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POST-TREATMENT AND POST-RETENTION EVALUATION OF PROTRACTION FACEMASK THERAPY USING TRADITIONAL CEPHALOMETRICS

by

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Abstract

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The protraction facemask has been used for more than twenty-five years yet the treatment effects and long-term stability are still questioned by many practitioners. The most frequently debated aspects are the behavior of A point, extrusion of upper first molars, proclination of upper incisors, inclination of palatal plane and mandibular plane angle. This study evaluated post-treatment and post-retention changes in twenty-four class III subjects (16 females and 8 males) with ANB ranging from -5° to 3°, treated with protraction facemask. Lateral cephalograms were obtained at pre-treatment (T1, 8.8 ± 1.1 of age), post-treatment (T2, 10 ± 1.1 years of age), and post-retention (T3, 12.7 ± 1 years of age) phases. The treatment group was matched for age, sex, race, and malocclusion with twenty-four controls selected from the Bolton-Brush growth center at Case Western Reserve University. Matched paired t-tests were used for comparison between the treatment and the control group at different phases. The results showed that maxillary skeletal changes accounted for 27% of the treatment effect and the average anterior movement of A

point was 1.97 mm greater post-treatment and 0.89 millimeters greater post-retention than the control group. Mandibular skeletal changes accounted for 35% of the treatment effect, which relapsed entirely during the retention phase. The average difference of distance between articulare and gnathion was 2.67 mm less post treatment and 2.83 mm greater post-retention than the control group. Maxillary dental changes were mostly stable throughout the treatment and accounted for 23% of the treatment effect. The average upper incisor anterior movement was 1.01 mm greater post-treatment with no change during the post-treatment wait period compared to the control group. Vertical changes were minimal and only 15% of the overall treatment effects were due to rotational changes. The average upper first molar extrusion was 0.25 mm greater post-treatment and 0.31 mm post retention compared to the control group.

The results suggest that the maxilla assumes a more normal growth direction and pattern once it is in a more physiological position and relation to the mandible and that skeletal class III correction with protraction facemask may be stable long-term.

DEDICATION

To my mom, thanks for teaching me how to be strong and determined.

To my dad, thanks for your tremendous support throughout my life.

I will never forget the sacrifices that both of you made to allow me the opportunities I have had. I hope I can be the same kind of parent for Taraneh that you have been for me.

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GLOSSARY

1. The landmarks used for the cephalometric analysis are listed in alphabetical order with the corresponding definitions.

ANS: Anterior Nasal Spine. The anterior tip of the bony process of the maxilla at the lower margin of the anterior nasal opening.

Ar: Articulare. The point at the junction of the posterior border of the ramus and the inferior border of the posterior cranial base (occipital bone).

Go: Gonion. The point on the curvature of the angle of the mandible located by bisecting the angle formed by lines tangent to the posterior ramus and the inferior border of the mandible.

Gn: Gnathion. The point located by taking the mid-point between the anterior (pogonion) and inferior (menton) points of the bony chin.

L1C: Lower Incisor Crown. The most incisal point on the crown of permanent mandibular central incisor.

L1R: Lower Incisor Root. The root apex of the permanent mandibular central incisor.

L6C: Lower Incisor Crown. The buccal groove of the permanent mandibular first molar.

N: Nasion. The most anterior point on the frontonasal suture in the mid-sagittal plane.

Pog: Pogonion. The most anterior point on the chin.

A point: Subspinale. The most posterior midline point in the concavity between the anterior nasal spine and the prosthion (the most inferior point on the alveolar bone overlying the maxillary incisors).

PNS: Posterior Nasal Spine. The posterior spine of the palatine bone constituting the hard palate.

PTV: Pterygomaxillare. The contour of the pterygomaxillary fissure formed anteriorly by the retromolar tuberosity of the maxilla and posteriorly by the anterior curve of the pterygoid process of the sphenoid bone. The lowest point of the opening is used.

S: Sella. The geometric center of pituitary fossa located by visual inspection.

U1C: Upper Incisor Crown. The incisal most point on the crown of the permanent maxillary central incisor.

U1R: Upper Incisor Root. The apex of the maxillary central incisor root.

U3C: Upper Canine Crown. The incisal most point on the crown of the permanent maxillary canine.

U6C: Upper Molar Crown. The midpoint of the mesiobuccal cusp of the permanent maxillary first molar at the cusp tip.

2. The definitions of the linear and angular measurements used in the cephalometric study. The definitions are listed in the order in which they appear in the text.

Descriptive Measurements

Maxillary Skeletal

SNA: The angular measurement between the lines sella-nasion and nasion-A point.

Articulare to A-pint. The linear measurement in millimeters between articulare and A-point.

Articulare to ANS. The linear distance between articulare and ANS.
Mandibular Skeletal

SNB. The angular measurement between the sella-nasion and nasion-B point.

SN to Pogonion. The angular measurement between the lines sella-nasion and nasion-pogonion.

Articulare to Gnathion. The linear measurement in millimeters between articulare and gnathion.

Articulare to Gonion. The linear measurement in millimeters between articulare and gonion.

Gonion to Pogonion. The linear measurement in millimeters between gonion and pogonion.

Articulare to SN. The linear measurement in millimeters between articulare and the line between sella and nasion.

Maxillary to Mandible

ANB. The angular measurement between A point-nasion and nasion-B point.

Wits. The linear distance between the perpendicular projections of A point and B point to the occlusal plane.

Articulare to PTM. The linear distance between articulare and pterygomaxillare.

Maxillomandibular differential. The difference between the linear distances articulare-gnathion and articulare-A point.

Vertical

SN to Occlusal Plane. The angular measurement between sella-nasion and anterior nasal spine-posterior nasal spine.

SN to Mandibular Plane. The angular measurement between sella-nasion and gonion-menton.

Facial Axis Angle. The angular measurement between sella-nasion and sella-pogonion.

Upper Facial Height. The linear measurement between nasion and anterior nasal spine.

Lower Facial Height. The linear measurement between anterior nasal spine and menton.

Ant Facial Height. The linear measurement between nasion and menton.

Gonial angle. The measurement between articulare-gonion and gonion-gnathion.

Posterior Facial Height. The linear measurement between sella and gonion.

Post/Ant Facial Height. The posterior facial height (S-Go) divided by the anterior facial height (N-Me), multiplied by one hundred.

Maxillary Dental

Upper 1 to SN. The posterior inferior angle formed between the intersection of long xis of the maxillary central incisor and sella-nasion.

Mandibular Dental

Lower 1 to A-Pogonion. The linear measurement between the mandibular central incisor tip the line between A-point and pogonion.

Lower 1 to Mandibular Plane. The posterior-superior angle between the long axis of the mandibular central incisor and gonion-menton.

Interdental

Overbite. The vertical measurement between the incisal edges of the maxillary and mandibular central incisors, perpendicular to the occlusal plane.

Over jet. The horizontal measurement between the incisal edge of maxillary central incisor and the facial surface of the mandibular incisor, parallel to the occlusal plane.

Interincisal Angle. The angular measurement between the long axis of maxillary central incisor and the long axis of the mandibular central incisor.

Molar relationship. The linear distance between the mesiobuccal groove of the mandibular first molar and the cusp tip of the maxillary first molar and parallel to the occlusal plane.

Superimposition Measurements

Overall

Nasion horizontal. The change in the linear position of nasion between Time-1 and Time-2, measured parallel to the average occlusal plane.

ANS horizontal. The change in the linear position of anterior nasal spine between Time-1 and Time-2, measured parallel to the average occlusal plane.

ANS vertical. The change in the linear position of anterior nasal spine between Time-1 and Time-2, measured perpendicular to the average occlusal plane.

A point. The change in the linear position of A-point between Time-1 and Time-2, measured parallel to the average occlusal plane.

PNS horizontal. The change in the linear position of posterior nasal spine between Time-1 and Time-2, measured parallel to the average occlusal plane.

PNS vertical. The change in the linear position of posterior nasal spine between Time-1 and Time-2, measured perpendicular to the average occlusal plane.

Upper 1 horizontal. The change in the linear position of incisal edge of the maxillary central incisor between Time-1 and Time-2, measured parallel to the average occlusal plane.

Upper 1 vertical. The change in the linear position of incisal edge of the maxillary central incisor between Time-1 and Time-2, measured perpendicular to the average occlusal plane.

Upper 6 horizontal. The change in the linear position of mesiobuccal cusp tip of the maxillary first molar between Time-1 and Time-2, measured parallel to the average occlusal plane.

Upper 6 vertical. The change in the linear position of mesiobuccal cusp tip of the maxillary first molar between Time-1 and Time-2, measured perpendicular to the average occlusal plane.

Lower 1 horizontal. The change in the linear position of the incisal edge of the mandibular central incisor in between Time-1 and Time-2, measured parallel to the average occlusal plane.

Lower 1 vertical. The change in the linear position of the incisal edge of the mandibular central incisor in between Time-1 and Time-2, measured perpendicular to the average occlusal plane.

B point horizontal. The change in the linear position of B point between Time-1 and Time-2, measured parallel to the average occlusal plane.

Pogonion horizontal. The change in the linear position of Pogonion between Time-1 and Time-2, measured parallel to the average occlusal plane.

Maxilla

ANS horizontal. The change in the linear position of anterior nasal spine between Time-1 and Time-2, measured parallel to the average occlusal plane from the maxillary superimposition.

A point horizontal. The change in the linear position of anterior nasal spine between Time-1 and Time-2, measured parallel to the average occlusal plane from the maxillary superimposition.

Upper 1 horizontal. The change in the linear position of the incisal edge of the maxillary central incisor between Time-1 and Time-2, measured parallel to the average occlusal plane from the maxillary superimposition.

Upper 1 vertical. The change in the linear position of the incisal edge of the maxillary central incisor between Time-1 and Time-2, measured perpendicular to the average occlusal plane from the maxillary superimposition.

Upper 6 horizontal. The change in the linear position of mesiobuccal cusp tip of the maxillary first molar between Time-1 and Time-2, measured parallel to the average occlusal plane from the maxillary superimposition.

Upper 6 vertical. The change in the linear position of mesiobuccal cusp tip of the maxillary first molar between Time-1 and Time-2, measured perpendicular to the average occlusal plane from the maxillary superimposition.

Mandible

B Point horizontal. The change in the linear position of B point between Time-1 and Time-2, measured parallel to the average occlusal plane from the mandibular superimposition.

Lower 1 horizontal. The change in the linear position of incisal edge of the mandibular central incisor between Time-1 and Time-2, measured parallel to the average occlusal plane from the mandibular superimposition.

Lower 1 vertical. The change in the linear position of incisal edge of the mandibular central incisor between Time-1 and Time-2, measured perpendicular to the average occlusal plane from the mandibular superimposition.

Lower 6 horizontal. The change in the linear position of the mesiobuccal groove of the mandibular first molar between Time-1 and Time-2, measured parallel to the average occlusal plane from the mandibular superimposition.

Lower 6 vertical. The change in the linear position of the mesiobuccal groove of the mandibular first molar between Time-1 and Time-2, measured perpendicular to the average occlusal plane from the mandibular superimposition.

Articulare. The change in the linear position of articulare between Time-1 and Time 2, measured parallel to the average axis of the condyle.

INTRODUCTION

One of the many challenges in orthodontics is treating class III malocclusion. Practitioners avoided early treatment of class III malocclusion for a long time, because they believed the malocclusion was caused by overgrowth of the mandible. Since mandibular growth could not be controlled, surgery was inevitable. There have been several studies in regards to the efficacy and stability of the orthopedic effect of headgear in treating class II malocclusion. Similar studies in the treatment of class III malocclusion is lacking from the literature. Early studies trying to qualify the effects of protraction facemask therapy often lacked a control group or adequate statistics. Many recent longitudinal studies have limited number of treatment and control groups.

Cephalometric radiography has greatly contributed to the treatment planning and evaluation of orthodontics since H.B. Broadbent invented the Broadbent-Bolton roentgenographic cephalometer in 1926. Cephalometric radiographs have been used for a variety of clinical and research purposes. The manual superimposition of two cephalometric radiographs of the same individual taken at two different times to evaluate changes from growth or treatment is a common clinical practice. Improvement in superimposition techniques and cephalometric measurements over the years has allowed practitioners to effectively measure any skeletal changes due to growth, treatment or both.

LITERATURE REVIEW

There have many debates over the treatment of class III malocclusion (Kapust et al. 1998). Some orthodontists believe that treatment of class III patients at early ages will help to establish a more normal growth pattern. Others rely on surgical correction after growth has been completed.

2.1 Epidemiology of Class III Malocclusion

The incidence of class III malocclusion varies in different populations. Estimates of prevalence of class III malocclusion in the United States range from 1.6 % (Ast et al. 1965 from Mermigos et al. 1990) to less than 1% of the population (Kelly et al. 1977 from Popp et al. 1993). According to Masaki (1980), there is an increased prevalence of class III malocclusion in Asian populations, which has led to a great demand for treatment of this type of malocclusion.

Many investigators have examined the diagnostic characteristics present in class III malocclusion. Masaki (1980) concluded that the maxillary length as opposed to the mandibular length is significantly different in Japanese adolescents compared to Caucasian adolescents. The palatal length (ANS-PNS) in ten-year old Japanese boys was 4.75 mm smaller on the average than in Caucasians boys. Mandibular linear measurements were similar between the two groups, but compensation in the Japanese population for a smaller maxilla seems to be a clockwise rotation of the mandible. Dhopatkar et al. (2002) concluded that unlike

jaw length, the cranial base angle does not play a pivotal part in the establishment of malocclusion. They observed that the cranial base length (nasion-sella), sella-basion, and all maxillary skeletal parameters were very similar in class I and class III malocclusions, however, the mandibular length measurements were reported to be significantly larger in the class III group compared to the class I group.

2.2 Etiology of Class III Malocclusion

The presence of an anterior cross bite in the deciduous dentition may indicate an underlying dental, functional or skeletal problem. Dentally, an early cross bite can occur due to the lingual eruption of the maxillary incisors, which is usually the result of an arch length discrepancy or over retained deciduous tooth. Functionally, interferences in the dentition can result in a forward posturing of the mandible leading to an anterior cross bite. Finally, the presence of an anterior cross bite can indicate an underlying skeletal disharmony between the maxilla and the mandible (Vadiakas et al. 1992).

Can we predict the development of a class III malocclusion by looking at the primary dentition? Chang et al. (1992) evaluated the craniofacial pattern found in developing class III skeletal malocclusions. They looked at forty Chinese children with class III malocclusions and forty Chinese children with normal occlusions. Both groups were in the full deciduous dentition. They reported no statistical difference in cranial base or SNA angle between the two groups. However, maxillary length (A point-pterygomaxillare) was smaller in the class III group. The class III group also had a greater mandibular length and the SNB was increased

compared to the class I control group. Dentally, the class III group showed more retrusive maxillary and mandibular incisors. They stated that all of these characteristics were accentuated later in life except for the retrusion of the upper anterior primary dentition. In the permanent dentition, tongue pressure was thought to cause flaring of the maxillary permanent incisors. In the primary dentition with a negative overjet, lower primary incisors exert a lingual force on the upper anterior primary dentition.

2.3 Diagnosis and Treatment Planning

Which jaw is the contributing factor for class III malocclusion? Many practitioners tried to establish specific guidelines to characterize class III malocclusion. Guyer et al. (1986) studied the characteristics of class III malocclusion compared to class I malocclusion. They noted that the effective lengths of class III maxillae were significantly shorter and the mandibles were longer by 3-6 mm creating a unit length difference of at least 6 mm between the maxilla and mandible. They also concluded that the mandibular plane angle and the lower facial height were greater in class III samples. They felt that these characteristics were present at an early age and, although may worsen with time, they did not develop later in life. Based on their cephalometric criteria, 25 percent of their sample was maxillary retrusive, 19% were mandibular prognathic, and 22% had a combination of the two. Forty-one percent of the overall sample had an excessive lower facial height.

William Proffit (2000) categorizes class III malocclusion as either normal maxilla with mandibular protrusion, maxillary retrusion with a normal mandible, or a combination of maxillary retrusion and mandibular protrusion. He states that children under eight years of age will have more skeletal response to protraction headgear and that the dental compensations become more significant in older children. Ideally permanent first molars and central incisors should be erupted for the protraction facemask therapy. An acrylic occlusal splint is desirable to create an anchor unit. He discourages a bonded appliance for oral hygiene reasons and recommends twelve ounces of force per side for fourteen hours a day. To avoid the downward rotation of the maxilla, the elastics should be attached to the primary canine area. He states that many children with maxillary deficiency are also vertically deficient and therefore a downward and forward direction of force is desirable. This, however, should be avoided if the facial height is already increased.

