and calculations were applied to all the variables.

4.1.1. Soft-tissue facial angle

Changes measured in the Steyn VTO were smaller than the changes measured on the post-treatment cephalometric tracing for the Facial angle in 19 cases. The converse was true for 25 cases, with one case having no difference (Table 5).

Table 5. Facial angle as predicted by Steyn

# of cases "Steyn smaller than Post"	# positive	19
# of cases "Steyn larger than Post"	# negative	25
	Median of difference (°)	-0.4
The Post measurement were under estimated by the prediction formula of Steyn for most of the cases (25)		

Descriptive statistics and the statistical test to determine whether the actual prediction of the Soft tissue Facial angle by Steyn was equal to the post-treatment measurement

Wilcoxon Signed Rank Sum Test

# = Number
Post = Post-treatment result
Number of Nonzero Differences = 44
T+ = 396
T- = 594
Large Sample Approximation
Test Statistic Z = -1.155
P-Value = 0.2479

From the Wilcoxon test above it was seen that there was no significant difference between the Steyn prediction and the post-treatment measurement . The Steyn VTO tended to underestimate the final result in most of the cases.

Table 6. Facial angle as predicted by Jacobson and Sadowsky

# of cases "Jacobson smaller than Post"	# positive	30
# of cases "Jacobson larger than Post"	# negative	14
	Median of difference (°)	0.7
	Over estimated by Jacobson for 30 individuals	

Descriptive statistics and the statistical test to determine whether the prediction of the Facial angle by Jacobson and Sadowsky was equal to the post-treatment measurement.

Wilcoxon Signed Rank Sum Test

# = Number
Post = Post-treatment result
Number of Nonzero Differences = 44
T+ = 685.5
T- = 304.5
Large Sample Approximation
Test Statistic Z = 2.223
P-Value = 0.0262

The prediction by the VTO of Jacobson and Sadowsky was larger than the post-treatment measurement for the Soft tissue Facial angle in 30 cases. The converse was true for 14 cases. These counts were substantially different and significant by means of the Signed test (Table 6).

According to the Wilcoxon Signed Rank test the two sets of paired measurements were significantly different (i.e. between the predicted values of Jacobson and Sadowsky and the actual post-treatment values).

Table 7. Facial angle as predicted by Ricketts

# of cases "Ricketts smaller than Post"	# positive	16
# of cases "Ricketts larger than Post"	# negative	28
	Median of difference (º)	-0.2
	Under estimated by Ricketts for 28 individuals	

Descriptive statistics and the statistical test to determine whether the prediction of the Soft tissue Facial angle by Ricketts was equal to the post-treatment measurement.

Wilcoxon Signed Rank Sum Test

# = Number
Post = Post-treatment result
Number of Nonzero Differences = 43
T+ = 335
T- = 655
Large Sample Approximation
Test Statistic Z = -1.867
P-Value = 0.0619

The postreatment measurement was under estimated by the prediction formula of Ricketts for most of the cases (28 cases). The prediction of Ricketts' VTO was smaller than the post-treatment measurement for the Facial angle in these cases. The converse was true for 16 cases and one case having no difference between the predicted and post-treatment result. These counts were substantially different and significant by means of the Signed test (Table 7).

According to the Wilcoxon Signed Rank Test the difference between the paired measurements were significant ($p > 0.05$). The two tests gave opposing results. The best option here is to state that when the tests were combined, the difference between the predicted values of Rickets and the post-treatment results were not significantly different.

Table 8. Facial angle as predicted by Holdaway

# of cases "Holdaway smaller than Post"	# positive	29
# of cases "Holdaway larger than Post"	# negative	16
	Median of difference (°)	0.9
	Over estimated by Ricketts for 29 individuals	

Descriptive statistics and the statistical test to determine whether the prediction of the Soft tissue Facial angle by Holdaway was equal to the post-treatment measurement.

Wilcoxon Signed Rank Sum Test

# = Number
Post = Post-treatment result
Number of Nonzero Differences = 45
T+ = 766
T- = 269
Large Sample Approximation
Test Statistic Z = 2.805
P-Value = 0.005

The postreatment measurement was over estimated by the prediction formula of Holdaway for most of the cases (29 cases). The prediction of Holdaway was larger than the post-treatment measurement for the Facial angle in 29 cases. The converse was true for 16 cases. These counts were substantially different and significant by means of the Signed test (Table 8).

According to the Wilcoxon Signed Rank Test the differences between the paired measurements were not significant ($p > 0.05$). As with the Ricketts prediction, the combined tests showed that the difference was not significant.

Table 9. Comparison of the four VTO predictions for the Facial angle

	Steyn	Jacobson	Ricketts	Holdaway
# Positive	19	30	16	29
# Negative	25	14	28	16
Median difference	-0.4	0.7	-0.2	0.8
	Steyn Under Estimated	Jacobson Over Estimated	Ricketts Under Estimated	Holdaway Over Estimated
Statistical Significance	Not Significant	$p<0.05$	Not Significant	$p<0.01$

= Number

The above table summarizes the information obtained comparing the four VTO's to the measurement on the post-treatment cephalogram: Steyn, Jacobson, Holdaway and Ricketts (Table 9).

From the above table it can be seen that none of the four VTO's consistently predicted the final treatment result. The Rickett and the Steyn VTO performed the best in predicting the final result for the Soft tissue Facial angle with the difference being not significant between the VTO's and the final treatment result.

(1) Superior sulcus depth

Table 10. VTO predictions for the Superior Sulcus Depth

	Steyn	Jacobson	Holdaway	Ricketts
# positive	24	35	18	32
# negative	21	10	27	13
Median	0.3	0.6	-0.4	0.3
	Over estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hs***	Ns**	Hs***

****Ns** – **Not significant** $p>0.1$
***S** – **Significant** $p<0.1$
*****Hs** – **Highly significant** $p<0.01$
******Hhs** – **Highly highly significant** $p<0.001$

Most of the predicted Superior sulcus depth measurements on the Steyn, Jacobson and Sadowsky and Ricketts VTO's were larger than the post treatment VTO, with the Superior sulcus depth measurements predicted by Jacobson and Sadowsky and Ricketts significantly different from the post treatment measurements (Table 10).

(2) Soft tissue subnasale

Table 11. VTO predictions for the Soft tissue subnasale

	Steyn	Jacobson	Ricketts	Holdaway
# positive	21	35	24	35
# negative	24	10	21	10
Median	-0.5	0.6	0.3	1.0
	Under estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

The predicted Soft tissue subnasle measurements on the Steyn, Jacobson and Sadowsky and Ricketts VTO's were larger than those on the post-treatment cephalogram, with the Soft tissue subnasale measurements predicted by Jacobson and Sadowsky and by Holdaway significantly different from the post-treatment measurements (Table 11).

(4) Skeletal profile convexity

Table 12. VTO predictions for the skeletal profile convexity

	Steyn	Jacobson	Ricketts	Holdaway
# positive	21	30	20	34
# negative	24	15	25	11
Median difference (mm)	0.2	0.5	0.2	0.8
	Over estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

**Ns – Not significant p>0.1
*S – Significant p<0.1
***Hs – Highly significant p<0.01
****Hhs – Highly highly significant p<0.001

As stated previously, Holdaway uses this value as it has a bearing on the soft tissue convexity although it is a skeletal measurement. The skeletal measurements predicted by Jacobson and Sadowsky and Holdaway was significantly different from the post-treatment measurements. The Skeletal measurements were relatively well predicted by Steyn and Ricketts with Holdaway being the worst predictor (Table 12).

