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Effects of Rapid Maxillary Expansion Followed by Inter-Maxillary Elastic Traction on Skeletal Class III Patients with Permanent Dentition

By

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DEDICATION

To my family, and Albert

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EFFECTS OF MAXILLARY EXPANSION FOLLOWED BY INTER-MAXILLARY ELASTIC TRACTION ON CLASS III PATIENTS WITH PERMANENT DENTITION

ABSTRACT

By

Xingzhong(John) Zhang

Skeletal Class III patients can be effectively treated using orthopedic forces for young adolescents, or surgical correction for adults. However, the best treatment protocol for post-adolescents remains unclear.

This study compared 43 consecutively treated Class III patients using a bonded expander and class III elastic traction to a full-bonded lower arch to 43 untreated subjects from the Bolton collection matched on race, gender, and age. Nineteen linear and 12 angular variables were measured on the before (T1) and after (T2) lateral cephalograms, and 14 variables were measured from superimposition of T1 and T2 on cranial base, maxilla, and mandible. A p value ≤ 0.05 was used to assign statistical significance.

Statistically significant differences were found on

superimposition for horizontal movement of A-point (0.63 ± 1.48 mm forward), upper first molars (1.24 ± 2.32 mm mesially), B point (1.27 ± 2.98 mm backward), and lower incisors (1.42 ± 2.65 mm lingually). Importantly, no differences between treatment and controls were found for the ratio of posterior and anterior facial height or mandibular plane angle.

This treatment protocol produced clinically and statistically significant improvements in the occlusion of post-adolescent class III patients, and could be considered as an acceptable option for selected patients.

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LITERATURE REVIEW

Class III Malocclusion

Epidemiology of Class III malocclusion

The incidence of Class III malocclusion varies in different populations. In Caucasian population, it is less than 5% (Gallagher, Miranda et al. 1998; Proffit, Field et al. 1998); but in Korea the prevalence of Class III malocclusion is approximately 16.7% (Cha 2003), and 12%(Lew and Foong 1993) to 23%(Johnson, Soetamat et al. 1978) in Chinese population, and 5 to 20% of the Japanese population has the characteristics of Class III malocclusion (Chen, Wu et al. 2007).

Etiology of Class III malocclusion

Skeletal Class III malocclusion has its multifactorial etiology. Litton (1970) examined 51 probands demonstrating Class III malocclusion and found that about 13% of the siblings exhibited the traits, suggesting a strong genetic influence in the transmission of Class III malocclusion. Studies have reported that 32% to as high as 63% of the patients with skeletal Class III malocclusion presented with retruded

maxilla or a combination of a retruded maxilla and excessive growth of the mandible. Jacobson et al (1974) found that approximately 25% of Class III malocclusion had components of maxillary deficiency. Ellis et al also reported that 20% to 30% adult Class III patients presented maxillary retrusion without mandibular prognathism (Ellis and McNamara 1984). As Pangrazio-Kulbersh states, Sue et al found that 62% of their patients had a component of maxillary skeletal retrusion (Pangrazio-Kulbersh, Berger et al. 2007).

Treatment Options for Skeletal Class III Malocclusion

Orthodontists always face the challenge of treating skeletal Class III malocclusion (Dellinger 1973; McNamara 2005), and the challenge primarily comes from the unpredictable and potentially unfavorable nature of growth in the patients with this skeletal pattern (Kim, Viana et al. 1999).

Classically, Class III can be treated by protraction facemask and/or chin-up, orthodontic camouflage treatment, and orthognathic surgical treatment after patient's growth is done.