Mouakeh (2001) examined the morphologic characteristics of the craniofacial complex of Syrian children with class III malocclusion. He compared sixty-nine children aged 5-12 with class III malocclusion with a class I control group matched for age, sex, and ethnicity generated from the Rocky Mountain normative data. He reported that both the anterior and posterior cranial bases were significantly shorter in the class III group. He also noted that in the class III group the maxilla was smaller and retrusive and the mandible was within the normal range of protrusion. The effective mandibular length, however, was 3 mm larger and the glenoid fossa was positioned more forward. Contrary to the expected compensations, maxillary

anterior teeth were upright or retruded and the mandibular anterior teeth were slightly retruded. He also reported that the anterior facial height was smaller in children with class III malocclusion. He recommended early intervention with orthopedic facemask therapy as the treatment method of choice.

2.4 Early Animal Studies

Many animal studies have been done over the years to study the effects of appliances on the craniofacial complex. All the animal studies have shown that the maxillary complex does move forward once the appropriate forces are applied.

Janzen and Bluher (1965) studied the effects of continuous retracting forces to the mandible in three Macaca mulattas. The purpose of the study was to evaluate the effectiveness of the head-chin cup appliance for clinical management of developing class III malocclusion. There were three experimental animals and one animal in the control group and 140 grams of force was applied per side for 140 days. The animals were evaluated cephalometrically, anatomically, and histologically. They noted a decrease in mandibular plane angle and an increase in maxillary alveolar development, with little increase in ramus height. These changes disturbed the normal downward and forward development of the craniofacial complex. Histologically, there was resorption of the posterior surfaces of the condyles and the glenoid fossae. The mandibular body length was unchanged relative to the control animal. The post-treatment results could not be evaluated, however, since no experimental animals were kept alive.

Jean-Pierre Joho (1973) evaluated the post-treatment changes in four Macaca mulatta monkeys when he applied continuous distal and downward forces to the mandible in different treatment times. A force of 250-400 grams was applied to the mandibular first molars on each side using a Kloehn type facebow. One animal was killed after four and half weeks and the other three had a six-week retention period followed by a six-week relapse period before they were killed. He described the results cephalometrically, histologically and with dental casts. The skeletal changes were a reduction of the gonial angle and remodeling of the temporomandibular joint. Reversal lines in the temporomandibular joint indicated relapse while gonial angle changes were stable with a minimal effect on the maxilla or the maxillary dentition. The overall effect of the forces resulted in a change from a class I to a class II malocclusion.

Eugene Dellinger (1973) evaluated whether the maxilla could be positioned forward if anterior forces were applied. He experimented on two Macaca speciosa monkeys in the mixed dentition, using a spring-loaded palatal expansion appliance with preformed bands. Six pounds of force was applied for seven days with a spring attached to the palatal appliance. Since the animals had to be tied down, the duration of force application was short. Cephalometric evaluation showed that the maxilla was displaced anteriorly but the author realized some limitations in the study and suggested additional studies with better appliance technique, force application and proper clinical timing.

Brousseau and Kubisch (1977) used eight male Macaca nemestrina monkeys to study the difference between intermittent versus continuous forces on the maxillofacial sutures. They showed that the changes from continuous forces were significant, however, both types of forces would cause significant protraction of the mid-facial complex. They also concluded that there was a strong relapse tendency and lack of stability if the maxillary complex was rotated or dental movement occurred.

Kambara (1977) studied the effects of protraction on the craniofacial complex using six experimental and five control Macaca irus monkeys. He applied 300 grams of force per side fifteen hours per day for ninety days and found that there was bone deposition along the stretched sutural connective tissue fibers in younger animals. The changes were significantly more in younger animals than the adult animals suggesting that protraction of the maxillary complex should be done as early as possible for a predictable positional change with minimal counterclockwise rotation of the maxilla.

Nanda (1978) used six experimental and three control female rhesus monkeys to evaluate the effects of different directions of anterior force application to the maxillary complex. Five hundred grams of force per side was applied through a device at varying angles of force application for 81-95 days. He concluded that the center of resistance of the maxilla varied depending on the direction of force application.

Jackson et al. (1979) demonstrated the effects of anteriorly directed extraoral force on the craniofacial complex. He cemented a cast vitalium splint to the maxilla of four pigtail macaques. Three hundred grams of force per side was delivered through springs to create eleven millimeters of overjet before the force was discontinued. Titanium implants were used to allow accurate cephalometric analysis. One animal was sacrificed at the completion of protraction and cephalometric histologic and dry skull evaluations revealed that skeletal remodeling occurred in all circummaxilary sutures. The amount of remodeling depended on the distance and the orientation of the suture to the applied force system. There was a small amount of counterclockwise rotation of the maxillary complex during the experimental period.

2.5 Protraction Facemask Therapy

Protraction facemask therapy has been reported predominantly in the form of case reports (Nakamura 1975; Campbell 1983; McNamara 1987; Turley 1988; Staggers et al. 1992; Turley 1996). Recently longitudinal clinical investigations have appeared in the literature. Both class III, class I or a combination of class I and class III control groups have been compared to protraction facemask treatment groups (Baccetti et al. 1999; Kapust et al. 1998; Wenger 1998; Wolf 1998; Baccetti et al 1999; Saadia and Torres 2000; Gu et al. 2000; Ucuncu et al. 2000). The following aspects of protraction facemask treatment have been examined in the literature:

1. Types of protraction facemask therapy
2. Duration of wear and amount of force
3. Direction of force application
4. Effects of protraction facemask therapy
5. Expansion versus non-expansion
6. Timing of the treatment: Early versus late
7. Retention and second phase treatment
8. Post-retention effects

2.5.1 Types of Protraction Facemask

Many different facemask designs have been used to treat class III malocclusion. The older versions were modifications of the Kloehn headgear. Irie and Makamura (1975) used a modification of the Kloehn headgear, which had a U-shaped inner bow that could be inserted into the molar tubes and an outer bow that could be adjusted for proper direction of force. They used intraoral protraction elastics that were attached to the molar bands of a palatal bar.

Nanda (1980) used a combination of chin cup with maxillary protraction also by modifying a Kloehn headgear. The inner bow was U-shaped which allowed for insertion into the distal of the molar tubes. The outer bow could be adjusted to deliver the desired direction of force to the maxilla and elastics were attached from the outer bow on both sides to the chin cup wire.

The more modern designs are of two forms (Figure 1). Petit (1983) designed a facemask (Petit facemask), which is one of the two most often used designs. It has a

single middle metal bar with forehead and chin rests. He recommended a custom made framework with nose rollers, forehead gliders and chin gliders, which allows for full mobility of the mandible.

Another commonly used facemask was designed by Campbell (1983) called the Delaire type facemask. It has a boxed framework with metal supports on either side of the face.

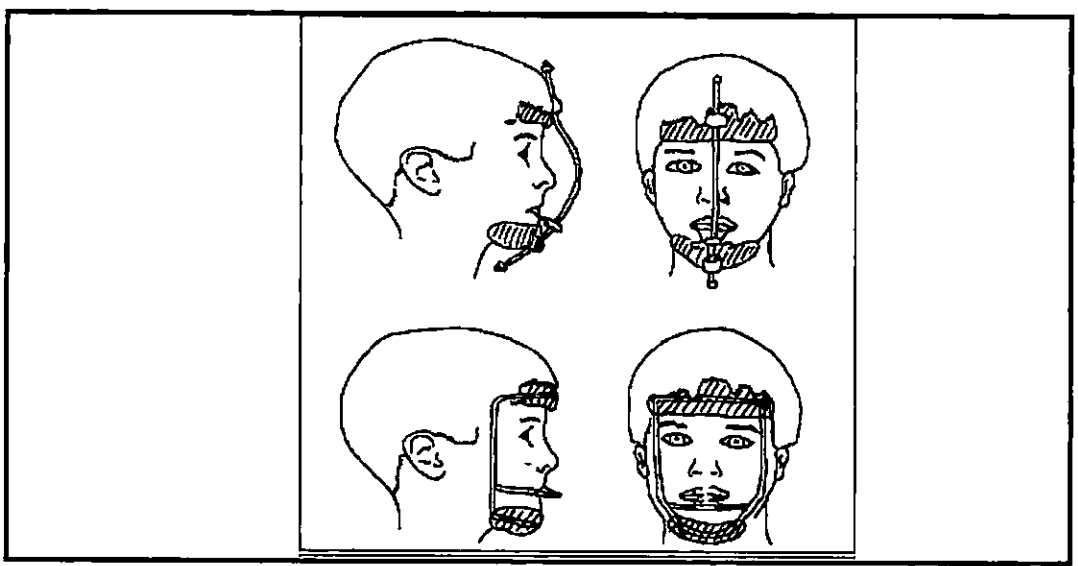


Figure 1. Types of Protraction Facemasks: Petit facemask (top) and Delaire facemask (bottom). Source: Adopted from Wenger R. 1988. Evaluation of protraction facemask therapy, using traditional morphometrics and Procrustes analysis. Thesis. Case Western Reserve University, Cleveland, OH.

Orton (1983) used facial impressions similar to Turley (1988) to fabricate a Kingston facemask that resembles the Delaire facemask with close fitting acrylic rests for better patient comfort. Staggers et al. (1992) used a Delaire facemask with a modified Kloehn headgear, stating that this design helped control the moments on the maxilla.

TABLE 1.–Summary of the Literature on Protraction Facemask.

Author	Year	Type of Maxillary Expansion (RME)	Maxillary Protraction	Force Magnitude
Irie, Nakamura	1975	Haas	Sky Hook/Chincap Sky Hook alone	400 gm 400 gm
Nanda	1980	Haas	Sky Hook with Protraction HG	500 gm /side 750 gm /side
Cozzani	1981	Does not expand	Delaire Mask	500-1000 gm /side
Campbell	1983	Hyrax	Mask or sky hook	14 and 16 oz /side
Wisth et al.	1987	Quadhelix	Delaire Mask	300 gm/side
Ishii et al.	1987	Does not expand	Sky Hook	200-300 gm /side
McNamara	1987	Bonded Expander	Petit Mask	14 oz /side
Turley	1988	Haas	Delaire Mask	150-200gm initial 400-600gm
Tindlund	1989	Quadhelix	Mask	700gm
Silva et al.	1989	Haas	Skyhook	----
Memingos et al.	1990	No expansion	Delaire Mask	125gm 2months 175gm 2 months 250 gm remainder
Capelozza et al.	1990	Haas	Sky Hook	450gm /side
Hickham	1991	Hyrax	Mask	600-800gm /side
Ngan et al.	1992	Hyrax	Mask	600-800gm /side
Staggers et al.	1992	RME	Delaire Mask	500gm /side
Orton et al.	1992	Variable	Kingston Mask	200gm /side
Major, Elbadrawy	1993	Hyrax	Mask	100-150gm /side 300-500gm /side
Baik	1995	Hyrax and No expansion	Delaire Mask	300-500gm /side
Shanker et al.	1996	Hyrax	Delaire Mask	400 gm /side
Silva et al.	1998	Haas	Mask	350gm
Kapust et al.	1998	Haas	Delaire Mask	600-800 gm /side
Baccetti et al.	1998	Bonded Expander	Petit Mask	14 oz
Kilicoglu, Kirlic	1998	No expansion	Delaire Mask	400 gm /side

Source: Adopted from Wenger R. 1988. Evaluation of protraction facemask therapy using traditional morphometrics and Procrustes analysis. Thesis. Case Western Reserve University, Cleveland, OH.

2.5.2 Duration of Wear and Amount of Force

How long does the facemask need to be worn and how much force is necessary to protract the maxilla? Nanda (1980) believed that the amount of force needed to achieve orthopedic effects depended on patient compliance. Those who wore the appliance close to twenty-four hours received 500 grams per side for four months while less compliant patients received higher forces (750 grams) for seven to eight months.

Petit (1983) used the protraction facemask on patients with a prognathic mandible and applied heavy forces (800-1500 grams) to "bend" the maxilla, causing a clockwise rotation of the mandible.

Turley (1988) believed that full time wear of the appliance would correct the problem in two to six months and anything less than full time would prolong the treatment. He took alginate impression of the patient's face, which was used to fabricate a customized Delaire type protraction headgear. He felt that compliance could be improved with a better adaptation of chin and forehead rests.

2.5.3 Direction of Force Application

What is the best direction to apply the force? McNamara and Brudon (1993) indicated that the direction of force varied depending on the position of the hooks on the splint.

Nanda (1978) tried to identify the center of resistance of the maxilla based on an animal study. He concluded that the center of resistance of the maxilla varied, depending on the direction of force application. He further stated that in general the

direction of stretched sutural fiber bundles corresponded with the direction of the force applied. Consequently, the nature of the movement was related to the direction of force.

Nanda (1980) further tried to identify the most effective direction of force for protraction. He stated that the direction of force application for protraction headgear is determined to some extent by the interlabial gap if elastics are used to apply the protraction force to the maxilla. In order to avoid this limitation, he designed a facebow to control the direction of force application. The outer bow extended posteriorly and angled to approximate the apices of the maxillary premolars. The sample consisted of twenty patients, aged 9-13. The inner bow was attached to the molar tubes on the permanent first molar bands. Five hundred to 750 grams of force per side were applied to a chin cup through the elastics. He reported 1-3 mm of anterior displacement of the maxilla and 1-4 mm of anterior displacement of the maxillary dentition.

Petit (1986) studied the adaptations following brutal sudden force application on sutures in prognathic syndrome cases as it pushes mandibular sutures posteriorly and pulls maxillary sutures anteriorly. He emphasized that a downward direction of force is important on the maxilla to prevent the rotation of the maxillary pyramids over the fronto-naso-maxillary articulations, creating an open bite anteriorly.

Ishii et al. (1987) compared the first molar attachment to the first premolar attachment for protraction elastics. There was not any maxillary expansion done but both groups had maxillary fixed plates for anchorage. They reported that there was

a greater upward and forward rotation of the maxilla in the first molar group since the angle between the palatal plane and sella-nasion decreased more in this group. They also noted that there was more increase in the SNA angle in the first molar group. They concluded that the first premolar attachment was desired for control of the vertical dimension and that the first molar attachment was preferred when the greatest maxillary anteroposterior displacement was desired.

2.5.4 Effects of Protraction Facemask Therapy

What are the changes that occur after the protraction therapy? There have been many studies done to evaluate the effects of protraction facemask therapy, however, many lack a control group and many are simply case reports. Turley (1988) presented two case reports where anterior and downward rotation of the maxilla and consequently clockwise rotation of the mandible occurred. As a result, an increase in lower facial height was achieved. He felt that these changes contributed greatly to the class III correction. He also reported on the successful management of the second phase of treatment in two cases where protraction facemask therapy was the treatment of choice in the first phase of treatment. He used a modified Haas type palatal expander and felt that dental changes were minimal due to rigidity of the appliance.

McGill and McNamara (1996) evaluated the treatment effects of facemask therapy. They looked at pre-treatment and post-treatment headfilms of thirty-eight females and thirty-one males (a total of sixty-nine patients) and headfilms for twenty-nine of the patients six months after removal of the expander. They

concluded that a combination of dentoalveolar and skeletal changes was responsible for correction of the class III malocclusions. Twenty percent of the correction was attributed to mandibular repositioning while 53% was due to maxillary skeletal and dental changes. Twenty-three percent of the reduction of class III correction was due to mandibular growth while a net forward movement of the mandibular incisors accounted for 3% of the correction.

Chong (1996) evaluated the changes after protraction headgear therapy in sixteen treated patients and thirteen untreated controls matched for age. A labio-lingual wire with bands on the first permanent molars or second deciduous molars and 0.036-size wire soldered on the labial and lingual was used. Eight to ten ounces of force were applied 12-16 hours per day using a Delaire type facemask. Bonded palatal expansion was used only when cross bites were present and no retention appliance was used. Forces were discontinued when a positive overjet was achieved. Cephalometric evaluation revealed that the major treatment effect was a downward and backward rotation of the mandible and retroclination of the lower incisors. Forward movement of the maxilla and upper teeth was not statistically significant, however it contributed to the correction of the class III malocclusion. They noted a significant improvement in maxillomandibular relationship and overjet correction.