(4) Basic upper lip thickness

Table 13. VTO predictions for upper lip thickness (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	25	16	27	21
# negative	20	29	17	24
Median difference (mm)	0.2	-0.1	0.4	-0.3
	Over estimated by Steyn	Under estimated by Jacobson	Over estimated by Ricketts	Under estimated by Holdaway
Statistical Significance	Ns**	Ns**	S*	Ns**

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

The predicted Basic upper lip thickness measurements on the Steyn and Ricketts VTO's were larger than the post-treatment measurements, with the Basic Lip thickness measurements predicted by the Ricketts VTO being significantly different from the post-treatment measurements (Table 13).

(5) Upper lip strain

Table 14. VTO predictions for Upper lip strain (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	22	37	23	39
# negative	23	7	19	5
Median difference (mm)	-0.1	0.5	0.1	0.7
	Under estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

The predicted Upper lip strain measurements on the Jacobson and Sadowsky Ricketts and Holdaway VTO's were larger than the post-treatment measurements. The Upper lip strain measurements predicted by Jacobson and Sadowsky and Holdaway being highly significantly different from the post-treatment measurements (Table 14).

(6) H-angle

Table 15. VTO predictions for the H-angle (º)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	15	40	20	39
# negative	30	5	25	6
Median difference (º)	-1.1	2.8	-0.4	3
	Under estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

Ns – **Not significant $p>0.1$
*S – **Significant** $p<0.1$
***Hs – **Highly significant** $p<0.01$
****Hhs – **Highly highly significant** $p<0.001$

The predicted H-angle measurements on the Jacobson and Sadowsky and Holdaway VTO's were larger than that on the post-treatment measurements. The H-angle measurements predicted by Jacobson and Sadowsky and Holdaway being highly significantly different from the post-treatment measurements. Once again the Steyn and Ricketts VTO predicted the post-treatment measurement the best (Table 15).

(7) Lower lip to H-line

Table 16. VTO predictions for the Lower lip to H-line (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	24	39	22	41
# negative	21	5	23	4
Median difference (mm)	0.3	1.3	-0.1	1.5
	Over estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	S*	Hhs****	S*	Hhs****

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

The predicted Lower lip to H-line measurements on all four VTO's were larger than that on the post-treatment cephalogram. The Lower lip predicted measurements were significantly different from the post-treatment measurements for all four VTO's. The lower lip to H-line, together with the Lower lip to the E-line were parameters for which all four VTO's had significantly different measurements to that of the post-treatment cephalogram (Table 16).

(8) Inferior sulcus depth

Table 17. VTO predictions for the Inferior sulcus depth (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	29	22	28	20
# negative	16	21	17	24
Median difference (mm)	0.5	0	0.4	-0.2
	Over estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Under estimated by Holdaway
Statistical Significance	S*	Ns**	Ns**	Ns**

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

Most of the predicted Inferior sulcus depth measurements on the Steyn, Jacobson and Sadowsky and Ricketts VTO's were larger than the actual post-treatment measurement. The Inferior sulcus depth measurements predicted by Jacobson and Sadowsky and Ricketts being significantly different from the post-treatment (Table 17).

(9) Chin thickness

Table 18. VTO predictions for Chin thickness (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	18	17	21	15
# negative	27	28	24	28
Median difference (mm)	-0.3	-0.3	-0.2	-0.2
	Under estimated by Steyn	Under estimated by Jacobson	Under estimated by Ricketts	Under estimated by Holdaway
Statistical Significance	Ns*	S*	Ns**	S*

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

Most of the predicted Chin thickness measurements on the Steyn, Jacobson and Sadowsky and Ricketts VTO's were smaller than that on the post-treatment measurement. The Chin thickness dimensions predicted by Jacobson and Sadowsky and Holdaway being significantly different from the actual post-treatment measurements. Here again the Ricketts and Steyn VTO were the best in predicting the post-treatment result for the Chin thickness measurement (table 18).

(10) Lower lip to E-line

Table 19. VTO predictions for Lower lip to E-line (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	29	37	38	37
# negative	16	8	7	8
Median difference (mm)	0.8	1.5	1.6	1.9
	Over estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Hhs****	Hhs****	Hhs****	Hhs****

****Ns** – **Not significant** $p>0.1$
***S** – **Significant** $p<0.1$
*****Hs** – **Highly significant** $p<0.01$
******Hhs** – **Highly highly significant** $p<0.001$

Most of the predicted Lower lip to E-line measurements on all four VTO's were larger than that on the post-treatment data. The Lower lip predicted measurements being significantly different from the actual post-treatment measurements for all four VTO's (Table 19).

4.2. DENTAL CHANGES

(1) Inter-incisal angle

Table 20. VTO predictions for the Inter-incisal angle (º)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	20	4	16	3
# negative	25	41	28	42
Median difference (º)	-0.6	-2.5	-0.5	-3
	Under estimated by Steyn	Under estimated by Jacobson	Under estimated by Ricketts	Under estimated by Holdaway
Statistical Significance	Ns**	Hhs****	S*	Hhs****

****Ns** – **Not significant** $p>0.1$
***S** – **Significant** $p<0.1$
*****Hs** – **Highly significant** $p<0.01$
******Hhs** – **Highly highly significant** $p<0.001$

Most of the predicted Inter-incisal angle measurements were smaller than the post-treatment measurements, with the Inter-incisal angle measurements predicted by Jacobson and Sadowsky, Ricketts and Holdaway being significantly different from the post-treatment measurements (Table 20).

(2) Upper incisor to palatal plane

Table 21. VTO predictions for the Upper incisor to palatal plane (º)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	24	37	22	39
# negative	21	8	23	6
Median difference (º)	0.9	1.9	-0.3	2.9
	Over estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

****Ns** – **Not significant** $p>0.1$
***S** – **Significant** $p<0.1$
*****Hs** – **Highly significant** $p<0.01$
******Hhs** – **Highly highly significant** $p<0.001$
******Hhs – Highly, highly significant**

Most of the predicted Upper incisors to palatal plane measurements were larger than the post-treatment measurements, with the Upper incisor to palatal plane measurements predicted by Steyn, Jacobson and Sadowsky and Holdaway being significantly different from the post-treatment measurements Table 21).

(3)Lower incisor to mandibular plane

Table 22. VTO predictions for the Lower incisor to mandibular plane (°)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	21	39	26	41
# negative	24	6	19	3
Median difference (°)	-0.2	1.7	0.8	1.9
	Under estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

Most of the predicted Lower incisors to mandibular plane measurements were larger than the post-treatment measurements, with Lower incisor to mandibular plane measurements predicted by Jacobson and Sadowsky, Ricketts and Holdaway being significantly different from the post-treatment measurements (Table 22).