Orthopedic Treatment

Protraction facemask and/or Chin-cup

Considering maxillary retrusion as one of the major etiological contributory components of skeletal Class III malocclusion, protracting maxilla downward and forward could be the desired treatment for this type of Class III malocclusion. This treatment modality may reduce the possibility of being treated by orthoganthic surgical correction. A retrospective study done by Pangrazio-Kulbersh et al(2007) at University of Detriot Mercy compared the effects and long-term (7.5 years) stability of protraction facemask therapy (9 females and 8 males) with 949 untreated Class III controls (Reyes, B.C., 2006, cross-sectional data) and the later surgical maxillary advancement with the LeFort I osteotomy (7 females and 10 males). The authors concluded that orthodontic and surgical treatments both produced positive and stable changes in the anteroposterior position of the maxilla; both treatment modalities produced acceptable clinical improvements and stable long-term results. However, as the authors pointed out, one of the weaknesses of this study is that "the protraction group did not reflect the overall growth pattern of the control group," the surgical treated

sample at the onset had a more severe retrognathic maxilla than the protraction group. Moreover, considering the small sample size, and the low coefficients for the intraclass correlation of some cephalometric measurements, the reliability of this study should be a concern.

Treatment timing for Reverse Pull Headgear

The optimization of treatment timing is one of the most important facts when considering facial mask treatment (Cha 2003). It is important to assess individual's growth and development, and various methods, such as evaluating status height, dental age, secondary sexual characteristics, skeletal maturation using hand-wrist or vertebrae(Baccetti, Franchi et al. 2002), can be used.

The optimal treatment timing is still not clear and under controversy. According to Cha, Irie and Nakamura suggested that the period of Hellman's dental age IIC and IIIA is the optimal time. However, Kapust's study(1998) showed that minimal significant differences among the three age groups (4-7, 7-10 and 10-14 years old) when comparing angular and linear measurements alone; but using Johnston analysis, significantly ($p < 0.01$) greater differences were observed in apical base change (ABCH) and total molar correction (6/6)

in the younger age groups. Cha et al (2003) concluded that there was no difference in the effects of maxillary advancement of protraction between prepubertal and pubertal groups. However, in this study, no sample inclusion criteria was mentioned, no control group provided, no sample size calculation included. So the conclusion may be due to other potential explanatory variables, such as the duration of protraction and gender. Because of the small sample size, chance may play great role.

Merwin (1997) compared two different age groups (5 to 8 years and 9 to 12 years) treated with maxillary protraction and expansion. In this study, thirty patients were included totally, experimental subjects served as their own controls. The results of multivariate analysis of variance indicated that the therapeutic response was strikingly similar between these two age groups. The authors suggested that either starting maxillary protraction before age 8 (5 to 8 years) or after age 8 (8 to 12 years) can obtain similar skeletal response. Considering the small sample size in each group (n=15), Type II error may be high, and the true treatment difference may not be identified due to the small sample size.

Treatment effects assessment

Williams considered longer than 6 months after protraction therapy as long-term (Williams, Sarver et al. 1997). During recent ten years, limited long-term data of maxillary protraction were published (Ngan, Hagg et al. 1997; Williams, Sarver et al. 1997; Yoshida, Ishii et al. 1999; Hagg, Tse et al. 2003; Franchi, Baccetti et al. 2004; Wells, Sarver et al. 2006; Pangrazio-Kulbersh, Berger et al. 2007).

Wells (2006) provided the longest, 10-year-observation after reverse pull headgear (RPHG) treatment (Wells, Sarver et al. 2006). In this longitudinal retrospective cohort study, the sample subjects came from three different orthodontic clinics, and included "all children with Class III malocclusion treated with RPHG" before. The final selected sample included 41 subjects who had cephalometric radiographs before and after RPHG and a recall radiograph at least 5 years post-treatment. Since no detail of the parent sample was provided, it was not clear how many subjects were dropped. Among the 41 subjects, one subject is Asian, all others are Caucasians. Furthermore, the treatment protocols applied to these 41 subjects were not all the same. Only 29 of them had a second phase of comprehensive orthodontic treatment. No

intra-examiner reliability was provided. The author concluded that "there was no difference in the chance of long-term success with treatment starting at any age younger than 10 years." However, it should be cautious when interpreting this conclusion because of the small sample size in each age group (Age<7.92yrs, n=11; Age 7.92 to 9.08 yrs, n=10; age 9.08 to 10.25yrs, n=10; age>10.25, n=10). As one of the strengths of this study, it provided the longest observation until now. The finding of pretreatment difference between the success and failure using discriminant analysis will help to distinguish the patients destined to success or failure. This may be useful to making a treatment plan and having consultation with the patient and parents. If the sample size can be accumulated in the future, re-analysis of this data will be more meaningful.