Ngan et al. (1992) studied the profile changes associated with protraction headgear and maxillary expansion therapy. Twenty consecutively treated patients were evaluated with headfilms taken at six months prior to the initiation of

protraction therapy (T0), at the initiation of the protraction therapy (T1) and six months after the start of the protraction (T2). The author considered each patient serving as his or her control and the changes between T1 and T0 represent the untreated changes. They found significant improvements in the facial profile after six months with forward movement of the maxilla, accompanied by 50-79% forward movement of the soft tissue. The author felt that the treatment effects associated with the mandibular skeletal and the dental variables were less predictable.

Wenger (1998) studied the effect of the protraction facemask in his thesis. He compared twenty-nine class III patients, treated with a bonded maxillary expander and petit facemask to an untreated control group chosen from the Bolton Brush growth study, matched for age, race, gender, and malocclusion. Fifty-eight measurements of nineteen different landmarks were used employing traditional cephalometric superimpositions. He reported that anterior movement of point A and permanent maxillary first molars was 1.45 mm and 1.59 mm respectively more in the treatment group when compared to the untreated control group. He also employed Procrustes analysis and concluded that greater maxillary dental than skeletal changes occur due to facemask therapy.

Wolf (1998) looked at twenty-nine class III patients treated with maxillary bonded expander and Petit facemask to differentiate treatment effects of protraction headgear from normal growth, qualitatively and quantitatively. He compared pre- (mean age 8.81 years) and post-treatment (mean age 9.95 years) lateral

cephalograms of the twenty-nine patients with a control group matched for age, race, sex and malocclusion obtained from the Bolton-Brush Growth Center at Case Western Reserve University. He concluded that the overall anterior movement of the maxilla, and anterior movement of the maxillary molars and incisors were twice as great in the protraction group compared to normal growth in the control group. He also noted that the ANB angle was increased 2.5° more in the protraction group. He observed tipping of the palatal plane due to downward movement of PNS. A slight increase in mandibular plane angle was observed in addition to the lower incisors becoming more upright.

A study by Sung and Baik (1998) evaluated the skeletal changes caused by protraction facemask, how the skeletal and dental changes progressed with aging, and whether growth is actually stimulated by maxillary protraction. The treatment group consisted of 129 subjects, aged 7-13 years, with class III skeletal malocclusion and treated with maxillary protraction headgear. The control group consisted of nine male and twelve female subjects with Angle class I malocclusion. They used annual cephalometric records from the Yonsei growth study sample. Greater maxillary forward displacement and mandibular growth inhibition were observed in the protraction group during the treatment period than the control group. Maxillary protraction had a "growth-stimulating" effect on the maxilla during the treatment period. The effects were a downward and forward movement of the maxilla and maxillary dentition, lingual inclination of the mandibular teeth, and downward and backward rotation of the mandible. In this study, the protraction

group showed significant annual increases in the SNA angle and maxillary length when compared with the control group during the treatment and post-treatment periods.

Baccetti, Franchi and McNamara (1999) applied an effective morphometric method called the thin-plate spline analysis or TPS to evaluate shape changes in the craniofacial configuration of twenty-three children with class III malocclusion. TPS analysis facilitates the construction and display of transformation grids that capture the shape change between forms. The treatment group was in the early mixed dentition and all were treated with rapid maxillary expansion and protraction facemask. The control group was a sample of seventeen children with untreated class III malocclusion. Their findings indicated that the treated group exhibited a forward displacement of the maxilla associated with a marked advancement of the posterior nasal spine in relation to the pterygo-maxillary suture. They observed a counter-clockwise rotation of the palatal plane concomitant with maxillary advancement. The effect of the therapy on mandibular sutures was condylar growth in a forward direction associated with a restriction in sagittal advancement of the symphysis. This was interpreted as an anterior morphogenic rotation of the mandible, which dissipates excessive growth of the mandible relative to the maxilla.

Kim et al. (1999) conducted a meta-analysis of the literature to examine the effectiveness of maxillary protraction with orthopedic appliances in class III patients. They identified 440 articles on class III malocclusion, emphasizing fourteen studies that had comparable sample size. The data from selected studies

was categorized by age and appliance group for the meta-analysis. They concluded that the treatment effects of the protraction facemask therapy are a combination of skeletal and dental changes of the maxilla and mandible. The maxilla moves downward and forward with a slight upward movement anteriorly and a downward movement posteriorly. There was extrusion of the posterior teeth. The mandible rotates in a clockwise direction that improves the maxillo-mandibular skeletal relationship in the sagittal dimensions but results in an increase in anterior lower facial height. This rotation is the greatest reason for correction of the anterior overjet.

Saadia and Torres (2000) looked at the sagittal changes after maxillary protraction with expansion in class III patients in the primary, mixed, and late mixed dentitions. They conducted a longitudinal retrospective study and divided 112 patients into three groups, aged 3 to 6, 6 to 9, and 9 to 12 years. All patients were treated with a protraction facemask with maxillary expansion. The patients wore the facemask for an average of six months between the ages of 3 and 6 years, nine months for the patients 6 and 9 years, and twelve months for patients between 9 and 12 years. A force of 395 grams per side was applied. The expansion screw was activated three times a week even in the absence of maxillary constriction. The results showed no significant differences in the treatment effects between males and females at different ages with the exception of 3-6 year age group, where females showed significant changes in most linear and angular measurements compared to males of the same age. The treatment effects were maxillary advancement, counter

clock wise rotation of the mandible, labial tipping of the maxillary incisors, lingual tipping of the mandibular incisors, mesial movement of the maxillary molars, and changes in ANB angle toward a more positive value.

Gu, Rabie and Hagg (2000) studied the differences between patients treated with partial maxillary appliances (2 x 4) and those treated with reverse pull headgear. The sample consisted of seventeen patients in the mixed dentition (mean age of 9.7 years) with pseudo-class III malocclusion and an anterior functional shift treated by a 2 x 4 appliance. They were compared to twenty patients (mean age of 8.5 years) with a negative overjet and straight or concave profiles treated with reverse pull headgear. Lateral cephalometric films were taken at the beginning of treatment, the end of treatment, and one year after the active treatment. They reported that the overjet correction in the fixed appliance (2 x 4) group was 5.2 mm entirely due to dental changes. The reverse pull headgear group had 6.5 mm overjet change. This was due to 60% dental and 40% skeletal changes.

Alcan, Keles and Erverdi (2000) used a modified protraction headgear to eliminate the unwanted upward and forward rotation of the maxilla. They treated seventeen patients with an average age of 12.8 years with class III malocclusion. They used a full coverage acrylic capped splint rapid maxillary expansion appliance that was activated twice a day for five days and a modified maxillary protraction headgear with 750 grams of force per side. There was no chin rest and no elastics used on the headgear. The headgear was attached to the expander via metal hooks and rested only on the forehead. The study showed that the maxilla was displaced

anteriorly and rotated downward and backward. The upper incisors were extruded and tipped lingually, the upper molars were intruded, and the mandible and the functional occlusal plane were rotated downward and backward.

Ucuncu et al. (2000) conducted a retrospective investigation to compare cephalometrically the treatment effects of chin cup and maxillary protraction appliances in subjects with a class III skeletal malocclusion with a combination of an underdeveloped maxilla and prominent mandible. Twenty-four patients were divided into two groups according to the treatment type: the chin cup group with a mean age of eleven years and the Delaire type maxillary protraction appliance group with a mean age of 10.7 years. Both appliances applied 600 grams of force per side and were worn sixteen hours a day. The SNA angle increased significantly greater in the maxillary protraction group compared to the chin cup group. There was a greater decrease in both angular and linear dimensional parameters for lower incisor to NB line in the chin cup group than in the maxillary protraction group. The molar relationship became more class II in the maxillary protraction group. The nasolabial angle decreased significantly in the chin cup group while there was an insignificant increase in the maxillary protraction group. They concluded that both appliances were effective in the treatment of class III malocclusion. However, the protraction appliance had a significantly greater effect on the maxilla and in molar relationship correction.

2.5.5 Expansion versus Non-Expansion

What is the effect of expansion on maxillary protraction? Haas (1973) described the orthopedic benefits of rapid palatal expansion and demonstrated the effects of his tissue born appliance in the treatment of various skeletal malocclusions. He reported that as the mid-palatal suture opens, a downward and forward movement of the maxilla occurs which causes the mandible to rotate downward and backward. These two movements contribute to class III correction. He used the mandible as anchorage by adding a chin cup, which increased the effectiveness of the class III correction. He emphasized that the primary concern in any orthopedic appliance is a stable anchor unit. In the case of class III protraction therapy, this anchor unit is a stable wire framework expander with acrylic palatal coverage. He stated that although all wire expanders are more hygienic, they couldn't serve as a rigid anchor unit to gain orthopedic effects.

Sarver and Jonston (1989) compared the vertical and antero-posterior changes with a bonded and banded palatal expander. They looked at results in twenty adolescent subjects with a bonded rapid palatal expander and compared those with the sixty subjects having banded rapid palatal expander that Wertz (1970) studied. Wertz showed downward and forward movement of the maxilla with the banded expander in his study whereas, Sarver and Jonston reported upward movement of the maxilla posteriorly and downward and backward movement of the maxilla anteriorly with the bonded expander. They concluded that the use of bonded palatal expander by itself is not an effective method to correct the class III malocclusion.

McNamara and Brudon (1993) described the clinical usage of the Petit type facemask with a bonded maxillary splint. To facilitate mastication, they recommended that the 3-millimeter Bioacryl be placed over processed acrylic on which occlusal indentations can be created. They stated that the rapid palatal expander serves to disrupt the facial sutures and is recommended even when only minimal expansion is required.

Baik (1995) studied sixty patients 8-12 years old with deficient maxillae (ANB was a mean of -0.77° and Wits was a mean of -8.14 mm). A hyrax rapid palatal expander was used in forty-seven patients and a labiolingual appliance without palatal expansion was used in thirteen subjects. The expansion group was subdivided into three groups based on age: less than ten years old, 10-12 years old, and older than twelve years old. A Delaire facemask was used twelve hours per day. Three hundred to five hundred grams of force per side was applied in a slight downward direction and was discontinued once a positive overjet was achieved. In both the expander and non-expander groups, the maxilla moved forward and downward and the mandible moved downward and backward. The horizontal changes in A-point, ANS, and maxillary molars were statistically significant only in the expansion group.

Kim et al. (1999) did not observe any differences in the treatment effects between the palatal expansion group and non-expansion group except for upper incisor angulation, which increased in the non-expansion group.

2.5.6 Timing of the Treatment, Early versus Late Treatment

The question of whether class III malocclusions should be treated early orthopedically or wait for the growth to be complete and correcting the problem surgically or compromising for the skeletal disharmony orthodontically, has been addressed many times.

Chong (1996) used protraction therapy on patients as young as 4.5 years old. Campbell (1983) reported several cases advocating early intervention, believing that early correction created a more favorable environment for normal growth, occlusal relationships and improvement in facial esthetics for a more normal psychosocial development.

What is the optimal age to start protraction facemask therapy? Sung and Baik (1998) did not note a statistically significant difference in treatment effect or direction of maxillary growth between seven year old patients and thirteen year old patients, However, Saadia and Torres (2000) concluded that patients treated in primary and mixed dentition showed greater significant changes in less time than patients treated in the permanent dentition.

Kim et al. (1999) concluded from their meta-analysis that greater treatment changes can be expected in the younger group and that the facemask therapy is less effective in patients who are older than ten years of age.

Suda et al. (2000) hypothesized that an evaluation of bone age would help to determine the effective planning and optimum timing using reverse pull headgear. They looked at the differences in the cephalometric measurements between the

initiation of treatment and after one year of treatment of sixty Japanese patients. Bone age was appraised by using hand-wrist radiographs at the initiation of treatment. The control groups were treated with lingual arch and/or chin cup with a mean age of ten years, and the experimental groups were treated with reverse pull headgear with a mean age of nine and one-half years. Their results showed a significant inverse correlation with the bone age but not with the chronological age in the male experimental group. This supports the hypothesis that bone age is a useful clinical indicator to determine the effective treatment timing with reverse pull headgear. The bone age represents the difference of treatment outcome between younger and older male samples more clearly than the chronological age.

Yuksel, Ucem and Keykubat (2001) evaluated the effect of age on the dental and skeletal effects of facemask therapy. Two groups of seventeen patients were formed. The two groups were an early treatment group with a mean age of nine years and eight months and a late treatment group with a mean age of twelve years and six months. A control group of seventeen children with a mean age of nine years and five months was matched only to the early treatment group according to age and sagittal dental and skeletal relationships. They did not note any significant difference between the groups for the effect of the age on the treatment response. Although no significant difference was found between the two treatment groups, they concluded that the improvement in facial aesthetics on psychosocial development can result in a significant advantage for early treatment.

2.5.7 Retention and Second Phase Treatment

Should we retain the orthopedic correction achieved after the protraction therapy? If retention is necessary, how long should we retain the correction? Most studies suggest that the overjet should be overcorrected (Turley 1988; Ngan 1992; McGill, McNamara 1996; Chong 1996; Wenger 1998; Sung, Baik 1998; Kim et al. 1999; Saadia and Torres 2000; Alcan et al. 2000).

Jackson et al. (1979) noted a substantial reorientation of the maxillary complex following the termination of the active force and that the degree of relapse or reorientation was directly proportional to the length of stabilization. After a minimal period of stabilization the dentition underwent four times as much relapse when compared to the facial bones.

Petit (1983) believed that by reeducating the tongue to sweep forward and upward instead of forward and downward, the results achieved after the facemask therapy could be more stable. He incorporated a small pearl shaped cylinder to a palatal bar to allow the tongue to be held forward and upward. He also recommended the use of functional appliances to retain the abrupt changes from accelerated facemask therapy. McNamara and Brudon (1993) also recommended the Frankel 3 as a possible retention appliance following the facemask therapy. Saadia and Torres (2000), however, did not recommend any retention after correction unless minor skeletal changes were observed in the post-treatment cephalogram. In that case, they recommended retention with a removable occlusal splint and reverse pull headgear.

Turley (1996) used two case reports to evaluate the changes in the second phase of protraction facemask patients. He concluded that full-time wear provided better results and that revisional protraction facemask therapy might be needed after the first phase. He stated that over correction of the overjet was essential.

Mesial movement of the dentition along with the maxilla can be considered an adverse effect of protraction therapy. Maxillary molar distalization or premolar extraction in the second phase has been suggested in the literature due to these mesial dental changes (Turley 1996; Wenger 1998; Wolf 1998).

2.5.8 Post-Retention Effects

There are not many studies that have evaluated the post-retention changes. Wisth (1987) studied the stability of protraction facemask therapy for 6-48 months after the end of the therapy. No retention protocol was followed. He looked at forty patients treated with facemask and compared them with forty class I patients. The facemask was worn twelve hours a day. He stated that because of the limited amount of requested facemask wear, the class III correction was limited to dental and not skeletal changes. He concluded that only the mandibular dentition demonstrated significant relapse during the post-treatment period.

Chong et al. (1996) observed that the mandibular incisors proclined after discontinuation of the forces, which was considered dental relapse. To avoid this, they suggested over correction of the overjet during the protraction therapy.

McGill and McNamara (1996) evaluated the post-retention effects six months after the treatment ended. They observed that the positive overjet was reduced in

59% of the patients due to reduction in the ANB angle by 1.6°. This can be attributed to less than normal forward maxillary growth and normal mandibular growth. Another post-treatment change was an increase in Wits by 1.3 mm. They did not note any "catch-up" mandibular growth during the post-treatment period.

In a comparison between a partial maxillary appliance (2 x 4) and reverse pull headgear, Gu et al. (2000) noted that during the twelve months follow-up period, the overjet was unchanged in the 2 x 4 group and decreased in the reverse headgear group. The decrease in overjet in the reverse headgear group was mainly due to forward growth of the mandible and proclination of lower incisors.

2.6 Use of Implants for Protraction

How can implants affect the treatment outcome? Does an implant serve as more than just an anchor unit? Smalley et al. (1988) studied the use of osseointegrated implants to address the unwanted dental movements that happen during protraction headgear therapy. The methodology was patterned after the Jackson et al. study published nine years earlier. Smalley used four Macaca nemestrina monkeys in the mixed dentition. Titanium implants were placed in the cranium of each animal. Six hundred grams of force was applied through elastics to different implants and was discontinued after eight millimeters of maxillary protraction. The conclusion was that implants provided stable anchorage for protraction of the maxillo-facial complex and that there were more skeletal changes than dental changes. Histologic evaluation revealed that the changes were due to

sutural and skeletal remodeling. Post-treatment evaluations showed that 80% of the changes were still present 22 months after the protraction therapy.