(4) Upper incisor to NA line (º)

Table 23. VTO predictions for the Upper incisor to NA line (º)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	15	40	24	42
# negative	30	5	21	3
Median difference (º)	-0.6	2	0.2	2.1
	Under estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	S*	Hhs****	Ns**	Hhs****

****Ns**	–	**Not significant**	p>0.1
***S**	–	**Significant**	p<0.1
*****Hs**	–	**Highly significant**	p<0.01
******Hhs**	–	**Highly highly significant**	p<0.001

Most of the predicted Upper incisors to NA line (º) measurements were larger than that on the post-treatment measurements, with Upper incisor to NA line (º) measurements predicted by Steyn, Jacobson and Sadowsky and Holdaway being significantly different from the post-treatment measurements (Table 23).

(5) Upper incisor to NA line (mm)

Table 24. VTO predictions for the Upper incisor to NA line (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	21	40	22	43
# negative	24	5	23	2
Median difference (mm)	-0.1	0.9	-0.2	1.2
	Under estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Hhs****	Ns**	Hhs****

****Ns** – **Not significant** p>0.1
***S** – **Significant** p<0.1
*****Hs** – **Highly significant** p<0.01
******Hhs** – **Highly highly significant** p<0.001

Most of the predicted Upper incisors to NA line (mm) measurements were larger than the post-treatment measurements, with Upper incisor to NA line (mm) measurements predicted by Jacobson and Sadowsky and Holdaway being significantly different from the post-treatment measurements. Steyn and Ricketts once again were the best of the VTO's in predicting the post-treatment measurements.

(6) Lower incisor to NB line (º)

Table 25. VTO predictions for the Lower incisor to NB line (º)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	30	25	27	33
# negative	15	20	17	10
Median difference (º)	0.6	0.4	0.3	0.4
	Over estimated by Steyn	Over estimated by Jacobson	Over estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	S*	Ns**	S*	Hs***

****Ns**	–	**Not significant**	p>0.1
***S**	–	**Significant**	p<0.1
*****Hs**	–	**Highly significant**	p<0.01
******Hhs**	–	**Highly highly significant**	p<0.00

Most of the predicted Lower incisors to NB line (º) measurements were larger than the post-treatment measurements, with Lower incisor to NB line (º) measurements predicted by Steyn, Ricketts and Holdaway being significantly different from the post-treatment measurements. Jacobson and Sadowsky were the best of the VTO's in predicting the post-treatment measurements in this parameter (Table 25).

(7) Lower incisor to NB line (mm)

Table 26. VTO predictions for the lower incisor to NA line (mm)

	Steyn	Jacobson	Ricketts	Holdaway
# positive	24	24	24	31
# negative	21	19	21	14
Median difference (mm)	0.2	0.2	0.1	0.4
	Over estimated by Steyn	Over estimated by Jacobson	Under estimated by Ricketts	Over estimated by Holdaway
Statistical Significance	Ns**	Ns**	Ns**	Hs***

**Ns – Not significant p>0.1
*S – Significant p<0.1
***Hs – Highly significant p<0.01
****Hhs – Highly highly significant p<0.001

Most of the predicted Lower incisor to NB line (mm) measurements were larger than the post-treatment measurements, with Lower incisor to NB line (mm) measurements predicted by Holdaway being significantly different from the post-treatment measurements (Table 26).

Table 27. Accuracy of the four VTO

	STEYN	RICKETTS	*JACOB/SADOW	HOLDAWAY
Soft Tissue				
Facial angle	2	1	3	4
S.Sulcus depth	1	2	4	3
Subnasale	2	1	3	4
Convexity	1	1	3	4
Upper lip thickness	2	4	1	3
Upper lip strain	1	2	3	4
H-angle	2	1	3	4
Lower lip to H-line	2	1	3	4
Inferior sulcus	4	3	1	2
Chin thickness	3	1	4	2
E-line	1	3	2	4
Dental				
Inter-incisal angle	1	2	3	4
U1/Palatal plane	2	1	3	4
L1/Mand. Plane	1	2	4	3
U1/NA (°)	2	1	3	4
U1/NA (mm)	1	2	3	4
L1/NB (°)	4	2	1	3
L1/NB (mm)	2	1	2	4

1= Best predictor, 4 =worst predictor
***Jacobson and Sadowsky**

All the VTO's had some success when forecasting the hard tissue response. This is consistent with the findings in the literature. The VTO's were however less successful when forecasting the soft tissue response. This may be due to the number of factors involved in soft tissue prediction. From Table 27 it can be seen that the Ricketts and Steyn VTO's fared the best overall, with the Holdaway being the worst predictor of both hard and soft tissue response.

CHAPTER 5

DISCUSSION

Facial harmony and optimal functional occlusion has long been promoted as the two most important goals of orthodontic treatment. To achieve these goals a good understanding of normal growth and treatment response is essential (Bishara et al 1998). When treating patients with bimaxillary protrusion this understanding of growth and treatment response is of paramount importance if one is to confidently predict the final outcome. The reliability of the VTO in these cases is there very important.

Being able to predict growth is of vital importance to the orthodontist as this has an enormous bearing on the treatment outcome. With experience comes insight but the overall approach still requires a sound scientific knowledge of growth. Various factors should be considered when dealing with prediction of craniofacial growth. These factors include the direction, magnitude, timing, the rate of change, and the effect that orthodontic treatment (Ricketts 1960b). These growth changes are complex and highly variable and predicting them has proven to be very difficult (Bishara 2000).

The orthodontist is often confronted with the need to predict soft-tissue profile changes that may result from orthodontic treatment. The problem arises because the contribution of many of the factors influencing the soft-tissue profile is still not fully understood. The complexity of the problem is increased in growing patients in whom the post-treatment soft-tissue profile is the result of both growth and orthodontic treatment (Talass et al 1987).

The soft tissue profiles of patients with bimaxillary protrusion may not be considered aesthetically pleasing. These patients characteristically have dentoalveolar flaring of the maxillary and mandibular anterior teeth, with resultant protrusion of the lips and convexity of the face. To reduce the facial convexity and allow retraction of the anterior teeth to a more pleasing and possibly a more stable position, the treatment of choice includes extracting the four first premolars (Farrow et al 1993).

Lu et al (2003) found that the computer-generated image prediction was suitable for patient education and communication. However they stressed that efforts are still needed to improve the accuracy and reliability of the prediction program and to include the consideration of, as with this study, changes in soft tissue tension and muscle strain. The accuracy of this system in soft tissue prediction should therefore be carefully interpreted (Lu et al 2003).

Sample et al (1998) in assessing the reliability of manual and computer-generated VTO found that both the manual and computer VTO methods were accurate when predicting skeletal changes that occurred during treatment. This was also found to be so in this study with all four VTO's predicting the skeletal changes with some degree of success. They concluded that the prediction of the final position of the incisor was always difficult even in non-extraction cases as was the case in this study.

Toepel-Sievers and Fisher-Brandies (1999) also found that the Ricketts VTO yielded satisfactory results for the skeletal variables tested but were unsuccessful in predicting the dental relations, of dentoskeletal relations or of soft-tissue configuration. They concluded that the VTO is capable of giving a largely valid prognosis of skeletal growth tendencies, however, in view of the large number of parameters affected by therapeutic measures, the VTO prognosis must be expected to differ from the actual treatment outcome (Toepel-Sievers and Fisher-Brandies 1999).