A protocol named Alternate Rapid Maxillary Expansions and Constrictions (Alt-RAMEC) was developed by Liou (2005). The devices included the double-hinged maxillary expander (Best Medical & Dental International, Inc. U.S. Patent No. 6334771 B1) and a protraction spring (U.S. Patent No. 6273713 B1). Liou and his co-workers (2005) applied this protocol to treat the patients with cleft patients, and they found the forward

displacement of maxilla was about 2 times (3.0±0.9mm) of conventional protraction in conjunction with rapid maxillary expander (1.6±1.0 mm). More recently, Isci et al (2010) reported similar results on the Class III patients treated with activation-deactivation reverse pull headgear protocol, and the mean anterior displacement of A point was more than 4.0mm.

Uslu (2007) evaluated the long-term satisfaction of the patients who received orthodontic treatment alone for the skeletal Class III malocclusion. Forty out of 315 post-retention patients responded to the questionnaires. The authors claimed that 92.5% patients satisfied with their facial appearance, 90% patients satisfied with the overall treatment results, and 72.5% patients stated their social communication had been improved. It should be aware of that only 15.8% (40/315) patients responded before applying these results.

Orthodontic Camouflage Treatment

Orthodontic treatment could be another option for the patients with minor to moderate skeletal Class III malocclusion. Kim (1987) introduced the Multiloop Edgewise

Archwire Technique (MEAW) to treat patients with anterior open and Class III malocclusion. In this technique, except the multiloop archwire with 3 to 5 degrees tip-back bends, 3/16" heavy anterior elastic force was also added to level the occlusal plane that usually sloped upward and forward.

Lin et al (2003) reported 18 cases (5 males and 13 females, mean age 13.7± 2.5 years) with skeletal Class III malocclusion (mean ANB -4.1°) treated with Tip-Edge or Begg light wire technique. The authors found that, during a mean treatment time of 2.5 years, ANB was improved 1.9°, A point moved forward 1.1 mm; upper incisors were proclined, and lower incisors were retroclined significantly; the overjet and profile was improved significantly. Similar finding was reported by Lin et al (2006) from the 13 cases with mean age of 13.2± 0.8 years treated with lower second molar extraction and Tip-Edge technique. Since no control group was included in both these studies, the net treatment effect could not be separated.

Prediction of the Prognosis of Class III Malocclusion Treatment

Many clinicians (Campbell 1983; Joondeph 1993) recommended the early treatment of Class III malocclusion. Campbell (1983) concluded that "the early interception of

Class III malocclusion should be attempted in all patients," and suggested to start the treatment as soon as the maxillary first molars, central, and lateral incisors are erupted.

As Moon (2005) stated, the prognosis of the early treatment of Class III treatment is under controversy. If the prognosis could be predicted accurately, it will be very helpful for the clinicians to provide the treatment options and for the patients to make the final treatment decision. However, there is no consensus of the variable(s) that can serve as the predictor(s).

Zentner et al (2001) studied 80 Class III subjects with completed pre- and post-treatment lateral cephalograms and study models. The authors found that the upper and lower apical base ratio (ABR), midfacial length/mandibular length ratio(MMR), gonnion angle, mandibular ramus height/mandibular body length ratio, net sum of maxilla difference, and mandible difference (Sum Diff) had the predictive value. The combination of ABR, MMR, and Sum Diff as covariates showed the highest predictive value explaining 19% of occlusal improvement. The authors claimed that the size ratio of maxillary and mandibular apical bases was the strongest predictor.