Omnell and Sheller (1994) applied the protraction headgear for twenty months to intentionally ankylosed maxillary primary canines, demonstrating primarily skeletal changes. On average the SNA angle increased 6° and the anterior overjet increased 8 mm.

2.7 Use of Chin Cup Therapy

Chin cup has been commonly used since the last century to restrain the mandibular growth. The stability of the effects of the chin cup, however, has been questioned in the past. Mitani and Sakamoto (1984) reported based on a case control study that when the chin cup was finally removed the direction of mandibular growth reverted back toward the pre-treatment direction. Deguchi and Kitsugi (1996) studied post-treatment effects. They reported that an increase of 1.8° in ANB angle and 3.4 millimeters in Wits, achieved from chin cup treatment, remained stable until age eighteen.

There have also been many studies trying to find the optimal timing for this therapy. Sugawara et al. (1990) evaluated longitudinal data on sixty-three Japanese girls with skeletal class III malocclusion and anterior crossbite and divided them into three groups based on their age. They compared the results to cross-sectional data from 500 untreated girls with class III skeletal profiles. All treated patients wore a chin cup at least fourteen hours a day and 250-300 grams of force per side was applied along the gnathion-sella line. If started at age seven, these forces

caused the mandible to rotate downward and backward and the maxilla to be displaced downward and forward. At age nine the mandible returned to a downward and forward direction. When started at age nine, a similar clockwise rotation of the mandible occurred and after age eleven, the mandible returned to a counterclockwise growth direction. When started after age eleven, the mandible was displaced more vertically. There were no statistically significant differences in skeletal profiles between the patients who started the treatment at age seven or eleven; however, there was variation in responses. There was also no statistically significant difference in the final profile of the treatment group compared to the control group.

A great amount of effort has been put into identifying how the chin cup's effect can lead to class III correction. Mitani and Sato (1992) studied the treatment effects of the chin cup therapy for varying treatment periods and retention periods, choosing three female patients eight years and four months, four years and nine months, and six years and five months, with the chin cup delivering 500 grams of force. They reported that the gonial angle decreased, antegonial notch increased and the mandible rotated downward and backward, and that the amount and velocity of changes were not predictable.

Allen et al. (1993) studied the effects of chin cup on the correction of negative overjet. They treated twenty-three patients with negative values for Wits, ANB and anterior cross bite with chin cup and matched them with class I controls. Some patients had partial maxillary appliances to procline the maxillary incisors.

Evaluation of the treatment effects showed an improvement in anterior overjet, a reduction in Wits, increase in the lower facial height and upper incisor proclination. The fact that the ANB value was unaffected suggested that the changes were primarily dental.

2.8 Posterior Vertical Maxillary Control

According to Guyer et al. (1986), 41% of class III patients have an excessive lower facial height. It is important to improve or control the increased vertical dimension while treating class III malocclusion. Active vertical correctors (AVC) and posterior bite blocks are appliances that have been used often in the past for vertical control.

Barbre and Sinclaire (1991) studied the effects of the AVC (active vertical corrector) in open bite patients and concluded that the open bite correction was due to the intrusion of the maxillary and mandibular molars and maxillary incisor eruption. They measured the posterior facial height to study the maxillary vertical skeletal inhibition, which showed no change between the treatment group and the control group.

Pearson (1991) described mandibular headgears, high pull headgears, vertical pull chin cups and maxillary and mandibular posterior bite blocks as effective ways to control the vertical dental and skeletal changes. He emphasized repeatedly the importance of vertical control on anterior facial height and open bite corrections.

Iscan et al. (1992) evaluated the use of posterior bite blocks for the vertical management of skeletal open bite malocclusion. They compared a passive bite

block exceeding the freeway space supplemented by a vertical pull chin cup to a spring loaded bite block. Both appliances showed improvement in the skeletal malocclusion by inhibition of vertical movement of the maxillary complex and the dentition, however the former was found to be more effective.

Kuster and Ingervall (1992) compared the magnetic active vertical corrector (AVC) with the spring-loaded bite block in treating open bite malocclusions. They reported that the open bite correction was achieved by intruding the posterior maxillary and mandibular teeth while extruding the anterior teeth. They concluded that both were effective but greater change could be achieved by using AVC.

2.9 Other Methods

A variety of other appliances for class III malocclusion correction by affecting the maxilla, the mandible or both, have appeared in the literature. Ulgen and Firatli (1994) compared twenty class III patients with a mean age of 9.5 years treated with FR-3 with twenty untreated class III patients with a mean age of 9.3 years. The mean treatment time with FR-3 was 1.9 years. They reported that a combination of downward and backward rotation of the mandible and retrusion of the mandibular incisors contributed to the reduction of ANB angle and overjet correction. Increase in SNA and upper incisor protrusion were insignificant.

Tollaro et al. (1995) evaluated the effects of mandibular retractor appliance in class III correction. They compared eighteen patients treated with mandibular retractor appliance to eighteen untreated class III controls. Cephalometric analysis showed upward and forward direction of condylar growth in the treated group,

which caused anterior mandibular rotation compensating for excessive mandibular growth.

McNamara (1985) discussed the use of FR-3 and its skeletal and dental effects. Although both skeletal and dental changes have been documented, he recommended the use of this appliance in mild skeletal disharmonies and during retention phase after facemask therapy. Skeletally, FR-3 causes forward movement of the maxilla, backward rotation of the mandible and an increase in the lower anterior facial height. Dental changes were reported to be proclination of the maxillary incisors and retroclination of the mandibular incisors.

2.10 Summary of the Literature

Based on the animal and clinical studies on maxillary protraction, it can be concluded that continuous forces caused remodeling of the circum-maxillary sutures. Anterior displacement of the maxilla was more desirable when accompanied by a clockwise rotation. This could be achieved by altering the direction of the force application. Forward and downward direction of force, produces a downward and forward movement of the maxilla and a clockwise rotation of the mandible. Most studies showed a variable amount of dental movement including forward movement of the maxillary incisors and molars, and backward movement of the mandibular incisors. The use of implants resulted in almost no dental movement. Over correction was suggested in most studies due to the suggested relapse. Many studies addressed the problem of increased facial vertical dimension by incorporating bite blocks to the palatal expander or using a

chin cup. One can gather from the literature that the latter causes a clockwise rotation of the mandible and that the stability has been questionable. No study could answer the exact timing of protraction therapy since facial growth is unpredictable. The majority of the studies suggest that the best treatment outcome can be achieved during the mixed dentition or at a young age when sutures are most adaptable. Cooperation and psychosocial factors appear to play a major role in the treatment outcome.

HYPOTHESES

The purpose of the study is to determine whether the changes seen following the retention phase of protraction facemask therapy are due to dental relapse, rotational skeletal relapse or normal growth. Using traditional cephalometric analyses, this study will compare a group treated with protraction facemask to a matched untreated control group. The hypotheses of this study are:

1. Any dental change (upper incisor horizontal, upper molar horizontal, and lower incisor horizontal) would relapse.

2. Any rotational skeletal change (PNS vertical) would relapse.

3. Any maxillary skeletal change (articulare-A point and A point movement) would be stable.

MATERIALS AND METHODS

4.1 Protraction Facemask Therapy

A Petit design facemask was used in conjunction with a bonded acrylic maxillary expander. The bonded expander was fabricated with the entire palate covered with acrylic and the expansion screw embedded in the acrylic. The acrylic was extended on the buccal completely to the gingival margins to maximize retention and to minimize the risk of decalcification. Arch wire tubes were placed in the first molar area to allow partial maxillary appliances to be used during the protraction phase. The protraction hooks were of a recurved hook design, which improved elastic retention and patient comfort. The hooks were placed in the deciduous canine and deciduous first molar area with the point of insertion of the elastic as occlusal as possible. The occlusal positioning of the hook was designed to minimize the extrusive component from the headgear by allowing for a more horizontal direction of the force application. The acrylic coverage of the expander extended mesially to the deciduous canines, if present.

The buccal and lingual surfaces of all teeth covered by the expander were etched for 90 seconds. A Bis-GMA material, such as Excel from Reliance Orthodontic Products, Orange, California, was used for placement. An activation schedule of one turn every other day was followed with the amount of expansion ranging from 4-8 mm (15-32 turns) with a mean of 6 mm (23 turns). The

protraction headgear was added after the expansion phase was completed and although the amount of expansion varied, some expansion was attained in all cases prior to protraction.

The mean length of time with the protraction headgear was 5.63 months full-time and the bonded expander was worn a mean length of time of 9.23 months (Table 2). The headgear manufacturer was Great Lakes Orthodontic Products, Tonawanda, New York, or Ormco Corporation, Glendora, California. The reasons for selection included the adjustability of the appliance, patient comfort, and compliance. Extraoral elastics from Dextra Corporation, Napa, California (#64, 5/16 inch, 8 oz.) were placed onto the elastic hooks, exiting the mouth as parallel as possible to the palatal plane to minimize the downward component of force. The facemask was instructed to be worn after school, the first week, adding nightwear the second week, and then full-time wear the third week. Exceptions to the full-time wear included eating, brushing, and sports. The headgear wear was reduced to nightwear for one appointment before the expander was removed. In general, compliance was judged to be very good, based on reports from parents.

TABLE 2.--Treatment Data for Twenty-four Patients Treated with Protraction Headgear and Bondable Expander.

	Mean	Range
Treatment time (months) (with bonded expander)	9.23	7.49-10.97
Time with Protraction headgear full-time (months)	5.63	(3.88-7.38)
Time with protraction headgear including nightwear	6.76	(5.02-8.50)
Number of turns with expander	23.2	(14.9-31.5)

Horizontal overjet, measured from labial of maxillary incisors to labial of mandibular incisors was used as an indicator of over correction. A horizontal overjet of 5-7 mm was attempted.

After two days of tissue healing, an impression for a maxillary tru-tain retainer was taken. In many cases, clear acrylic was added to the lingual of the incisors and the patient was instructed to close into the soft acrylic. The appliance was finished opposite to an anterior repositioning splint with the ramp extended labially to the mandibular incisors. It was felt that this might inhibit the maxillary skeletal relapse, minimize the maxillary dental relapse, and maintain the maxilla ahead of the mandible by the anteroposterior thickness of the ramp. The retainer wear was reduced to nightwear after 3-6 months and then discontinued when the patient could no longer wear it.

4.2 The Sample

The sample consisted of twenty-four consecutively treated patients with a class III malocclusion. All were treated with a bonded palatal expansion appliance, protraction headgear and elastic traction. The sample was taken from the private practice of a board certified orthodontist. The sample consisted of sixteen female and eight male Caucasians. All patients were part of the sample of twenty-nine, used in previous studies conducted by Wolf 1998 and Wenger 1998. Five patients were dropped due to the inability to obtain Time 3 lateral cephalograms. All subjects had headfilms taken prior to beginning the protraction therapy, immediately after removal of the bonded expander and after a mean wait period of

3.07 years, prior to the second phase of orthodontic treatment. The mean age pre-treatment (Time 1) was 8.8 years, the mean age post-treatment (Time 2) was 10 years and the mean age post-retention (Time 3) was 13 years (Table 2).

TABLE 3.--Age Characteristics, Pre-treatment (T1), Post-treatment (T2), and Post- retention (T3) of Treatment and Control Groups.

	Control group (n = 24)		Treatment group (n = 24)	
	Mean	S.D.	Mean	S.D.
Age at T1 (years)	8.8	1	8.8	1
Age at T2 (years)	10	1.2	10	1
Age at T3 (years)	12.7	1	13	0.6

The control group consisted of an age, sex, and race matched sample of untreated malocclusions selected from the Bolton-Brush Growth Center at Case Western Reserve University. New controls were picked in four instances where the Time 3 lateral cephalograms were not available or the control had undergone orthodontic treatment between the Time 2 and 3 periods. Every effort was made to match the cephalometric characteristics of the treatment group as closely as possible to the control group using similar ANB differences and anterior facial heights. The average age of the control group was 8.8 years at Time 1, 10 years at Time 2, and 12.7 at Time 3.

The treatment recommendations were based on clinical and cephalometric evaluations. Evidence of midfacial deficiency, mandibular prognathism, or a combination of both was clinical criteria that were used for further evaluation with diagnostic records. Additionally, a positive medical history for chronic nasal

obstruction, enlarged adenoids, chronic allergies or enlarged turbinates generally accompanied the class III diagnosis of maxillary hypoplasia.

The mean ANB in the treatment group was negative 0.50°. The mean Wits in the treatment group was negative 5.00 mm. The control group had untreated class III malocclusions and had a mean ANB of 0.63° and Wits of negative 3.57 mm (Table 5).

4.3 Data Capture

Tracings were done on all 144 headfilms at T1, T2, and T3 (twenty-four controls and twenty-four samples). A 0.5 mm lead pencil was used on DCA 0.003-mm matte acetate. Since the difference in headfilm magnification was insignificant between the subjects and the controls (Wolf 1998; Wenger 1998), no adjustment was made to compensate for the measurement differences due to magnification.

To facilitate accuracy in measuring the dental changes, lines were drawn along the long axis of the maxillary and mandibular central incisors. A line was drawn bisecting the buccal cusp tips of the maxillary and mandibular first molars. A perpendicular line was drawn to identify the middle of the mesiobuccal cusps of the maxillary first molar and the mesial buccal groove of the mandibular first molar. The perpendicular lines would be coincident in an Angle class I molar relationship. Differences in a class III direction were given a negative value while differences in a class II direction were given a positive value. Perpendicular lines drawn at the cusp tips of the maxillary and mandibular incisors helped accurately identify vertical and horizontal movements of these teeth.

Superimpositions were done with the Time 3 headfilm oriented with the Time 2 headfilm to show overall changes, changes within the maxilla, and changes within the mandible. Five fudiciary points were placed on the Time 2 tracing. Once each respective superimposition was completed, these points were marked on the Time 3 tracing. This was done for the overall and regional superimpositions. For the Time 1 and Time 2 superimpositions, the same values were used as in Wolf's study except for the four incidences when different controls were selected. For a total of eight tracings (four controls and four treated), the five fudiciary points were placed on the Time 1 tracings. These points were marked on the Time 2 tracings, once each respective superimposition was completed. The five fudiciary points were marked on the Time 3 tracings once the superimposition was completed for the Time 2 and Time 3 tracings. For consistency with the previous study, all the superimpositions were done by Dr. Wolf.

The overall superimpositions were done using the anterior cranial base as the stable anatomical landmark. The anterior cranial base, specifically the ethmoid triad consisting of the greater and lesser wings of the sphenoid, the superior aspect of the cribriform plate of the ethmoid bone and the planum of the sphenoid bone are relatively unchanging after age seven (Elmajian 1959). The internal trabecular patterns within the ethmoid triad enhance the accuracy of the superimposition. Unlike sella and nasion that remodel during growth, the ethmoid triad changes little during the ages most orthodontists render treatment (after age 7). An average occlusal plane was drawn bisecting the occlusal plane of the T2 and T3 tracings.

Horizontal changes were measured parallel to this line and vertical changes were measured perpendicular to this line. The changes measurable with the overall superimposition are the direction and amount of maxillary skeletal change.

The maxillary superimpositions were done as outlined by Doppel et al. (1994). The anteroposterior orientation is determined by the inferior third of the anterior and posterior outlines of the key ridge of the maxilla. The vertical orientation is determined by a ratio of 1.5 to 1.0 of the inferior border of the orbit to the inferior portion of the palate. The average occlusal planes were drawn bisecting the occlusal plane of the T2 and T3 headfilms. Horizontal changes were measured parallel to this line and vertical changes were measured perpendicular to this line. The changes noted from the maxillary superimposition are dental movements within the maxilla. Some changes in palatal plane and remodeling can also be described.

The mandibular superimposition was done based on the implant studies of Bjork (1963). The landmarks used in the mandibular superimposition are the internal architecture of the inner aspect of the lingual symphysis, the inferior outline of the third molar crypt, and the inferior alveolar canal. The average occlusal plane was drawn bisecting the occlusal plane of the T2 and T3 headfilms. Horizontal and vertical changes were measured parallel and perpendicular to this line. Downward or forward movements were assigned a positive value. Upward or backward changes were given a negative value. The mandibular superimposition quantifies

the vertical and horizontal dental movements and the amount of mandibular lengthening.