When examining the results of this study it is very evident that the prediction of the soft tissue response remains problematic. The Facial angle was best predicted by the Rickets VTO followed by the Steyn VTO. Surprisingly the Holdaway VTO fared the worst. It would have been expected that the Holdaway VTO would have fared the best, giving his emphasis on soft tissue balance. The reason for this poor result may once again be due to his sample as well as his method of first draping the soft tissue and then positioning the upper incisor followed by the lower incisor being positioned according to the upper. The same explanation could hold be true for the Jacobson and Sadowsky VTO being not much better.

The reason as to why the Ricketts and Steyn VTO performed the best could be due to the fact that the lower incisor is first positioned and then the soft tissue is draped accordingly. Ricketts first predicts the result without treatment and then subsequently predicts the final VTO with treatment. The Steyn VTO uses different values for males and females and this may be a contributing factor in his VTO achieving better results. The position of the upper lip was found to be further anteriorly than predicted by the VTO. In the lower face, the position of the lower lip, inferior labial sulcus and the soft tissue chin was found to be more anteriorly than predicted. The thickness of the upper lip and the lip strain was found to be slightly greater than predicted.

Generally the results for the soft tissue predictions were poor, with all VTO's having difficulty in predicting the upper lip response and this may be due to the fact that predicting the lip response to the amount of incisor retraction.Generally the VTO fared slightly better when predicting the dental changes. The VTO tended to overestimate the amount of angular change and underestimated the bodily movement of the incisors. Once again the Ricketts and Steyn VTO fared the best when evaluating the dental response. The Holdaway, Jacobson and Sadowsky VTO's tended to overestimate the amount of incisor retraction, both linear and angular measurements.

Even though the movement of the molars did not form part of the study an additional finding was that although all cases were treated as maximum anchorage cases, this still did not prevent the upper molars from moving forward. The VTO's therefore also proved to be inaccurate in measuring the antero-posterior changes in molar position.

One has to agree with Bishara (2000), that contemporary methods are generally not capable of providing an efficient estimate of individual changes attributable to growth.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

Being able to predict the final treatment outcome would be extremely beneficial to the orthodontic profession. Not only does it assist in the treatment planning procedure, but it also helps the patient to visualize the final result. This is especially helpful in patients with bimaxillary protrusion as their main concern often centres on the procumbency of the lips which affects the soft tissue profile which in turn affects the aesthetics of the patient.

From this study it can be seen that the final soft tissue result is very difficult to predict, with the hard tissue prediction being slightly better. It can therefore be concluded that the present VTO predictions, in patients with bimaxillary protrusion, cannot be relied upon totally to indicate the final treatment outcome.

Further studies are required to determine the soft tissue response in bimaxillary protrusive cases as very few studies are quoted in the literature. The response of the hard tissue as well as the soft tissue to treatment needs to be further evaluated. The response of the upper as well as the lower lip to incisor retraction needs to be studied more closely. Considering that the soft tissue integument is different in the patient with bimaxillary protrusion it would be interesting to compare the lip response to that listed in the literature.

Therefore VTO's, like cephalometrics should be used only as an aid to treatment planning and not be relied upon exclusively to predict the final result. Their use in patient education and treatment planning has been very successful. As stated previously, most of the studies relating to VTO's were done on Caucasian patients and cannot be applied to the bimaxillary protrusive cases.

Although 3-D craniofacial techniques have offered hope to better study the soft and hard tissues, the response of these tissues to treatment still needs to be predicted and this response varies from patient to patient. A better understanding of the soft and hard tissue will help in predicting the final treatment outcome. 3-D craniofacial techniques offer hope that these tissues and their response may now be better studied and prediction will then be able to be applied to each individual patient. The costs and the increased exposure time needed are still considered to be prohibiting factors in the use of 3-D imaging (Silva et al. 2008).

It is therefore recommended that further studies be done to determine the soft and hard tissue response to orthodontic treatment in cases with bimaxillary protrusion. The best that can be hoped for is a range of values that can be applied to these cases.

In conclusion it should be remembered that the balance of the facial structures is affected by both orthodontic treatment and growth. It is therefore essential that the clinician understand the amount and the direction of growth expected in the facial structures in addition to the effects of treatment. The development of the soft tissue profile is a result of complex changes within the hard and soft tissue structures of the face and is not based on a single variable, making prediction a very difficult process (Nanda and Ghosh 1995). This fact has clearly been demonstrated in this study when dealing with the prediction of the hard and soft tissue in patients with bimaxillary protrusion.

APPENDICES

APPENDIX A. Data capture form

PATIENT NUMBER:________________ **DATE:** __________________

GENDER: _________

BIRTH DATE:

____

START DATE:_______________________

END DATE:__________________________

SPACE SHORTAGE: ________**mm (upper)**

________**mm (lower)**

Soft Tissue Changes	**Pre-Treatment**	**Post-treatment**	**Steyn**	**Jacobson**	**Ricketts**	**Holdaway**
Facial angle (º)						
S.Sulcus depth						
Soft tissue subnasale (mm)						
Convexity (mm)						
Upper lip thickness (mm)						
Upper lip strain (mm)						
H-angle (º)						
Lower lip to H-line (mm)						
Inferior sulcus (mm)						
Chin thickness (mm)						
E-line (mm)						
Dental Changes						
Inter-incisal angle (º)						
U1/Palatal plane (º)						
L1/Mand. Plane (º)						
U1/NA (º)						
U1/NA (mm)						
L1/NB (º)						
L1/NB (mm)						

APPENDIX B. Ricketts VTO (1982)

1. Trace the Basion-Nasion Plane. Put a mark at point CC.
2. Grow Nasion 1mm/year (average normal growth) for 2 years (estimated treatment time)
3. Grow Basion 1mm/year (average normal growth) for 2 years (estimated treatment time.
4. Slide tracing back so Nasions coincide and trace Nasion area.
5. Slide tracing forward so Basions coincide and trace Basion area.
6. Superimpose at Basion along the Basion-Nasion plane. Rotate "up" at Nasion to open the bite and "down" at Nasion to close the bite using point DC as the fulcrum. This rotation depends on anticipated treatment effects (whether treatment can be expected to open or close the facial axis).
7. Trace Condylar Axis. Coronoid Process and Condyle.
8. On condylar axis, make mark 1mm per year down from point DC.
9. Slide mark up to the Basion-Nasion plane along the condylar axis. Extend the condylar axis to XI point, locating a new XI point.
10. With old and new XI points coinciding, trace corpus axis, extending it 2mm per year forward of old PM point. (PM moves forward 2mm/year in normal growth.)
11. Draw posterior border of the ramus and lower border of the mandible.
12. Slide back along the corpus axis superimposing at new and old PM. Trace the symphysis and draw in mandibular plane.
13. Construct the facial plane from NA to PO.
14. Construct facial axis from CC to GN (where facial plane and mandibular plane cross).
15. To locate the "new" maxilla within the face, superimpose at Nasion along the facial plane and divide the distance between "original" and "new" Mentons into thirds by drawing two marks.
16. To outline the body of the maxilla, superimpose mark #1 (superior mark) on the original Menton along the facial plane. Trace the palate (with the exception of point A).
17. Point A can be altered distally with treatment. Place according to orthopedic problem and treatment objectives. For each mm of distal movement, Point A will drop 2mm.
18. Construct new APo plane.
19. Superimpose mark #2 on original Menton and facial plane, then parallel Mandibular planes rotating at Menton. Construct occlusal plane (may tip 3 degrees either way depending on Class II or Class III treatment). The lower incisor is placed in relationship to the symphysis of the mandible, the occlusal plane and the APO plane. The arch length requirements and realistic results dictate its location.