Schuster et al (2003) analyzed 88 patients with Class III malocclusion from multi-centers using discriminant analysis and logistic regression. They found that Wits appraisal, palatal plane angle and individualized inclination of lower incisors were the variables could be used to classify the prepubertal children with Class III malocclusion into non-surgery and surgery patients.

After conducting the discriminant analysis for the 56 patients with Class III malocclusion who underwent chin-cup therapy, Tahmina et al (2000) reported gonial angle, N-A-Pg and ramus plane to SN plane were the significant variables for discriminating the two groups with and without acceptable treatment outcomes.

Moon et al (2005) studied the long-term stability of 45 subjects with Class III malocclusion from a patient pool of 82 subjects. The authors found that in general patients with small gonial angle and a more hypodivergent skeletal pattern had good prognosis, N-perpendicular to point and AB to mandibular plane angle classified 77.8% cases correctly. AB to mandibular plane angle was the most significant variable to predict the prognosis of the treatment, could predict 93.3% of the poor prognosis.

Midpalatal Suture and Circum-Maxillary Sutures

Igleburger (1970) observed the skeletal changes of the two Macaca Mulatta monkeys who received rapid maxillary expansion. The first female monkey was about 5-year-old (dental development age comparable to a 15-year-old human), the second female monkey was two years, three months of age (comparable to a 6 to 7 year old human). Using the placed metallic implants and cephalometric superimposition method, the author found that both the zygomatic and maxillary bones moved laterally after the rapid palatal expansion, and rotated around an antero-posterior axis close to the zygomatico-frontal suture.

Melson (1975) claimed that after age 13 to 15, the palatal suture growth was found to cease except the apposition seemed to continue for some years. However, Persson et al (1977) found that a high percentage of ossification in the midpalatal suture was rarely observed in subjects aged from 15 to 35 years. The histological study done by Knaup et al (2004) also confirmed that, among the 22 subjects aged from 18 to 63 years, the mean obliteration was very little (3.3% in the older subjects) even though the suture width changed slightly. The authors implied that for patients under 25 years old, conventional rapid maxillary expander "would have to be

successful in 100% of the individuals."

Miroue and Rosenberg (1975) examined the morphological and histological changes of three hundred and fifty four sutures from 99 human cadaver specimens. The authors found that the facial sutures except the midpalatal suture do not fuse before seventh or eighth decades, and the midpalatal suture fuses "sometime between the third and fourth decades." Kokich (1976) concluded that the human frontozygomatic suture remained open until the eighth decade with progressive synostosis. Jackson et al (1979) observed the experimental and post-experimental response for the four healthy young, growing pigtail macaques (M. nemestrina) aged from 40 to 48 months. In this study, the applied 300 grams anteriorly directed forces parallel to the occlusal plane on both sides. The authors concluded that skeletal remodeling exists in all circum-maxillary sutures, and the amount of remodeling appears to be "proportional to a suture's distance from the orientation to the applied force system." Maxilla was displaced anteriorly significantly with a small counterclockwise rotation during the experimental period ranged from 63 to 114 days. It was also observed that the overjet increased much more rapidly after first month of force application. The author pointed out it is a necessary

that a period of stabilization following the application of a force to the maxillary complex.

Heymann et al (2010) claimed that all the 6 reported patients receiving Class III elastics showed a positive (outward) displacement in the zygomatic process region, and all but one patient demonstrated positive change in the anterior maxilla region. Wang (2009) also reported the circum-maxillary sutures opened significantly wider using Alt-RAMEC protocol than with the conventional RPE in the rats.

Rapid Maxillary Expander

Many types of maxillary expander have been applied to treat transverse maxillary constriction(Proffit, Fields, et al. 2007).Commonly used expanders include removable expander with a jackscrew or a heavy midline springs, lingual arch such as quad-helix design or W-arch design, and fixed palatal expander such as Hyrax expander, Haas expander, bonded rapid expander.

Effects of Maxillary Expander on Anterior-Posterior Dimension

Haas (1970) pointed "when the midpalatal suture opens, the maxilla always moves forward and downward" when patients who are under 16 or 17 years.