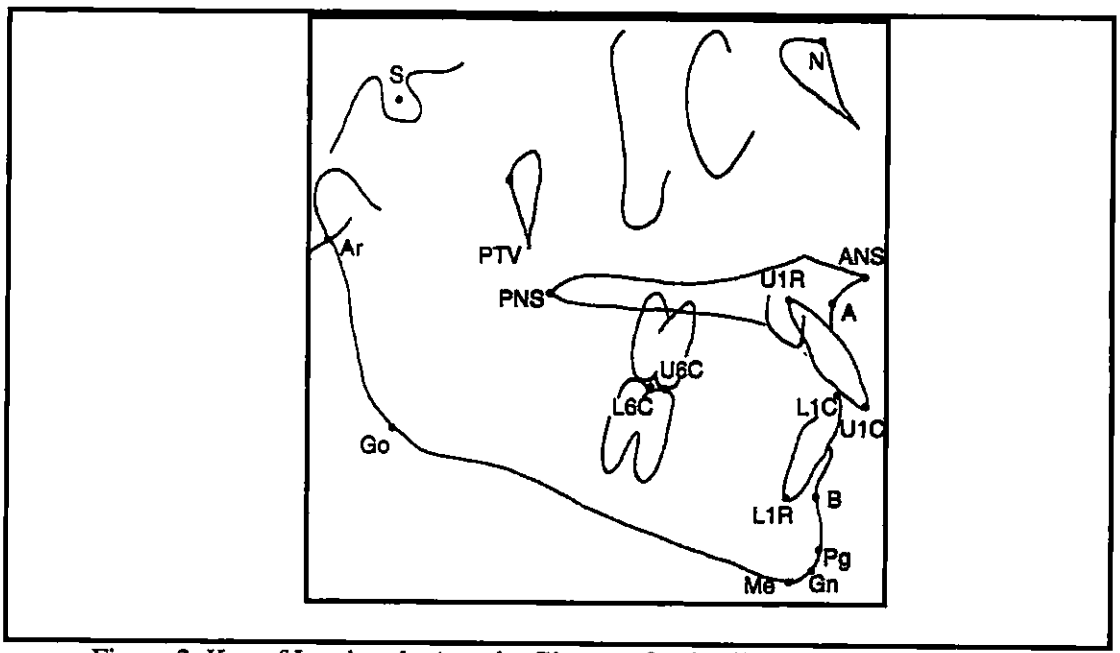


Figure 2. Key of Landmarks (see the Glossary for details)

Eighteen landmarks were used to record a total of thirty measurements for each of the 144 tracings in the treatment group and control group (Table 4).

TABLE 4.--The eighteen landmarks used in the traditional cephalometric analysis

NASION; SELLA; PTV; LOWER FIRST MOLAR CROWN; LOWER INCISOR ROOT APEX; LOWER INCISOR CROWN; UPPER INCISOR ROOT APEX; UPPER INCISOR CROWN; UPPER FIRST MOLAR CROWN; MENTON; GNATHION; POGONION; GONION; B POINT; ARTICULARE; ANTERIOR NASAL SPINE; A POINT; POSTERIOR NASAL SPINE

Linear measurements were made with the Ultra-Cal Mark III, a digital electronic caliper, to one hundredth of a millimeter. Angular measurements were made with a protractor to the nearest one-half of a degree.

The differences between the descriptive measurements made on the T1, T2 and T3 films were calculated with Time 1 subtracted from Time 2, and Time 2 subtracted from Time 3. The differences in measurement between Time 1 and Time 2 in the treatment group and the controls represent the treatment effect. The differences between T2 and T3 for each measurement in the treatment group and the controls represent the post-treatment changes.

Sella-nasion plane was used instead of Frankfurt horizontal because of the difficulty in identifying anatomical porion, particularly in the control group headfilms. Articulare was chosen instead of condylion because of the much greater accuracy in identification, as shown by both Jacobson (1995) and Baumrind (1971).

4.4 Statistics

All measurements were entered into a Microsoft Excel spreadsheet for compilation and statistics. Matched-paired t-tests were done on twenty pairs of variables that the author felt would best test the hypothesis.

4.5 Intra-operator Calibration

Intra-operator variance is the ability of one operator to reproduce the same measurements. In this study, the intra-operator variance was determined by selecting twenty lateral cephalograms randomly from the T1 control group and by recalculating the thirty measurements from Table 5.

RESULTS

The pre-treatment (T1), post-treatment (T2), and post-retention (T3) descriptive cephalometric measurements for both the control and treatment groups are listed in Tables 5, 6, and 7. Table 5 shows that the control group and the treatment group are closely matched. Table 6 shows the treatment effect from protraction facemask therapy when compared to normal growth. The ANB difference was increased with protraction facemask therapy. The mean ANB is 1.56° in the treatment group compared to 0.5° in the control group. The mean Wits value is -1.05 mm in the treatment group and -4.03 mm in the control group. Overjet was increased to a mean of 4.06 mm in the treatment group compared to 1.67 mm increase in the control group from normal growth. Table 7 shows the changes after about of 3 years after the completion of the protraction facemask therapy (retention phase). The mean ANB value was decreased to a mean of 0.21° in the treatment group and -0.40° in the control group. The mean value for Wits was decreased to a mean value of -2.82 mm in the treatment group compared to -4.32 mm decrease in the control group. Overjet was decreased to a mean of 2.01 mm in the treatment group and 1.56 mm in the control group. Table 8 shows the differences (T2-T1) between post-treatment (T2) and pre-treatment (T1) descriptive cephalometric measurements for both the control and treatment groups. Table 8 shows how effective the treatment is. The mean ANB value was increased to a

mean of 2.06° in the treatment group compared to -0.13° decrease in the control group. The mean Wits value was increased to a mean of 3.95 mm in the treatment group compared to -0.47 mm decrease in the control group. Overjet was increased to a mean of 3.95 mm in the treatment group compared to 0.49 mm decrease in the control group. Table 9 shows the differences (T3-T2) between post-retention (T3) and post-treatment (T2) descriptive cephalometric measurements for both the control and treatment groups. Table 9 shows the changes after the retention phase. The mean ANB value was decreased to a mean of -1.35° in the treatment group and 0.90° in the control group. The mean value for Wits was decreased to a mean of -1.66 mm in the treatment group compared to -0.29 mm decrease in the control group. Overjet was decreased to a mean of -2.05 mm in the treatment group compared to -0.01 mm decrease in the control group.

The differences between the descriptive measurements made on the T1, T2 and T3 tracings were calculated with Time 1 subtracted from Time 2, and Time 2 subtracted from Time 3. The differences in measurement between Time 1 and Time 2 in the treatment group and the controls show the treatment effect (Table 10). The differences between T2 and T3 for each measurement in the treatment group and the controls were used to identify skeletal and dental changes during the retention phase (Table 11). Table 10 and 11 shows the results for the fourteen measurements from the overall superimpositions, the six measurements from the maxillary superimpositions, and the six measurements from the mandibular superimpositions. Table 10 shows that the changes in A point, PNS vertical, upper 1 horizontal, upper

6 horizontal, lower 1 horizontal and lower 1 vertical, were significant ($p < 0.005$). Table 11 shows that only the changes in A point was significant ($p < 0.005$).

The results of the twenty t-tests performed on selected descriptive measurements and measurements taken from the superimpositions are shown in Tables 12 and 13. The changes in articulare to gnathion and upper 1 horizontal were shown to be significant at the $p < 0.05$ level (Table 12). Wits, maxillomandibular difference, A point, PNS vertical, upper 6 horizontal, lower 1 horizontal and lower 1 vertical are found to be also significant after the Bonferroni correction ($p < 0.0025$). Table 13 shows that the changes at articulare-A point, Wits and maxillomandibular difference are significant ($p < 0.05$). The changes in articulare to gnathion were also found to be significant after the Bonferroni correction ($p < 0.0025$). Table 14 compares the control group with the treatment group at Time 1 (pre-treatment) using two tailed paired t-tests. The anterior facial height is the only measurement that is significantly different between the two groups ($p < 0.05$). Tables 15 and 16 summarize the changes that occurred during the treatment and the post-treatment phase (post-retention) in those measurements that were statistically significant ($p < 0.0025$). Calculation of these changes, defined as (T2-T1) - (C2-C1), (T3-T2) - (C3-C2) and (T2-T1) - (C2-C1) + (T3-T2) - (C3-C2) are presented in Table 16. A negative sign in the last three columns demonstrates changes in the class III direction. Table 15 and 16 show that there is overall positive effect in articulare-A point, Wits, maxillomandibular difference, A point, PNS vertical, upper 1 horizontal and upper 6 horizontal due to protraction facemask therapy.

TABLE 5.--Pre-treatment (T1) Descriptive Cephalometric Measurements for Control and Treatment Groups.

	Control group			Treatment group		
	Mean	S.D.	Range	Mean	S.D	Range
Maxillary Skeletal						
SNA (°)	79.08	3.78	67-84.5	78.40	3.32	73-85
Articulare - A-Point (mm)	75.94	4.25	67.95-83.76	78.42	4.60	66.53-85.53
Articulare - ANS (mm)	79.37	4.48	71.36-86.76	82.13	4.57	71.71-89.73
Mandibular Skeletal						
SNB (°)	78.46	3.56	71.5-84	78.88	4.32	71.5-86.5
SN to pogonion (°)	79.17	3.51	72-84.5	79.42	4.60	71-87
Articulare to Gnathion (mm)	82.22	5.36	72.6-99.05	84.27	8.29	71.01-111.7
Articulare to Gonion (mm)	16.39	2.45	11.78-22.19	15.85	2.12	11.2-19.37
Gonion to Pogonion (mm)	65.98	4.02	58.24-74.45	69.78	4.70	62.61-79.5
Articulare to SN (mm)	25.27	3.20	18.97-30.59	24.89	2.83	17.82-29.05
Maxillary to Mandible						
ANB (°)	0.63	1.88	-4.5-3.5	-0.50	1.98	-5-3
WITS (mm)	-3.57	2.69	-9.66-4.5	-5.00	2.25	-9.02-0
Articulare to PTM (mm)	22.87	3.42	16.37-31.78	26.41	3.60	22.16-36.36
Maxillomandibular diff (mm) Articulare/Gnathion – Articulare/A pt)	5.22	2.14	1.69-10.14	4.99	3.46	-4.88-9.18
Vertical						
SN to Occlusal Plane (°)	18.65	3.99	9.5-26	17.63	4.90	6.5-25
SN to Palatal Plane (°)	9.65	3.50	2-15.5	8.19	3.45	-1.5-15
SN to Mandibular Plane (°)	35.94	5.04	30-47	36.13	6.53	26-47.5
Facial Axis Angle (SN-SPg) (°)	63.14	3.04	59-69.5	63.63	4.57	53.5-70.5
Upper Facial Height (N-ANS)(mm)	45.83	2.52	40.86-51.54	46.70	3.04	41.19-52.23
Lower Facial Ht (ANS-Me) (mm)	58.79	5.44	51.81-72.2	61.24	4.29	54.36-70.05
Ant Facial Ht (N - Me) (mm)	104.87	7.01	95.2124.38	108.15	5.61	97.22-116.9
Gonial angle (Ar - Go -Gn) (°)	129.56	4.09	122-137	130.29	5.73	120-141
Post Facial Height (mm)	64.90	4.63	57.12-75.22	65.99	4.23	59.01-73.99
Post/Ant Facial Height (%)	62.05	4.23	53.32-67.81	61.15	4.85	52.85-68.81
Maxillary Dental						
Upper 1 to SN (°)	104.40	7.85	87.5-115.5	105.10	8.33	91-121
Mandibular Dental						
Lower 1 to A-Pogon. (mm)	2.27	1.86	-0.74-5.44	2.91	1.75	0.34-7.11
Lower 1 to Mand. Plane (°)	88.79	7.13	64-100	85.77	6.05	69-95.5
Interdental						
Overbite (mm)	1.10	1.66	-2.32-4.8	0.63	1.05	-1.13-2.94
Overjet (mm)	1.17	1.41	-3.01-4.45	0.11	1.40	-2.17-2.72
Interincisal Angle (°)	129.60	8.87	114-146	132.85	9.79	111-149.5
Molar relationship (mm) (Neg = III, pos =II)	-1.49	1.92	-6.28-0.97	-1.15	1.96	-5.88-1

TABLE 6.–Post-treatment (T2) Descriptive Cephalometric Measurements for Control and Treatment Groups.

	Control group			Treatment group		
	Mean	S.D.	Range	Mean	S.D	Range
Maxillary Skeletal						
SNA (°)	79.08	3.87	67-85.5	79.31	3.46	74.5-87
Articulare - A-Point (mm)	77.78	4.56	65.85-86.46	81.11	4.04	74.4-88.62
Articulare - ANS (mm)	81.22	4.86	70.56-89.65	84.17	4.15	76.74-90.89
Mandibular Skeletal						
SNB (°)	78.69	3.33	72.5-84	77.75	4.31	70-85
SN to pogonion (°)	79.48	3.44	72.5-85	78.54	4.64	69.5-86.5
Articulare to Gnathion (mm)	82.94	3.67	77.39-91.33	82.32	5.31	74.7-95.1
Articulare to Gonion (mm)	16.14	2.20	11.28-19.82	14.19	2.22	11.02-18.7
Gonion to Pogonion (mm)	68.28	4.16	61.46-75.27	68.76	6.03	59.84-81.37
Articulare to SN (mm)	25.95	2.78	19.34-30.01	25.30	3.26	19.17-31.53
Maxillary to Mandibular						
ANB (°)	0.50	2.07	-6.5-3.5	1.56	1.99	-4.5-5
WITS (mm)	-4.03	2.31	-11.26-(-0.2)	-1.05	1.96	-5.25-1.62
Articulare to PTM (mm)	24.48	3.20	17.33-30.45	26.93	4.19	20.73-37.41
Maxillomandibular diff (mm) Ar/Gn – Ar/A pt)	5.15	2.50	1.8-13.34	1.21	3.09	-5.49-8.71
Vertical						
SN to Occlusal Plane (°)	18.46	4.13	10.5-25	15.92	5.10	7.5-25
SN to Palatal Plane (°)	9.33	3.47	1-15	8.94	3.30	1-13.5
SN to Mandibular Plane (°)	36.00	5.04	29-46	36.56	6.70	24.5-49
Facial Axis Angle (SN-SPg)	63.79	3.48	57.5-70	64.50	4.81	56.5-73
UF Height (N-ANS) (mm)	47.78	2.69	43.44-55.6	49.19	3.26	43.82-54.5
Lower Facial Ht (ANS-Me)	60.21	5.55	53.39-73.92	62.54	3.84	55.09-70.84
Ant Facial Ht (N - Me)	107.83	6.60	98.34-125.16	111.93	5.67	102.33-121.96
Gonial angle (Ar - Go -Gn)	129.06	3.75	121-135	129.52	5.74	120-142
Post Facial Height (mm)	66.76	4.46	59.38-74.6	68.89	4.34	61.56-77.96
Post/Ant Facial Height (%)	62.01	3.96	54.5	61.74	5.06	54.26-72.4
Maxillary Dental						
Upper 1 to SN (°)	105.44	8.36	85.5-119	107.96	8.92	88.5-123
Mandibular Dental						
Lower 1 to A-Pogon. (mm)	2.39	1.64	-0.46-6.47	2.07	1.74	-0.97-5.91
Lower 1 to Mand. Plane (°)	88.85	7.06	66-98	87.23	6.52	74-102
Interdental						
Overbite (mm)	1.43	1.32	-0.6-4.36	2.08	1.42	-0.36-4.51
Overjet (mm)	1.67	1.54	-2.8-4.27	4.06	1.29	1.91-6.65
Interincisal Angle (°)	129.75	10.60	116-155	127.58	9.22	115-148
Molar relationship (mm) (Neg = III, pos =II)	-1.67	2.16	-6.36-1.12	1.76	2.70	-4.13-6.2

TABLE 7.–Post-retention (T3) Descriptive Cephalometric Measurements for Control and Treatment Groups.