20. For this exercise, superimposed on the corpus axis at PM. Place a dot representing the tip of the lower incisor in the ideal position to the new occlusal plane, which is 1mm above the occlusal plane and 1mm ahead of the APO plane.
21. Aligning over the original incisor outline or using a template, draw in the lower incisor in the final position as required by arch length. The angle is 22º at 1 mm to the APo plane and + 1mm to occlusal plane, but the angle increase 2º with each mm of forward compromise. Without treatment, the lower molar will erupt directly upward to the new occlusal plane. With treatment 1mm of molar movement equals 2mm of arch length. We moved the lower incisor forward 2mm in this case. There was also 4mm of leeway space. Therefore, the following calculation allows us to move the lower molar forward 4mm on each side:
lower incisor
forward 2mm = + 4mm arch length
leeway space = <u>+ 4mm arch length</u>
+ 8mm arch length
22. Superimpose the lower molar on the new occlusal plane at the molar (*), slide forward 4mm, upright molar and draw it in.
23. Trace the upper molar in good Class I position to the lower molar. Use the old molar as a template. Place upper incisor in good overbite-overjet position (2½mm overbite, 2½mm overjet) with an interincisal angle of 130º ± 10º. Open bite patterns at a greater angle, deep bite patterns at a lesser angle.
24. Trace the upper incisor in its proper relationship, aligning over the original incisor or by use of a template.
25. Superimpose at Nasion along the facial plane. Trace bridge of nose.
26. Superimpose along the facial plane at the occlusal plane. Using the same technique as for marking the symphysis, divide the horizontal distance between the "original" and "new" upper incisor tips into thirds by using two marks.
27. Soft tissue Point A remains in the same relation to Point A as in the original tracing. Superimpose new and old bony Point A, and make a mark at soft tissue Point A.
28. Keeping the occlusal planes parallel, superimpose mark #1 (posterior mark) on the tip of the original incisor (slide forward 2/3rds). Trace upper lip connecting with soft tissue Point A.
29. Superimpose interincisal points, keeping occlusal planes parallel. Trace lower lip and soft tissue B point. The soft tissue below the lower lip remains in the same relation to point B as in the original tracing. Soft tissue point B drops down as the lower lip recontours.
30. Superimpose on the symphyses and arrange the soft tissue of the chin. It "drops down" and should be evenly distributed over the symphysis taking into consideration reduction of strain and bite opening.

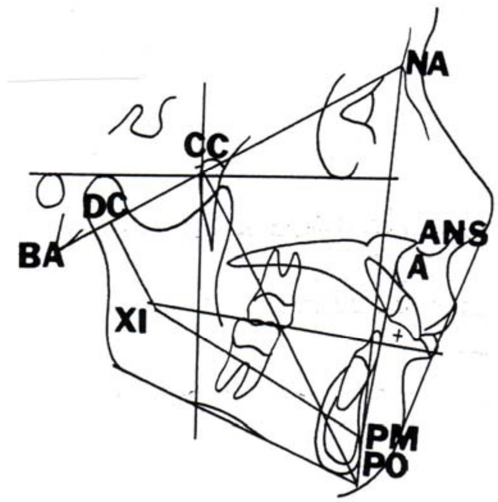


Figure13. Original tracing, Ricketts VTO.

A *- The deepest point, on the curve o1 the maxilla between the anterior nasal spine and the dental alveolus.*
ANS *- Tip of the anterior nasal: spine.*
BA *- Most interior posterior point of the occipital bone.*
CC *- Point where the Basion-Nasion plane and the facial axis intersect.*
DC *- A point selected in the centre of the neck of the condyle where the Basion-Nasion plane crosses it.*
NA *- A point at the anterior limit of the nasofrontal suture.*
PM *- Point selected at the anterior border of the symphysis between Point B and Pogonion where the curvature changes from concave to convex.*
PO *- Most anterior point on the mid-sagiitai symphysis tangent to the facial plane.*
XI *- The geometric center of the ramus of the mandible.*

APPENDIX E. Holdaway VTO (1984)

Step I

The first step is to place a clean sheet of tracing material over the original tracing, copying (1) the frontonasal area, both hard- and soft-tissue, with the soft tissue nose carried down to near the point where the outline of the nose starts to change directions; (2) the sella-nasion line; and (3) the nasion-point A line.

Step II

First, superimpose on the SN line and move the tracing to show expected growth (0.66 to 0.75 mm per year unless a pubertal growth spurt is expected from wrist plate studies). Second, copy the outline of sella. Third, either copy or change the facial axis (Ricketts' foramen rotundum to gnathion) as you expect it to behave according to the facial type of the patient and the treatment mechanics that you customarily use in such cases. (The facial axis line is usually opened about 1°, but it may even be closed if one is confident that mandibular growth of the forward rotational type will occur during treatment.)

Note: It is important to understand that the prediction of growth at nasion, along the SN line, is actually an overall prediction for all midfacial structures, including the nasal bone, the maxilla, and the soft tissues.

Step III

First, superimpose the VTO facial axis on the original and move the VTO up so that the VTO SN line is above the original SN. The amount of movement will usually be 3 mm per year of growth, except in accelerated growth-spurt periods. *(Note: Since the facial axis may be opened or closed as judged from the facial pattern, the SN lines will not be parallel if we have changed the facial axis.)*

Second, copy the anterior portion of the mandible, including the symphysis and anterior half of the lower border. Also draw the soft-tissue chin, eliminating any hypertonicity evident in the mentalis area. *(Slightly round out this area.)*

Third, copy the Downs mandibular plane.

Step IV

First, superimpose on the mandibular plane and move the VTO forward until the original sella and the VTO sella are in a vertical relation. Next, with the tracing in this position, copy the gonial angle, the posterior border, and the ramus. Finally, superimpose on sella to complete the condyle.

Note: At this point total vertical height has been forecast, as has the forward location of the chin structures, both hard and soft, and consideration will have been given to effects of treatment mechanics on vertical dimension. One should not open the facial axis more than 1° to 2° because greater opening than this is usually inconsistent with good treatment mechanics.

Step V

First, superimpose the VTO NA line on the original NA line and move the VTO up until 40% of the total growth is expressed above the SN line and 60% below the mandible. *(Note: This may be varied as you perceive the facial type to be short or long.)*

Second, with the tracing in this position, copy the maxilla to include the posterior two thirds of the hard palate, PNS to ANS to 3 mm below ANS.

Third, also with the tracing in this same position, complete the nose outline around the tip to the middle of the inferior surface. *Note: The vertical growth of the nose over the usual 18 to 24 months of estimated treatment time keeps pace with the growth from the maxilla vertically to the anterior cranial base. Thus, its relationship to ANS is relatively constant. In some cases there may be an elevation of the nasal bone and greater development of the nasal bulk, but this is difficult to predict and thus some noses will have changed form more than this VTO procedure suggests.*

Step VI

First, with the VTO still superimposed on the line NA, move the VTO so that vertical growth between the maxilla and the mandible is expressed 50% above the maxilla and 50% below the mandible.

Second, with the tracing in this position, copy occlusal plane.
Note: Ideally, the occlusal plane is located about 3mm below the lip embrasure. This permits the lower lip to envelop the lower third of the crowns of the upper incisor teeth. If the cant of the occlusal plane is correct it should be maintained. If not, then it can be altered accordingly at this stage. In cases involving short upper lips, it may not be practical to intrude the upper incisors to this extent, but the vertical relationship of the teeth and gingival tissue will be more aesthetically pleasing if we can reach this goal.

Step VII

Note: When there is a uniform distribution of --soft tissues in the profile and the upper lip is of average length, and where the cant of the H line is not adversely affected by excessive facial convexity or concavity, the depth of the superior sulcus measured to the H line is most ideal at 5 mm. A range of 3 to 7 mm allows one to maintain type with short and/or thin lips and long and/or thick lips. Additional refinement of the technique, which covers all of the above, is gained by use of the vertical line from Frankfort plane to the vermillion border of the upper lip, which is ideal at 3 mm with a range from 1 to 4 mm. To find the point along the lower border of the nose outline at which the new H line will intersect it, both perspectives are used in the exceptional cases just mentioned.
First, line up a straight-edge tangent to the chin and angle it back to a point where there is a 3 to 3.5 mm. measurement to the superior sulcus outline of the

original tracing and draw the H line to this. As one redrapes the superior sulcus area to the new tip of the upper lip point, a 5 mm superior sulcus depth develops almost automatically. If you have trouble with this, the use of the Jacobson-Sadowsky lip-contour template is recommended.

Second, with the tracing still superimposed on the maxilla and line NA and using the occlusal plane as a guide for the lip embrasure, draw the upper lip from the vermilion border to the embrasure. Then from the point on the lower border of the nose where its outline stopped on the VTO, draw in the superior sulcus area. This is a gradual draping to the new vermilion border outline.

Third, superimpose on line NA and the occlusal plane. Form the lower lip, remembering that from 1 mm behind the H line to 2 mm anterior can be excellent, depending on variations of thickness of the two lips. Again, most cases will fall on the H line or within 0.5 mm of it.

Finally, complete the inferior sulcus drape from the lower lip to the chin in a form harmonious with the superior sulcus. *(Note: The lips are not expected to have fully adapted to this position in more than about one half of the cases at the time of retention.)*

Step VIII

First, with the exceptions noted earlier, lip strain that shows up as excessive upper lip taper is our first consideration. In the case of the example he used, the basic lip thickness measurement was 15 mm and the thickness at the vermilion border was 10 mm. One millimetre of taper is normal, leaving a lip strain factor of 4 mm.

Next we are concerned with how many millimetres the upper lip is back from its original position. This is measured with the tracings superimposed on line NA and the maxilla. In the present case this also amounts to 4 mm.

The third consideration is maxillary incisor "rebound." When the maxillary incisors have been retracted 5 mm or more and the case has been slightly over treated to a near edge-to-edge incisor overbite and overjet relationship, we can expect about 1.5 mm relapse tendency. Obviously, there will be no tendency to move labially in those cases in which the upper incisor is not retracted or in those cases, such as anterior crossbites and/or Class III cases, in which the maxillary incisors have been expanded labially. Here the incisor retraction is significant, and we will use 1.5 mm for incisor rebound. In this particular patient, then, calculations would be as follows: (I) Elimination of lip strain, 4 mm. (2) Upper lip change, 4 mm. (3) Maxillary incisor rebound, 1.5 mm.

Finally, with the tracing still superimposed on line NA and the maxilla, place the maxillary incisor template, taking cognizance of the amount that it is to be repositioned (9.5 mm in this case), its axial inclination, and the relationship of the incisal edge to the occlusal plane, and draw the tooth.

Step IX
First, superimpose the VTO on the mandibular plane and symphysis. Using the template, reposition the lower incisor to be in ideal retention occlusion with the maxillary incisor, using the occlusal plane a, a guide and by tipping the tooth about the apex unless bodily movement is needed to improve the form of the inferior sulcus area.

Second, with the tracing in this same position, measure the amount of lingual movement of the lower incisors. Twice this amount is the arch length loss due to lower incisor (uprighting) lingual tipping or gain from labial tipping when indicated. This loss of arch length is now combined with the arch length discrepancy determined from the model to obtain the total arch length discrepancy. In this case, the calculations would be:

(1) arch length loss from reposition, 2 x 4 = 8 mm;
(2) model discrepancy, 2 mm;
(3) total discrepancy, 10 mm.

Step X
With the tracing superimposed on the mandibular plane and symphysis and using the occlusal plane as a vertical guide, draw the lower molar where it must be to eliminate remaining space if extractions must be part of the treatment plan. In the case illustrated, each lower molar must be moved forward 2.5 mm.
Note: By using the VTO approach, you will come upon many cases where mesially tipped lower molars can be uprighted to gain all of the model arch length discrepancy when the incisor position is adequate. Distal tipping of lower molars 2.5 mm can allow nonextraction treatment in cases of a model discrepancy of 5 mm. In other cases, especially those having a history of thumb- or lip-sucking or in which serial extraction is contraindicated, the VTO will show that the lower incisors need to be moved forward, thus also increasing arch length and reducing the need to extract. On occasion both approaches can be used. In his opinion, lower incisors should not be moved forward to a point more than 1 mm anterior to the A-pogonion line, as post-treatment stability and long-term periodontal health are usually endangered by so doing.

The use of the VTO at this point to study and evaluate anchorage and arch length is one of its great advantages. If the lower molar must be moved anteriorly as much as 3.5 mm, the lower second premolars will be removed. There are cases in which there is an extremely thin alveolar process, particularly those cases that have deficient lower face height where the lower molars seem to get locked up in cortical bone if the second premolars are extracted.

Extraction of the second premolars instead of the first premolars actually increases the lower molar anchorage. When these two factors combine as contraindications to forward lower molar movement, it is sometimes better to look at judicious narrowing of the teeth through stripping and polishing than to extract at all.

Step XI

First, using the occlusal plane and the lower first molar as a guide, with a tooth template, position the upper first molar in ideal Class I occlusion with the lower first molar.

Second, superimposing tracings on the original NA line and the outline of the maxilla, evaluate the extent of upper molar movement. In cases that worked out as lower arch non-extraction cases, one may still need to think about other extraction alternatives in the upper arch, such as upper second molars when good third molar buds are developing or upper first premolars.

Step XII

Note: As to how point A changes with incisor retraction, it is imperative that the clinician study the before and after tracings of many cases superimposed on the original NA line and best fit of the maxilla to get the"feel" for this step. Obviously the change in point A is greater when the upper incisor root apices are moved a considerable distance than when the upper incisors are tipped lingually. More change in A point is also evident when the tracing is superimposed in this manner if we are going to use heavier orthopaedic forces, especially in younger patients (in the mixed dentition).