	Control group			Treatment group		
	Mean	S.D.	Range	Mean	S.D	Range
Maxillary Skeletal						
SNA (°)	79.27	4.33	66.5-86.5	79.85	4.16	72.5-89
Articulare - A-Point (mm)	80.76	3.58	69.75-86.76	85.60	5.22	74.97-97.73
Articulare - ANS (mm)	84.49	3.98	73.47-92.85	89.52	5.54	77.18-102.3
Mandibular Skeletal						
SNB (°)	79.50	3.05	76-84.5	79.98	4.65	72-88
SN to pogonion (°)	80.81	3.16	75.5-86	80.60	4.58	73-88.5
Articulare to Gnathion (mm)	87.07	3.39	79.9-94.49	89.29	5.85	77.68-105.57
Articulare to Gonion (mm)	15.65	2.23	11.33-19.39	15.33	2.65	8.5-19.25
Gonion to Pogonion (mm)	72.93	4.02	63.06-80.66	75.62	6.36	65.68-96.2
Articulare to SN (mm)	27.44	2.98	21.63-33.74	27.12	2.75	22.67-33.56
Maxillary to Mandible						
ANB (°)	-0.40	2.45	-9.5-2.5	0.21	1.88	-4-2.5
WITS (mm)	-4.32	2.83	-14.8-(-0.93)	-2.82	2.26	-7.78-0.41
Articulare to PTM (mm)	25.78	2.98	21.3-30.5	29.23	4.24	22.98-40.65
Maxillomandibular diff (mm) Articulare/Gnathion – Articulare/A pt)	6.31	3.43	2.38-19.78	3.72	3.80	-3.67-11.62
Vertical						
SN to Occlusal Plane	16.44	3.54	9.5-21.5	14.96	5.20	7-24
SN to Palatal Plane (°)	9.50	4.27	1-18	9.88	3.89	0.5-19
SN to Mandibular Plane (°)	35.08	4.92	27.5-45.5	35.23	7.37	24-49
Facial Axis Angle (SN-SPg)	63.40	3.19	58-68.5	63.69	4.90	55-73
Upper Facial Height (N-ANS)(mm)	50.37	2.24	46.4-55.55	52.70	2.81	47.58-57.51
Lower Facial Ht (ANS-Me)	63.11	6.69	51.29-77.02	65.78	5.15	56.41-76.53
Ant Facial Ht (N - Me)	113.67	7.37	101.17-130.78	118.71	6.12	108.9-131.46
Gonial angle (Ar - Go -Gn)	127.88	3.87	121-135	129.17	5.92	117-138
Post Facial Height (mm)	71.46	4.43	62.8-77.91	74.24	3.26	66.37-79.84
Post/Ant Facial Height (%)	62.98	3.83	56.48-69.12	62.72	4.55	55.58-71.45
Maxillary Dental						
Upper 1 to SN (°)	106.79	6.70	93.5-119	107.23	8.76	89-121
Mandibular Dental						
Lower 1 to A-Pogon. (mm)	2.67	1.81	-0.64-6.69	2.64	1.66	-1.37-5.31
Lower 1 to Mand. Plane (°)	88.54	7.51	64-99	88.31	4.59	80-97
Interdental						
Overbite (mm)	1.55	1.66	-2.25-5.24	1.75	1.40	0- 4.74
Overjet (mm)	1.56	1.98	-3.66-4.03	2.01	1.80	0-4.16
Interincisal Angle (°)	130.13	10.46	112.5-152	130.83	8.80	114-146
Molar relationship (mm) (Neg = III, pos =II)	-1.87	2.43	-7.21-2.47	-0.89	2.28	-8.55-2.59

TABLE 8.--Difference between Post-treatment (T2) and Pre-treatment (T1) (T2-T1) Descriptive Cephalometric Measurements for Control and Treatment Groups.

	Control group		Treatment group		
	Mean	S.D.	Mean	S.D.	P-value
Maxillary Skeletal					
SNA (°)	-0.01	1.05	0.92	1.50	
Articulare - A-Point (millimeter)	1.84	2.17	2.69	3.67	$4.03x10^{-1}$
Articulare - ANS (millimeter)	1.85	2.45	2.05	3.45	
Mandibular Skeletal					
SNB (°)	0.23	1.34	-1.13	1.56	
SN to pogonion (°)	0.31	1.19	-0.88	1.72	
Articulare to Gnathion (mm)	0.71	4.97	-1.96	6.25	$1.74x10^{-2}$
Articulare to Gonion (millimeter)	-0.25	1.88	-1.66	2.51	
Gonion to Pogonion (millimeter)	2.28	2.22	-1.03	3.13	
Articulare to SN (millimeter)	0.68	2.15	0.41	1.65	
Maxillary to Mandible					
ANB (°)	-0.13	0.76	2.06	1.82	
WITS (millimeter)	-0.47	1.85	3.95	1.82	$3.4x10^{-8}$
Articulare to PTM (millimeter)	1.61	1.55	0.52	2.34	
Maxillomandibular differential (mm) (Articulare/Gnathion – Articulare/A pt)	-0.07	1.50	-3.78	2.50	$9.6x10^{-6}$
Vertical					
SN to Occlusal Plane (°)	-0.19	2.23	-1.71	2.92	
SN to Palatal Plane (°)	-0.31	2.28	0.75	2.45	
SN to Mandibular Plane (°)	0.06	1.05	0.44	2.13	$3.57x10^{-1}$
Facial Axis Angle (SN - SPg) (°)	0.65	1.63	0.88	2.25	
Upper Facial Height (N-ANS)(mm)	1.94	1.72	2.49	1.74	
Lower Facial Ht (ANS-Me)(mm	1.43	0.76	1.30	1.73	
Ant Facial Height (N - Me) (mm)	2.96	1.37	3.78	1.90	$9.47x10^{-2}$
Gonial angle (Ar - Go -Gn) (°)	-0.50	2.57	-0.77	2.55	
Post Facial Height (mm)	1.87	1.26	2.90	1.51	
Post/Ant Facial Height (%)	-0.04	1.05	0.59	1.81	
Maxillary Dental					
Upper 1 to SN (°)	1.04	4.04	2.85	7.04	$2.00x10^{-1}$
Mandibular Dental					
Lower 1 to A-Pogonion (mm)	0.12	0.73	-0.93	1.61	
Lower 1 to Mandibular Plane (°)	0.40	5.36	1.46	5.63	$5.43x10^{-1}$
Interdental					
Overbite (millimeter)	-2.53	2.89	1.45	1.60	
Overjet (millimeter)	0.49	1.09	3.95	1.63	
Interincisal Angle (°)	0.15	8.25	-5.27	8.23	
Molar relationship (millimeter) (Neg = III, pos =II)	-0.17	1.97	2.91	2.93	

Increases were assigned a positive value and decreases assigned a negative value. (P-values were applicable)

TABLE 9.--Difference between Post-retention (T3) and Post-treatment (T2) (T3-T2) Descriptive Cephalometric Measurements for Control and Treatment Groups.

	Control group		Treatment group		
	Mean	S.D.	Mean	S.D.	P-value
Maxillary Skeletal					
SNA (°)	0.20	1.11	0.54	1.88	
Articulare - A-Point (millimeter)	2.98	2.41	4.49	2.82	$8.83x10^{-3}$
Articulare - ANS (millimeter)	3.27	2.85	5.35	3.03	
Mandibular Skeletal					
SNB (°)	0.81	1.70	2.23	2.83	
SN to pogonion (°)	1.33	1.65	2.06	1.83	
Articulare to Gnathion (mm)	4.14	3.10	6.97	3.72	$8.9x10^{-4}$
Articulare to Gonion (millimeter)	-0.49	1.63	1.13	2.26	
Gonion to Pogonion (millimeter)	4.67	3.07	6.86	4.38	
Articulare to SN (millimeter)	1.49	1.49	1.82	1.37	
Maxillary to Mandible					
ANB (°)	-0.90	1.38	-1.35	1.49	
WITS (millimeter)	-0.29	1.82	-1.66	2.05	$2.83x10^{-2}$
Articulare to PTM (millimeter)	1.30	3.48	2.30	2.74	
Maxillomandibular differential (mm) (Articulare/Gnathion – Articulare/A pt)	1.16	2.12	2.51	2.39	$3.68x10^{-2}$
Vertical					
SN to Occlusal Plane (°)	-2.02	2.58	-0.96	2.12	
SN to Palatal Plane (°)	0.17	2.24	0.94	2.28	
SN to Mandibular Plane (°)	-0.92	1.42	-1.33	3.09	$4.91x10^{-1}$
Facial Axis Angle (SN - SPg) (°)	-0.40	1.10	-0.81	1.92	
Upper Facial Height (N-ANS)(mm)	2.60	2.11	3.51	1.93	
Lower Facial Ht (ANS-Me)(mm	2.89	2.83	3.24	2.47	
Ant Facial Height (N - Me) (mm)	5.84	3.99	6.79	3.30	$3.12x10^{-1}$
Gonial angle (Ar - Go -Gn) (°)	-1.19	1.83	-0.35	2.56	
Post Facial Height (mm)	4.69	3.30	5.36	2.84	
Post/Ant Facial Height (%)	0.97	1.31	0.97	1.91	
Maxillary Dental					
Upper 1 to SN (°)	1.35	4.39	-0.73	4.74	$1.33x10^{-1}$
Mandibular Dental					
Lower 1 to A-Pogonion (mm)	0.29	0.88	0.66	1.13	
Lower 1 to Mandibular Plane (°)	-0.65	3.69	1.08	4.80	$2.81x10^{-1}$
Interdental					
Overbite (millimeter)	0.12	1.21	-0.33	1.66	
Overjet (millimeter)	-0.01	1.09	-2.05	1.51	
Interincisal Angle (°)	0.38	4.30	3.25	7.48	
Molar relationship (millimeter) (Neg = III, pos =II)	-0.21	1.53	-2.66	2.13	

Increases were assigned a positive value and decreases assigned a negative value. (P-value were applicable)

TABLE 10.--Differences between Post-treatment (T2) and Pre-treatment (T1) (T2-T1) Superimposition Tracings.

	Control group		Treatment group		
	Mean	S.D.	Mean	S.D.	P-value
Overall					
Nasion (millimeter) horizontal	0.61	0.66	0.85	0.83	
ANS horizontal (millimeter)	0.91	1.22	3.08	1.60	
ANS vertical (millimeter)	0.53	0.82	0.71	1.01	0.5119
A point (millimeter)	1.10	0.93	3.07	1.51	$1.12x10^{-5}$
PNS horizontal (millimeter)	-0.00	1.89	1.54	2.17	
PNS vertical (millimeter)	0.62	0.87	1.76	1.19	$3.28x10^{-5}$
Upper 1 horizontal (millimeter)	2.01	0.88	4.82	1.71	
Upper 1 vertical (millimeter)	1.16	0.90	1.43	1.58	
Upper 6 horizontal (millimeter)	1.51	1.60	4.99	1.49	
Upper 6 vertical (millimeter)	1.48	1.10	2.39	1.19	
Lower 1 horizontal (millimeter)	1.50	1.25	0.45	2.32	
Lower 1 vertical (millimeter)	0.71	0.73	0.27	1.58	
B point horizontal (millimeter)	1.44	1.17	0.45	1.97	
Pogonion (millimeter) horizontal	1.76	1.21	0.90	2.29	
Maxilla					
ANS (millimeter) horizontal	0.37	1.13	1.44	1.58	
A point (millimeter) horizontal	0.46	0.75	1.3	1.08	
Upper 1 horizontal (millimeter)	1.46	1.02	2.47	2.04	$1.75x10^{-2}$
Upper 1 vertical (millimeter)	0.7	1.01	1.06	1.40	0.44
Upper 6 horizontal (millimeter)	0.79	1.40	2.52	1.12	$2.71x10^{-5}$
Upper 6 vertical (millimeter)	1.06	0.96	1.31	1.20	0.45
Mandible					
B point (millimeter)	0.15	0.46	-0.42	0.58	
Lower 1 horizontal (millimeter)	0.72	0.94	-0.52	1.27	$1.02x10^{-3}$
Lower 1 vertical (millimeter)	-0.74	0.92	-1.79	1.87	$2.49x10^{-3}$
Lower 6 horizontal (millimeter)	0.83	0.85	0.69	1.08	$6.52x10^{-1}$
Lower 6 vertical (millimeter)	-0.71	0.86	-0.66	1.06	$8.77x10^{-1}$
Articulare (millimeter)	-3.06	1.89	-2.77	1.84	$5.09x10^{-1}$

The values were measured horizontal and perpendicular to an average occlusal plane, for control and treatment groups. Forward or downward changes were assigned a positive value while backward or upward changes were assigned a negative value. (P-value were applicable)

TABLE 11.--Difference between Post-retention (T3) and Post-treatment (T2) (T3-T2) Superimposition Tracings

	Control group		Treatment group		
	Mean	S.D.	Mean	S.D.	P-value
Overall					
Nasion (millimeter) horizontal	1.78	1.32	2.20	1.29	
ANS horizontal (millimeter)	2.07	1.84	3.33	2.11	
ANS vertical (millimeter)	2.08	1.35	2.88	1.99	6.72×10^{-2}
A point (millimeter)	1.80	1.74	2.69	1.80	4.16×10^{-3}
PNS horizontal (millimeter)	0.37	1.68	0.48	1.55	
PNS vertical (millimeter)	2.06	2.21	2.58	1.80	4.05×10^{-1}
Upper 1 horizontal (millimeter)	2.96	2.16	2.96	2.17	
Upper 1 vertical (millimeter)	3.08	1.84	3.88	2.70	
Upper 6 horizontal (millimeter)	3.50	2.49	3.48	2.58	
Upper 6 vertical (millimeter)	3.88	2.48	4.64	2.53	
Lower 1 horizontal (millimeter)	3.28	2.75	4.93	2.04	
Lower 1 vertical (millimeter)	3.08	2.12	4.29	2.66	
B point horizontal (millimeter)	3.23	2.89	5.34	2.49	
Pogonion (millimeter) horizontal	3.80	3.80	6.41	3.21	
Maxilla					
ANS (millimeter) horizontal	1.43	1.74	2.14	1.56	
A point (millimeter) horizontal	0.80	1.43	1.45	1.13	
Upper 1 horizontal (millimeter)	1.85	1.60	2.14	1.81	0.56
Upper 1 vertical (millimeter)	1.45	1.40	1.49	1.84	0.91
Upper 6 horizontal (millimeter)	2.46	1.81	2.60	1.64	0.73
Upper 6 vertical (millimeter)	2.24	1.55	2.55	1.53	0.36
Mandible					
B point (millimeter)	0.31	0.92	0.26	0.72	
Lower 1 horizontal (millimeter)	0.64	1.13	0.99	1.50	0.30
Lower 1 vertical (millimeter)	-1.4	1.44	-0.71	1.62	0.12
Lower 6 horizontal (millimeter)	0.95	1.27	1.83	1.67	5.15×10^{-2}
Lower 6 vertical (millimeter)	-2.08	1.73	-2.02	2.00	9.17×10^{-1}
Articulare (millimeter)	-7.38	5.88	-9.56	4.33	3.99×10^{-2}

The values were measured horizontal and perpendicular to an average occlusal plane, for control and treatment groups. Forward or downward changes were assigned a positive value while backward or upward changes were assigned a negative value. (P-value were applicable)

TABLE 12.–Summary of Two Tailed Paired t-Tests of Twenty Measurements, Both Descriptive and from Superimpositions, Comparing Changes in the Control Group and the Treatment Group From Time 1 (Pre-treatment) to Time 2 (Post-treatment).

	Control group		Treatment group			
	Mean	S.D.	Mean	S.D.	P-value	sig. (*)
Articulare - A-Point (millimeter)	1.83	2.17	2.68	3.67	0.4033	NS
Articulare to Gnathion (millimeter)	0.71	4.97	-1.96	6.25	0.0174	*
WITS (millimeter)	-0.47	1.85	3.95	1.82	3.4×10^{-8}	**
Maxillomandibular diff. (mm) (Ar/Gn - Ar/A pt)	-0.07	1.50	-3.78	2.50	9.6×10^{-6}	**
SN to Mandibular Plane (°)	0.66	1.05	0.44	2.13	0.3577	NS
Ant Facial Height (N - Me) (mm)	2.96	1.37	3.78	1.90	0.0947	NS
Upper 1 to SN (°)	1.04	4.04	2.85	4.07	0.2007	NS
Lower 1 to Mandibular Plane (°)	0.40	5.36	1.46	5.63	0.5431	NS
ANS vertical (millimeter)	0.53	0.82	0.71	1.01	0.5119	NS
A point (millimeter)	1.10	0.93	3.07	1.51	1.12×10^{-5}	**
PNS vertical (millimeter)	0.62	0.87	1.76	1.19	3.28×10^{-5}	**
Upper 1 horizontal (millimeter)	1.46	1.02	2.47	2.04	1.75×10^{-2}	*
Upper 1 vertical (millimeter)	0.7	1.01	1.06	1.40	0.44	NS
Upper 6 horizontal (millimeter)	0.79	1.40	2.52	1.12	2.71×10^{-5}	**
Upper 6 vertical (millimeter)	1.06	0.96	1.31	1.20	0.45	NS
Lower 1 horizontal (millimeter)	0.72	0.94	-0.52	1.27	1.02×10^{-3}	**
Lower 1 vertical (millimeter)	-0.74	0.92	-1.79	1.87	2.49×10^{-3}	**
Lower 6 horizontal (millimeter)	0.83	0.85	0.69	1.08	0.6528	NS
Lower 6 vertical (millimeter)	-0.71	0.86	-0.66	1.06	0.8779	NS
Articulare (millimeter)	-3.06	1.89	-2.77	1.84	0.5093	NS

* (*$P < 0.05$; **Significant with Bonferroni correction, $P < 0.0025$; NS = not significant)

TABLE 13.–Summary of Two Tailed Paired t-Tests of Twenty Measurements, Both Descriptive and from Superimpositions, Comparing Changes in the Control and Treatment Group between Time 2 (Post-treatment) and Time 3 (Post-retention).

	Control group		Treatment group			
	Mean	S.D.	Mean	S.D.	P-value	sig. (*)
Articulare - A-Point (millimeter)	2.98	2.41	4.49	2.82	0.0088	*
Articulare to Gnathion (millimeter)	4.14	3.10	6.97	3.72	0.00089	**
WITS (millimeter)	-0.29	1.82	-1.66	2.05	0.02835	*
Maxillomandibular diff. (mm) (Articulare/Gnathion - Articulare/A pt)	1.16	2.12	2.51	2.39	0.0368	*
SN to Mandibular Plane (°)	-0.92	1.42	-1.33	3.09	0.4917	NS
Ant Facial Height (N - Me) (mm)	5.84	3.99	6.79	3.30	0.31	NS
Upper 1 to SN (°)	1.35	4.39	-0.73	4.74	0.1330	NS
Lower 1 to Mandibular Plane (°)	-0.65	3.69	1.08	4.80	0.2815	NS
ANS vertical (millimeter)	2.08	1.35	2.88	1.99	0.0672	NS
A point (millimeter)	1.80	1.74	2.69	1.80	0.0041	**
PNS vertical (millimeter)	2.06	2.21	2.58	1.80	0.4050	NS
Upper 1 horizontal (millimeter)	1.85	1.60	2.14	1.81	0.56	NS
Upper 1 vertical (millimeter)	1.45	1.40	1.49	1.84	0.91	NS
Upper 6 horizontal (millimeter)	2.46	1.81	2.60	1.64	0.73	NS
Upper 6 vertical (millimeter)	2.24	1.55	2.55	1.53	0.36	NS
Lower 1 horizontal (millimeter)	0.64	1.13	0.99	1.50	0.30	NS
Lower 1 vertical (millimeter)	-1.4	1.44	-0.71	1.62	0.12	NS
Lower 6 horizontal (millimeter)	0.95	1.27	1.83	1.67	0.0515	NS
Lower 6 vertical (millimeter)	-2.08	1.73	-2.03	2.00	0.9171	NS
Articulare (millimeter)	-7.38	5.88	-9.56	4.33	0.0399	NS

* (*P < 0.05; **Significant with Bonferroni correction, P < 0.0025; NS = not significant

TABLE 14.--Summary of Two Tailed Paired t-Tests of Eight Descriptive Measurements, Comparing the Control Group and the Treatment Group in Time 1 (Pre-treatment)

	Control group		Treatment group			
	Mean	S.D.	Mean	S.D.	P-value	sig. (*)
Articulare - A-Point (millimeter)	75.94	4.25	78.42	4.60	0.058	NS
Articulare to Gnathion (millimeter)	82.22	5.36	84.27	8.29	0.21	NS
WITS (millimeter)	-3.57	2.69	-5.00	2.25	0.09	NS
Maxillomandibular diff. (mm) (Articulare/Gnathion - Articulare/A pt)	5.22	2.14	4.99	3.46	0.81	NS
SN to Mandibular Plane (°)	35.94	5.04	36.13	6.53	0.90	NS
Ant Facial Height (N - Me) (mm)	104.87	7.01	108.15	5.61	0.01	*
Upper 1 to SN (°)	104.40	7.85	105.10	8.33	0.77	NS
Lower 1 to Mandibular Plane (°)	88.79	7.13	85.77	6.05	0.16	NS

(* P < 0.05; ** significant with Bonferroni correction, P < 0.0025; NS = not significant)

TABLE 15.--Summary of Comparison between the Control and the Treatment Group after Treatment and after Retention.

	Control group				Treatment group				Cont./Treat. Group comparison	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Post Treat	Post Reten
	C2-C1	2.2	C3-C2	2.4	T2-T1	3.6	T3-T2	2.8	sig. (*)	sig. (*)
Articulare - A-Point (mm)	1.83	4.9	2.98	3.1	2.68	6.2	4.49	3.7	NS	*
Ar to Gn (mm)	0.71	1.8	4.14	1.8	-1.96	1.8	6.97	2.0	*	**
WITS (mm)	-0.47	1.5	-0.29	2.1	3.95	2.5	-1.66	2.3	**	*
Maxillomand. diff. (mm) (Ar/Gn -Ar/A pt)	-0.07	1.0	1.16	1.4	-3.78	2.1	2.51	3.0	**	*
SN-Mandibular Plane (°)	0.66	1.3	-0.92	3.9	0.44	1.9	-1.33	3.3	NS	NS
Ant Facial Hgt	2.96	4.0	5.84	4.3	3.78	4.0	6.79	4.7	NS	NS
Upper 1 to SN (°)	1.04	5.3	1.35	3.6	2.85	5.6	-0.73	4.8	NS	NS
Lower 1 to Mand Plane (°)	0.40	0.8	-0.65	1.3	1.46	1.0	1.08	1.9	NS	NS
ANS vertical	0.53	0.9	2.08	1.7	0.71	1.5	2.88	1.8	NS	NS
A point (mm)	1.10	0.8	1.80	2.2	3.07	1.1	2.69	1.8	**	*
PNS vertical	0.62	1.0	2.06	1.6	1.76	2.0	2.58	1.8	**	NS
Upper 1 horizontal (mm)	1.46	1.0	1.84	1.4	2.47	1.4	2.14	1.8	*	NS
Upper 1 vertical (mm)	0.7	1.4	1.45	1.8	1.06	1.1	1.49	1.6	NS	NS
Upper 6 horizontal (mm)	0.79	0.9	2.46	1.5	2.52	1.2	2.60	1.5	**	NS
Upper 6 vertical	1.06	0.9	2.24	1.1	1.31	1.2	2.55	1.5	NS	NS
Lower 1 horizontal (mm)	0.72	0.9	0.64	1.4	-0.52	1.8	0.99	1.6	*	NS
Lower 1 vertical	-0.74	0.8	-1.4	1.2	-1.79	1.0	-0.71	1.6	*	NS
Lower 6 horizontal (mm)	0.83	0.8	0.95	1.7	0.69	1.0	1.83	2.0	NS	NS
Lower 6 vertical	-0.71	1.8	-2.08	5.8	-0.66	1.8	-2.03	4.3	NS	NS
Articulare (mm)	-3.06	2.1	-7.38	2.4	-2.77	3.6	-9.56	2.8	NS	NS

The significance is determined through paired T-test. * Shows significance at $p < 0.05$ level and ** shows significance at $p < 0.005$ level

TABLE 16.--Summary of theTtreatment Effect, Post Retention Changes and the Net Changes in Twenty Measurements on which Paired t-Test Was Performed.

	Cont./Treat. Group comparison		Treatment. Effect	Post retention changes	Net effect
	Post Treat	Post Reten			
	sig. (*)	sig. (*)	(T2-T1)-(C2-C1)	(T3-T2)-(C3-C2)	(T2-T1)-(C2-C1)+(T3-T2)-(C3-C2)
Articulare - A-Point (mm)	NS	*	0.85	1.51	2.36
Ar to Gn (mm)	*	**	2.67	-2.83	-0.16
WITS (mm)	**	*	4.42	-1.37	3.05
Maxillomand. diff. (mm) (Ar/Gn - Ar/A pt)	**	*	3.71	-1.35	2.36
SN to Mandibular Plane (°)	NS	NS			
Ant Facial Hgt	NS	NS			
Upper 1 to SN (°)	NS	NS			
Lower 1 to Mand Plane (°)	NS	NS			
ANS vertical	NS	NS			
A point (mm)	**	*	1.97	0.89	2.86
PNS vertical	**	NS	1.14	0.52	1.66
Upper 1 horizontal (mm)	*	NS	1.01	0.3	1.31
Upper 1 vertical (mm)	NS	NS			
Upper 6 horizontal (mm)	**	NS	1.73	0.14	1.87
Upper 6 vertical	NS	NS	0.25	0.31	0.56
Lower 1 horizontal (mm)	*	NS	1.34	-0.35	0.99
Lower 1 vertical	*	NS	-1.05	0.69	-0.36
Lower 6 horizontal (mm)	NS	NS			
Lower 6 vertical	NS	NS			
Articulare (mm)	NS	NS			

The negative sign stands for changes toward class III direction. The significance is determined through paired T-test. * Shows significance at $p < 0.05$ level and ** shows significance at $p < 0.005$ level

TABLE 17.--Summary of Changes Resulting from Protraction Facemask Treatment when Compared to Normal Growth.

	Treatment effect	Post treatment Changes	Net effect
Maxillary skeletal	**27%**		
A point (mm)	1.97	0.89	2.86
Rotation	**15%**		
PNS vertical (mm)	1.14	0.52	1.66
Dental	**23%**		
Upper 6 horizontal (mm)	1.73	0.14	1.87
Mandibular skeletal	**35%**		
Articulare to Gnathion	2.67	-2.83	-0.16

DISCUSSION

The control group was closely matched to the treatment group in most of the cephalometric measurements (Tables 5 and 14). The control group was less class III than the treatment group because a limited number of untreated class III children were available in the Bolton-Brush sample. Anteroposteriorly, the control group was less class III in ANB, Wits, and overjet, and the mandibular incisors were less upright. All the vertical measurements in the treatment group were greater and all the differences except for the anterior facial height were insignificant ($p < 0.025$, Table 14).

The differences between the control group at Times 1, 2, and 3 showed a very slight increase in class III skeletal and dental characteristics with growth. The Wits decreased by 0.75 mm and the overjet increased by 0.39 mm. In general, the skeletal pattern remained constant with a slight increase in linear measurements as a result of growth and a slight reduction of angular measurements. This showed that the growth continues toward a class III direction.

Only twenty of the measurements were subjected to paired t-test. These values were selected because it was felt they would best test the hypotheses regarding the treatment protocol. In addition, these were the same measurements made in Wolf's study (1998).

Every effort was made to eliminate any bias in this study. Intra-operator variance was 0.36. This indicates that the accuracy of the results is quite high. Inter-operator variance relates to the human ability to detect the cephalometric landmarks. Although inter-operator variance was not calculated, the research advisor calibrated the single operator in the study. Future studies might statistically evaluate the tracing and landmark identification of multiple operators for the same data set.

6.1 Maxillary Skeletal Effect

The effects on the maxilla are best documented by the changes measured in the overall superimposition. The results from the overall superimposition (Table 10) show the skeletal differences between the control and treatment groups. A significantly greater anterior displacement of A point from T1 to T2 in the treatment group (3.07 mm, ranging from 0.43 mm to 6.9 mm, $p < 0.0025$) than in the control group (1.10 mm, ranging from -0.67 mm to 3.08 mm) was observed. Wolf (1998) demonstrated similar results with anterior displacement of A point of 2.78 mm in the treatment group and only 1.33 mm in the control group ($p < 0.002$). Kapust et al. (1998) used the measurement A point to nasion perpendicular and showed 2.3 mm of anterior movement at A point in the treatment group compared to 0.13 mm of posterior movement in the control group ($p < 0.001$). Merwin et al. (1997) also showed an anterior movement of A point of 2.1 mm in the treatment group and only 0.1 mm in the control group ($p < 0.001$).

During retention (Table 11), the anterior displacement of A point was measured as 2.69 mm, ranging from -0.43 mm to 5.9 mm in the treatment group compared to 1.80 mm ranging from -1.96 mm to 6.46 mm, ($p < 0.005$) in the control group.

The treatment effects and the changes that occurred during the retention phase are summarized in Tables 15 and 16. As a result of the treatment, A point moved anteriorly 1.97 mm (ranging from 1.1 mm to 3.82 mm) and continued to move forward an additional 0.89 mm (ranging from -0.56 mm to 1.53 mm) more than the control group during the retention phase. Turley (2002) showed that there was less growth at A point in the class III group compared to the class I group (0.4 mm versus 1 mm). Although the changes shown by articulare-A point are not statistically significant after treatment ($p < 0.5$), this measurement increases in the treatment group during the retention phase (mean of 4.49 mm, ranging from 0.28 mm to 10.36 mm in the treatment group and a mean of 2.98 mm in the control group ($p < 0.01$), ranging from -1.7 mm to 7.28 mm).

These finding suggests that A point continues to move forward once the protraction is completed, and a positive overjet is established, perhaps because a more physiological relationship between the maxilla and the mandible is established. The findings of Sung and Baik (1998) support this finding that forward movement of A point in the treatment group continues during the retention phase.

ANS showed three times more forward movement in the treatment group than the control group during treatment (3.08 mm in the treatment group, ranging from -

0.13 mm to 6.25 mm, versus 0.91 mm in the control group, ranging from -2.11 mm to 3.59 mm). This continued during the retention phase where one and half times more forward movement was measured in the treatment group than in the control group (3.33 mm ranging from -0.3 mm to 6.92 mm compared to 2.07 mm, ranging from -0.59 mm to 6.48 mm). These findings support the third section of my hypothesis suggesting that the maxillary skeletal changes from protraction facemask treatment are stable.

6.2 Maxillary Dental Effect

The maxillary superimposition shows what occurs to the maxillary dentition. The results summarized in Table 10 show a significant difference ($p < 0.001$) in the horizontal displacement of the upper first molar crown (U6C) between the control and treatment groups. Anterior displacement of the U6C in the treatment group was 2.52 mm, ranging from 0.44 mm to 5.73 mm, compared to only 0.79 mm, ranging from -2.38 mm to 4.92 mm, in the control group. Wolf (1998) showed an anterior displacement of 2.31 mm in the treatment group as opposed to 0.93 mm in the control group. Merwin et al. (1997) showed a difference of 3.5 mm between the treatment group and the control group.

During the retention phase (Table 11), the forward movement of the maxillary first molars measured 2.60 mm, ranging from -0.35 mm to 5.2 mm, in the treatment group and 2.46 mm, ranging from -0.97 mm to 6.63 mm, in the control group. This finding suggests that the anterior movement of the U6C during the treatment phase

was a stable change since this measurement is almost the same in both groups during the retention phase.

Although the extrusion of upper molars (U6C) is a dental change, it has a skeletal effect by rotating the mandible downward and backward. Comparing the treatment and the control groups shows that U6C extruded 0.25 mm more in the treatment group than the control group and an additional 0.31 mm during the retention phase.

The maxillary incisors (U1) were displaced anteriorly during the treatment phase with horizontal displacement of U1 being 2.47 mm, ranging from -1.27 mm to 6.36 mm, in the treatment group and only 1.46 mm, ranging from -0.44 mm to 3.69 mm, in the control group ($p < 0.05$). Comparing the changes of upper incisors between the two groups during the retention phase shows that the upper incisors moved forward 2.14 mm, ranging from -1 mm to 5.4 mm, as opposed to 1.85 mm ranging from -0.59 mm 5.01 mm, in the control group. The treatment group had 1.01 mm more forward movement of the upper incisal edges than the control group. The changes during the retention phase were insignificant (0.3 mm more forward movement in the treatment group).

Gu et al. (2000) reported a decrease in overjet correction during the retention phase after protraction facemask therapy. However, this was because of lower anterior proclination and not maxillary incisor movement.