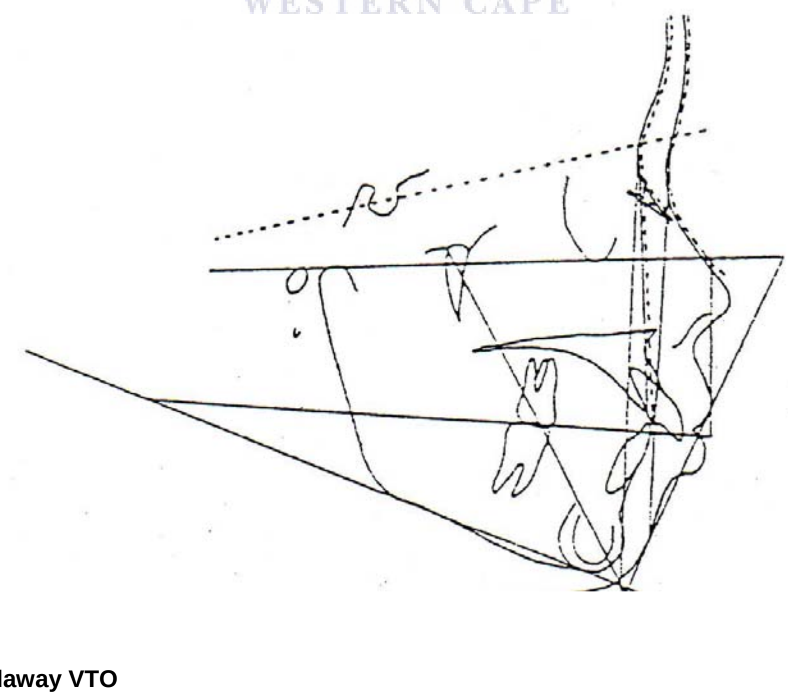


Figure 14. Holdaway VTO

APPENDIX D. Steyn VTO (1979)

Line's used in the VTO:

S-N
Ba-N
N-Pog
N-Pt A

1. Overlay the acetate paper onto the original cephalogram tracing. The front edge of the acetate tracing paper must be parallel to the N-Pog line. Draw the soft tissue profile from the frontal soft tissue, through soft tissue Na to about 1/3 from the tip of the nose.

2. Draw in the frontal bone, Nasion and the nasal bone.

3. Add line S-N, extended, as well as line N-A, Angle SnA remains constant throughout treatment.

4. Extend Sella ¾ mm per year posteriorly, i.e. *1 1/2 mm for two years growth for female patients and 1.5mm/year i.e. 3mm for two year treatment plan for male patients.*

5. Slide the tracing paper forward along S-N to the new Sella, draw the new sella turcica in and then draw in the facial axis, also extended.

6. From the original Ba-N line make a mark along the facial axis representing 2.5mm growth per year (5mm for two years growth for female patients) and 4mm/year for male patients. (8mm growth for the two years of treatment).

7. Slide the VTO up along the facial axis until this mark hits the original Ba-N line, then draw in the hard and soft tissue symphysis and chin and the inferior border of the mandible.

8. Place the tracing VTO SNA line so that it is superimposed over the true SNA line. Slide the VTO up along the NA line, such that the S-N line is a third and the new and old menton two thirds of the new vertical height. Draw in the maxilla and the palatal plane.

9. Slide up along the N-A line by another third and draw in the occlusal plane (molar to the lip embrasure).

10. Slide the VTO posteriorly along the palatal plane until the upper part of the VTO nose lies just posterior to the original (at this stage the posterior aspects of the nasal bones should overlie each other. Draw in the tip of

the nose until just above soft tissue pt A. (NB: *for two years growth, the change of the nasal contour in an antero-posterior dimension is 7mm for male patients and 4mm for female patients. Maintain the nasolabial angle and rotate the acetate paper to ensure that this change is achieved.)*

11. Slide the VTO tracing back to overlay on N-A along the palatal plane. Move the VTO up along the N-A line until the new nose outline overlies the original. Draw in the soft tissue point A.

12. Draw in line A-Pog.

13. Determine the arch space shortage/excess for the maxilla and the mandible.

14. Position the lower incisor according to the A-Pog line on the occlusal plane. (+1mm +/- 2mm to the A-Pog line).

15. Position the upper central incisor according to the lower central incisor.

16. Lip thickness: upper lip taper is 1mm. The lip thickness is measured at point A, and then 1mm is subtracted. This distance is then plotted from the upper incisor tooth. The VTO is then rotated and overlaid on this point so that a harmonious lip line is formed. Trace in the lip line.

17. The lower lip should touch the line connecting the top lip with the soft tissue pogonion. Place a rule on the top lip vermilion border and the soft tissue pogonion and make a mark where the lower lip should be. Draw in the lower lip only.

18. Overlay on the lower incisor. Soft tissue B point remains the same distance. Draw in the soft tissue point B and connect to the lower lip.

19. Calculate the space discrepancy using study models and the new incisor position.

20. Calculate and draw in the new molar position.

21. Evaluate the anchorage requirements.

APPENDIX E. Jacobson and Sadowsky VTO (1980)

The following points are traced.

1. The anterior and posterior cranial bases to include Basion (Ba) and Sella Turcica (S).
2. The pterygomaxillary fissure. Use the "Lip Contour Template" to locate foramen rotundum.
3. Lateral and inferior border of the orbits.
4. Anterior outline of the frontal bone.
5. Nasal bone and Nasion (N).
6. ANS and PNS and hard palate, also point A (Subspinale).
7. Upper central incisor tooth and its alveolar process.
8. Mandible, including condyle if possible and symphysis (anterior and posterior border).
9. Lower central incisor tooth.
10. Maxillary and mandibular first molar teeth.
11. Anatomical external auditory meatus-to locate, "Lip Contour Template" may be employed.
12. Soft tissue profile to include forehead, nose, lips and chin.

The following reference lines are constructed on the cephalometric tracing:

1. Basion-Nasion line (BaN).
2. Line Nasion to point A (NA).
3. The Frankfort horizontal from Porion to Orbitale (Por-Or).
4. The Occlusal plane.
5. Downs mandibular plane.
6. The facial axis (foramen rotundum opening to Gnathion GN)
7. Holdaway's line (soft tissue chin to tip upper lip).
8. The facial plane (NPo).

STEP I.

OBJECTIVE: to draw trontonasal area, line BaN and line NA.

a) Place a clean sheet of acetate paper over the original cephalometric tracing and copy the frontonasal area both hard and soft tissue, tracing through the bridge of the nose.
b) Copy the line BaN.
d) Copy the line NA.

STEP II.

OBJECTIVE: To express growth in the frontonasal area over a two-year period (or estimated treatment time).

a) Superimpose on line BaN and move the VT.O. tracing until there is 1 5mm of growth expressed in the frontonasal area (Dr. Holdaway's studies reveal that there is approximately ':mm of growth per year in this frontonasal area)

b) Holding the VTO tracing in the position as in a) above, copy the Ricketts facial axis (foramen rotundum to Gnathion).

NOTE: It should be appreciated that the predicted growth at Nasion along the BaN line is in effect an overall prediction of all midfacial structures which include the nasal bone, maxilla and soft tissues in this area.

STEP III.