6.3 Mandibular Skeletal Effect

The mandibular regional superimposition shows the dental changes as well as the amount of changes at articulare. These skeletal changes were tested statistically by comparing measurements from articulare to gnathion and also comparing horizontal changes at articulare in the mandibular superimposition. The second part of the hypotheses was to test the stability of any rotational changes following protraction facemask therapy between the control and treatment groups. Articulare to gnathion measures less in the treatment group post treatment compared to the control group (-1.96 mm, raging from -23.58 mm to 14.01 mm, in the treatment group and 0.71 mm, ranging from -20.16 mm to 8.16 mm, in the control group ($p < 0.025$)). This finding may be explained by the chin cup effect of the protraction facemask therapy (Sung and Baik 1998, Baccetti et al.1999, Saadia and Torres. 2000). This reduction relapses during the retention phase in the treatment group (6.97 mm, ranging from 0.6 mm to 15.76 mm). The control group had a mean of 4.14 mm of mandibular growth (articulare-gnathion), ranging from -1.66 mm to 10.34 mm ($p < 0.0025$). Gnathion continued to move more anteriorly in the treatment group than the control group during the retention phase (2.83 mm greater, ranging from -0.89 mm to 2.39 mm). This may be explained by more severe class III malocclusion in the treatment group compared to the control group (Table 11). Turley (2002) concluded that mandibular growth was similar in both groups during the retention phase.

These findings correspond to previous studies regarding the instability of inhibition of mandibular growth (chin cup effect). Therefore it may be concluded that rotation of the mandibular plane angle associated with protraction treatment is an unstable treatment effect.

6.4 Mandibular Dental Effect

Mandibular dental changes were also quantified using the mandibular regional superimposition. The significant mandibular incisor horizontal and vertical changes in the mandibular superimposition (Table 10) suggest incisor uprighting and extrusion in the treatment group relative to the control group. The net forward horizontal movement of upper incisors was 2.81 mm and the net backward horizontal movement of lower incisors was 1.34 mm. One may conclude that about one third of the overjet correction during treatment is due to retroclination of lower anterior teeth. The difference between the horizontal position of the lower incisor pre-treatment and post-treatment was -0.52 mm, ranging from -2.38 mm to 1.81 mm, in the treatment group and 0.72 mm, ranging from -1.07 mm to 3.68 mm, in the control group ($p < 0.005$). During the retention phase, this difference was 0.99 mm, ranging from -1.5 mm to 3.41 mm, in the treatment group and 0.64 mm, ranging from -1.72 mm to 2.85 mm, in the control group ($p < 0.5$). During retention, the lower incisors procline 0.35 mm more in the treatment group than the control group. These findings suggest that the treatment changes to the lower incisors are stable, once treatment is discontinued. This study does not support the

previous study by Chong et al. (1996) about the instability of the dental changes associated with protraction facemask treatment.

6.5 Rotational Changes

This study showed an insignificant increase ($p < 0.5$) in the mean SN-mandibular plane angle (0.44°, ranging from -4° to 4° in the treatment group compared to 0.06°, ranging from -2° to 2°, in the control group). This resulted in maintaining the anterior facial height. This may be explained by the use of a bonded expander and directing the protraction forces as parallel to the occlusal plane. This finding is not consistent with previous studies where much of the class III correction occurred by downward and backward rotation of the mandible. Kapust et al. (1998) found a significant increase in SN-GoGn from Time 1 to Time 2 in the treatment group (1.59°) relative to the control group (-0.15°). Ngan et al. (1992) had the same significant results ($p < 0.05$) with the mandibular plane angle in the treatment group increasing 1.16° and decreasing 0.11° in the control group.

6.6 Maxillomandibular Effect

The changes between the maxilla and the mandible were quantified by the horizontal and vertical projected differences relative to the occlusal plane. Wits and the ANB angle are two traditional cephalometric measurements, routinely used in previous studies to evaluate the maxillary and mandibular skeletal base relationship. In the present study, the Wits difference pre and post treatment (Table 13) in the treatment group measured 3.95 mm, ranging from 1.26 mm to 8.25 mm, compared to -0.47 mm, ranging from -7.63 mm to 2.2 mm, in the control group ($p < 0.0025$)

(Table 12). During the retention phase the mean of the difference in Wits in the treatment group was -1.66 mm, ranging from -6.1 to 3.63 mm. In the control group the difference in Wits was a mean of -0.29 mm, ranging from -4.73 to 3.9 mm ($p < 0.05$).

The mean difference in the ANB angle pre and post-treatment was 2.06°, ranging from -2.5° to 4° in the treatment group compared to a mean difference of -0.13°, ranging from -2° to 1° in the control group. There was a decrease of ANB angle in the treatment group 1.35°, ranging from -4.5° to 1°, during the retention phase, compared to a decrease of -0.90°, ranging from -4.5° to 1.5°, in the control group during the retention phase. These findings suggest that A point and B point continue to have a class III relationship after the protraction facemask is discontinued (3.07 years, ranging from 1.16 to 4.58 years). Wolf (1998) and Wenger (1998) demonstrated an increase of 3.72 mm in Wits and an increase of 2.14° in ANB in the treatment group compared to 0.46 mm increase in Wits and 0.19° decrease in ANB difference in the control group. Kapust et al. (1998) showed 6.41 mm increase in Wits in the treatment group and 0.02 mm increase in Wits in the control group.

Significant changes were observed in the unit length difference as well. The unit length difference is the maxillomandibular differential calculated by subtracting articulare/gnathion from articulare/A point. There was a significant treatment effect of 3.71 mm in a class II direction. The post-retention measurements, however, showed 1.35 mm difference between the treatment and the

control groups, the treatment group having a more class III relationship. This again may be explained by the fact that the treatment group was more class III to begin with.

Although the maxillomandibular measurements suggest that growth reverted to a class III pattern, all twenty-four cases retained a positive overjet. Turley (2002) demonstrated one-hundred percent positive overjet correction in his treatment group during the retention phase as well.

6.7 Vertical Effect

Vertical changes were quantified by calculating the differences in measurements projected onto a line perpendicular to the average occlusal plane. Previous studies (Kapust et al. 1998) have noted a significant decrease ($p < 0.001$) in palatal plane to sella-nasion in the protraction facemask group (1.53°) compared to the control group (0.17° increase). This study supports Wolf's findings that a significant inferior displacement ($p < 0.0025$) of the posterior nasal spine in the treatment group (1.76 mm, ranging from -2.05 mm to 3.25 mm) compared to the control group (0.62 mm, ranging from -2.1 mm to 1.92 mm). This significant posterior displacement, coupled with a lack of vertical change at anterior nasal spine (ANS), suggests some posterior palatal tipping. This study showed that this change was relatively stable during the retention phase even though the change was rotational in nature. During the retention phase, the downward movement of PNS in the treatment group averaged 2.58 mm, ranging from -1.12 mm to 5.85 mm. The control group changed about the same at PNS with an average downward

movement of 2.06 mm, ranging from -1.84 mm to 6.31 mm. The treatment effect ((T2-T1) - (C2-C1)) PNS was 1.14 mm of downward movement with an additional downward movement of 0.52 mm during the retention phase ((T3-T2) - (C3-C2)).

This study supports Guyer et al. (1986) that many class III skeletal malocclusions are not vertically deficient in the middle third as suggested by Proffit and Turley. The mean mandibular plane angle to SN for the treatment group was 36.13°, ranging from 26° to 47.5° and for the control group was 35.94°, ranging from 30° to 47°. Consequently vertical control was an important treatment planning consideration. Sarver showed that with the bonded expander the movement of the maxilla was downward anteriorly with minimal vertical change posteriorly. Any change in SN to mandibular plane angle was insignificant statistically post treatment and post retention. Wolf (1998), Wenger (1998), and Kapust et al. (1998) reported an increase in mandibular plane angle and a clockwise rotation of the mandible. Hiayama et al. (2002) reported an insignificant increase in the mandibular plane angle after the protraction therapy (0.5°, P = 0.064).

Although upper incisors had a more downward pattern of eruption in the treatment group (1.06 mm) than the control group (0.7 mm) during the treatment phase, this change was not statistically significant ($p < 0.5$). The downward movement of the upper incisor was almost the same in both groups during the retention phase (1.49 mm, ranging from -2.58 mm to 4.77 mm, in the treatment group and 1.45 mm, ranging from -0.42 mm to 4.66 mm, in the control group) and

statistically insignificant ($p > 0.05$). This effect may be related to the vertical control of the bonded expander.

This treatment protocol was highly successful using the Wits analysis as the criteria for success. The mean Wits value for class I malocclusion is zero. The mean Wits value for the twenty-four patients treated with protraction facemask in this study was 3.95 mm (ranging from 1.26 mm to 8.25 mm). All twenty-four individuals had a Wits measurement of greater than zero. Only eleven individuals in the treatment group maintained a Wits measurement in this normal range during the retention phase, however, reducing the "treatment success assessment" to 46%. Four individuals in the treatment group maintained a skeletal class III relationship based on ANB angle (mean of 2.06°, ranging from -2.5° to 4°) after the treatment phase and only nine individuals retained a positive ANB angle difference after the retention phase (mean of -1.35°, ranging from -4.5° to 1°).

Changes in the treatment and the control group during the treatment and post treatment phases are illustrated schematically in Figures 2 and 3. Figure 4 represents the net effect of the protraction therapy (Johnston 1996).

To evaluate the relapse of any treatment effect more effectively, one can compare post-treatment (T2-T1) and post-retention (T3-T2) changes with the overall changes (T3-T1). One can observe what was stable and what part of the treatment effect relapsed by these calculations.

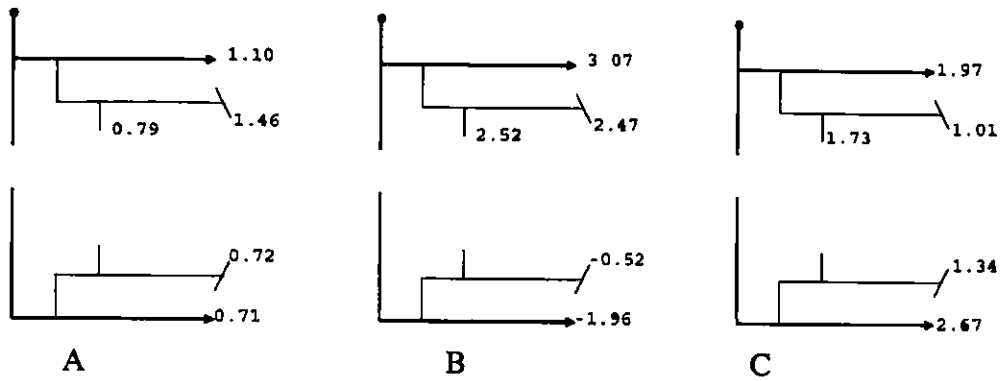


Figure 2. Schematic showing the changes during the treatment phase.
A- Average normal growth (T2-T1) in the control group. B- Treatment changes and average normal growth (T2-T1) in the treatment group. C- Treatment effect.

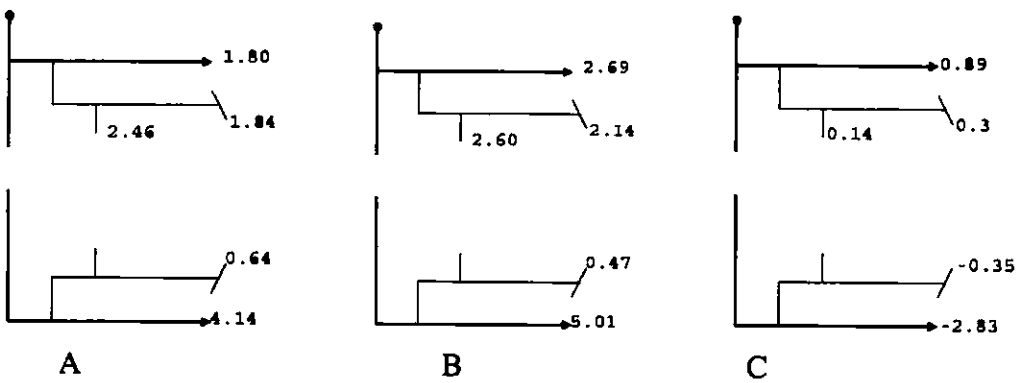


Figure 3. Schematic showing the changes during the post-retention phase.
A- Average normal growth (T3-T2) in the control group. B- Post retention changes and normal growth (T3-T2) in the treatment group. C- Post-retention changes.

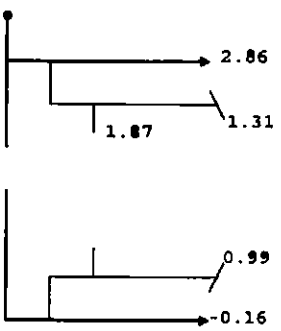


Figure 4. Schematic showing the net changes in the treatment group.

The results suggest that in a growing individual, physiology function and anatomy go hand in hand. Once the maxilla, or perhaps just the maxillary dentition, is in a more functional relationship, the maxilla will assume a more normal physiological growth pattern.

Would this normal physiological response after anterior crossbite correction occur if done by tooth movement alone? Gu et al. (2000) showed that the correction of anterior crossbite using a 2 x 4 appliance is due to incisor proclination. The subject of a future study may be to evaluate the maxillary growth several years post-treatment in a class III sample treated with only fixed orthodontic appliances (2 x 4). The questions to answer would be whether the class III corrections are as stable as demonstrated with protraction facemask treatment and would the amount of overall maxillary forward development be similar to what was documented with protraction facemask treatment. A follow up to this study would be comparing the maxillary and mandibular relationships after growth was completed (Time 4) for all twenty-four subjects. Is the net result (T4-T1) of horizontal maxillary change greater in the treatment group? This may be the best indicator of whether there is benefit to an early phase of orthopedic treatment with protraction facemask.

CONCLUSION

The treatment effects of protraction facemask therapy and the stability of these changes were evaluated cephalometrically. Differences in maxillary form between treated and control groups were examined using traditional cephalometric measurements. The treated group showed significantly greater anterior movement of A point, maxillary incisors, and maxillary first molars during treatment than the control group. These differences were comparable to previous studies (Chong 1996; Mervin 1997; Kapust et al. 1998; Wolf 1998). Maxillary incisor and molar changes were stable and no differences were noted in those measurements between the treatment and the control groups during the post treatment phase. The lower incisors were retroclined during treatment and very little change was observed during the retention phase. This study supports the findings of previous studies regarding the instability of any chin cup effect on the mandible. Although the mandibular growth was restrained during treatment, gnathion repositioned anteriorly post-treatment. Increase in vertical measurements (SN-mandibular plane) was minimized in the treated group compared to previous studies (Kapust et al. 1998, Ngan et al.1992). This finding may be due to the use of a bonded expander for vertical control and horizontally directed forces to minimize extrusion.

It may be concluded that, when compared to normal growth, on the average:

1. Maxillary skeletal changes accounted for 27% of the treatment

changes. A point moved forward about 2 mm more in the treatment group during the treatment period and 1 mm during the retention phase. This suggests stability of the changes in the maxilla after a protraction facemask therapy.

2. Dental changes accounted for 23% of the class III correction. Very little change was observed in the position of maxillary molars or incisors, during the post-retention phase suggesting that these are stable changes.

3. Rotational changes account for only 15% of the corrections. This rotational change appears to be a normal compensatory growth pattern in patients with a class III malocclusion.

4. Mandibular skeletal changes accounted for 35% of the treatment effect. All of this change relapsed during the retention phase.

5. There was no statistically significant change in the mandibular plane angle. This may be explained by the use of bondable type expander and horizontally directed forces during protraction.

6. Molar relationship becomes more class II after treatment. Some relapse occurs in this over-correction due to more mandibular than maxillary growth during the retention phase.

The benefits of protraction facemask therapy can be summarized as:

1. Surgery may be avoided by making the skeletal disharmony less severe.

2. The facial changes will have psychological benefits.

3. A better over all occlusion can be established with less orthodontic camouflage in the second phase of treatment.

4. A more physiological relationship can be established between the mandible and the maxilla, which creates a more normal growth pattern of the maxilla and better facial esthetics.

Compared to other studies, the advantages of this treatment protocol are:

1. Minimal vertical change.

2. Less downward and backward rotation of the mandible

3. Minimal change in anterior facial height
4. Greater treatment effect on the position of the maxilla.

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