OBJECTIVE: To express growth in a vertical direction in the mandible, and to draw the anterior portion of the mandible, soft tissue chin and the mandibular plane of Downs.

a) Superimpose the V.T.O facial axis along the original facial axis Move the VTO tracing upwards so that the V.T.O BaN line is above the original BaN line, the distance between these lines should be three times the amount of growth expressed previously in the frontonasal area. Therefore, in this instance the VTO would be moved up approximately 4.5 mm.

b) Holding this position, copy the anterior portion of the mandible to include the symphysis, anterior 1/3 of lower border of the mandible and Downs' mandibular plane,

c) Draw soft tissue chin from its anterior most point, extending this line posteriorly. Eliminate any evident hypertonicity (mentalis action) by rounding out this area.

STEP IV.

OBJECTIVE: To express growth in a horizontal plane in the mandible (or lower face) and draw the posterior border of the mandible.

a) Superimpose on mandibular plane and move the VTO forward until the original and V.TO. foramina rotundae are vertically aligned.

b) With the tracing in this position the posterior border and ramus of the mandible is drawn.

NOTE: Total vertical facial height as well as forward location of the chin have now been established. The amount of forward growth at the chin point will be much the same as that at Nasion.

STEP V.

OBJECTIVE: To locate and draw the maxilla, and lower half of nose.

a) Superimpose the VTO NA line on the original NA line and move the VTO up until the vertical growth expressed above the BaN line and below the mandibular plane is in the ratio of 40:60. In other words, there is 40% of total vertical growth above the BaN line and 60% below the mandibular plane

b) With the VTO tracing in this position copy the maxilla to include posterior 2/3 of hard palate, PINS to ANS to 2mm below the ANS.

c) With the VTO in the same position, draw the new nose up to the middle of the inferior surface of the nose. Estimated growth usually parallels the contour of the old nose in this area Average nose growth is 1mm per year.

STEP VI.

OBJECTIVE: To locate and draw the occlusal plane.

a) With the VTO superimposed on line NA, move the VT.O. tracing so that the vertical growth between the maxilla and the mandible is expressed as being 50% above the maxilla and 50% below the mandible

b) With the tracing in this position, copy the occlusal plane. Generally, the occlusal plane is located 3mm below the lip embrasure. This permits the tower lip to envelope the lower one-third of the upper central incisor teeth. If the cant of the occlusal plane in the original tracing is correct, then this should be maintained. However, should adjustments be indicated, then alter accordingly at this stage

STEP VII.

OBJECTIVE: To determine the soft tissue lip contour using the “new” Holdaway line (H-line).Dr Holdaway’s vast experience enables him to accurately access the desired soft tissue profile by drawing the H-line (judged from clinical experience) and then drawing the soft tissue lip profile to fit within the framework of this line. The H-line extends from the soft tissue chin to the lower border of the nose, but touches the tip of the upper lip. To assist the less experienced, the ' Lip Contour' Template" may be usefully employed as an aid in the location of the H-line.

Dr. Holdaway's studies have shown that in "ideal” pro files, the distance between the depth of the upper lip contour and the H-line is between 3 and 7 millimeters Clinically judge the length of the upper lip. For lips, use a 3 mm sulcus depth and a 7 mm sulcus depth for long lips. In lips of AVERAGE length a sulcus depth of 5mm is used. Having judged the lip length use the “Lip Contour Template" to locate the H-line.

STEP VIII.

OBJECTIVE: To relocate maxillary central incisor.

PRINCIPLES:

1) Lip strain - Dr. Holdaway contends that in well-balanced soft tissue profiles the distance along a horizontal extending between a point 3mm below the original point A to the point where the line crosses the upper lip is within 1mm of the distance between the labial surface of the maxillary incisor to the tip of the upper lip. Should the lower measurement be less than within 1mm of the upper measurement, then lip strain is said to exist. To eliminate lip strain where it exists, the upper incisor is moved back to allow the aforementioned readings to be within 1mm of each other.

2) Where no lip strain exists retraction of the maxillary incisors allows the upper lip to move backwards an equal amount, i.e. lip and incisors maintain a 1: 1 ratio.

3) Maxillary Incisor Rebound - Generally, during post-treatment, maxillary incisors tend to move labially 0.5mm in Class I cases and 1.5mm in Class II cases. This is referred to as "Incisor Rebound".

In their patient, the calculations were as follows:

a) Elimination of lip strain	4 mm
b) Distal movement of upper lip	4 mm
c) Maxillary incisor rebound	1.5 mm
	9.5 mm

Superimpose the VTO tracing on the NA line and the maxilla and trace in the maxillary incisor, taking cognisance of the amount it is to be repositioned (namely 9.5mm in this instance). The axial inclination of this tooth is judged and the occlusal plane is used to locate it vertically. The tip of the maxillary incisor touches the occlusal plane.

STEP IX.

OBJECTIVE: To reposition lower incisor and calculate resultant arch length change.

1) Having located the position of the upper incisor, judge the position and axial inclination of the lower Incisor.

2) To calculate lower arch length change, superimpose tracing on mandibular plane and register on symphysis. Measure the distance between old and new incisor position and double this measurement to determine total arch length discrepancy.

STEP X.

OBJECTIVE: To reposition lower first molar, use the plaster casts to determine arch length discrepancy due to crowding and/or rotation. In this case the discrepancy is 4mm.

Superimpose tracing on mandibular plane and register on symphysis.

Incisor repositioning was 2mm lingually, thus effectively decreasing lower arch length 4mm. The total arch length discrepancy is now 4 + 4 mm = 8mm

Due to mild lingual repositioning of lower incisors and total arch length discrepancy of 8mm, it is apparent that second bicuspids should be removed.

If two first bicuspids were extracted this would create 15mm of space whereas only 8mm are required. Due to anchorage consideration, the extraction of first bicuspids is contraindicated

In this case, therefore, the mandibular first molar was positioned $3^{1}/_{2}$mm forward on either side. Space due to the extraction of two second bicuspids = l5mm. Space required was 8mm. Thus to close residual space. molars were advanced $3^{1}/_{2}$mm on either side.

STEP XI.

OBJECTIVE: To reposition maxillary first molar.

Using the occlusal plane and lower first molar as a guide, draw the maxillary first molar in good Class I occlusion with the lower first molar.

STEP XII.

OBJECTIVE: To complete artwork.

1) ANS to upper incisor.
2) Anterior portion of hard palate.
3) Lower alveolus lingually and labially.

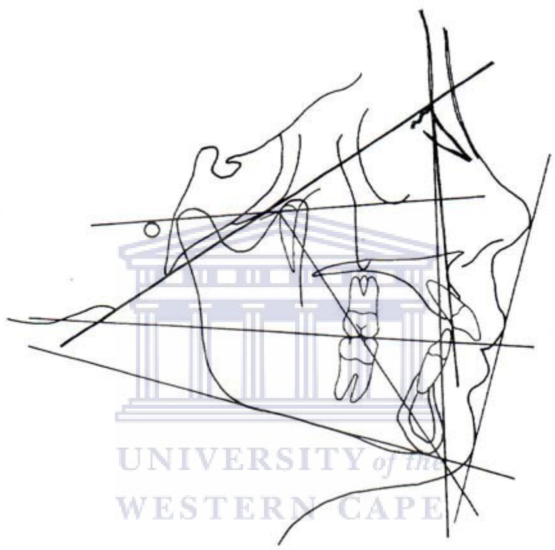


Figure 15. Jacobson and Sadowsky VTO.

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