Lindenfeldar (1970) observed the displacement of the

surgically placed metallic implants on the maxilla of the two Macaca Mulatta monkeys after receiving rapid palatal expansion (only the younger one was successfully expanded). With the three reference pins located on glabella, right and left fronto-zygomatic processes for superimposition with lateral cephalograms, the author found that the implants located in the front process of maxilla on both sides had moved downward approximately 1 mm; the implants in the left maxilla moved equally upward and forward about 0.5 mm.

Haas (1961) examined 10 patients (9 to 18 years old), and listed the change of SNA within a range of 0°to 2.5°. There was no statistical evaluation in this study. Wertz (1977) found SNA had a 0.54°change with a range of 1.91° to 3.91°.

The movement of A point is usually used to study the anterior-posterior movement of the maxilla followed the rapid maxillary expansion. The amount of the movement of A point in the patients receiving rapid maxillary expansion is under controversy. Haas (1965) reported A point moved forward 3 mm (female, age 9yr 7 months) and 2mm (male, 14yr 5 months) on his selected cases. He stated that "the lateral cephalometric tracing used to analyze the antero-posterior movement of these bones have shown the maxilla to always move forward if the

midpalatal suture opening occurs."

Among the 26 patients that Davis et al (1969) studied, all the 24 cases that received rapid expansion only presented A point forward movement as a result of splitting the palatal suture. Wertz (1970) studied 60 cases treated with rapid Haas-type expander; he claimed that A point did not routinely move forward a significant amount, and even moved slightly posteriorly in a few cases. However, from his results, 18 out of total 60 cases (30%) had at least 1.0 mm forward movement. Chung et al(2004) studied 20 children (6 male and 14 female) with average age 11.7 year old who received Haas-type RPE (4 of 20 only had bands on upper first molars). They found that maxilla moved forward significantly (SNA increased 0.35°, FH-NA increased 0.60°, A-Nperp increased 0.58mm) during the expansion phase (mean interval between T1 and T2 was 96.5 days, range 34 to 185 days). However, no control was included in this study. Since no control groups were included in all these studies, the treatment effects could be isolated from the normal growth.

Effects of Maxillary on Vertical Dimension

Haas (1970) claimed that when the midline suture opens, the maxilla always moved forward and downward. Consequently, rotates mandible to a downward and backward direction, thus increases the lower facial height. These skeletal and dental effects improve the patients with deep-bite type Class III skeletal pattern. Haas stated that the mechanics with rapid maxillary expansion followed with Class III elastics would "definitely" be contraindicated for those with open-bite type skeletal pattern.

Wertz (1970) also concluded that at stabilization the maxilla was routinely displaced downward 1 to 2 mm, but rarely was displaced forward more than 1.5mm, and forward displacement to any degree was limited to isolated cases. No specific inclusion criteria and control group was included. Chang et al (1997) compared 25 Class I or II patients who received RME with Haas-type expander as part of their overall treatment protocol with 23 control subjects. The authors concluded that the long-term effect on vertical dimension of RME therapy with Haas-type expander is little.

Sarver et al (1989) compared 20 patients treated with bonded rapid expansion with Wertz's study (1970). He found

that the anterior movement of maxilla in the bonded sample was less than the Wertz's banded sample, and concluded that the downward displacement that associated with the banded rapid palatal expansion appliance may be minimized with the bonded expander.

Wendling et al (2005) concluded that the acrylic-splint expander had a posterior "bite block effect" and intruded maxillary molars 0.7 mm (2005). Akkaya (1999) examined 24 patients with maxillary bilateral crossbite and Class I or II molar relationship. Those 24 patients were separated into two matched groups (according to ANB and mandibular angle): bonded RPE group and slow maxillary expansion (SME) group, each group included 12 subjects. The authors concluded that both groups showed anterior displacement, but the downward and backward mandibular rotation only in RME group.

Lagravere et al (2005) systematically reviewed the long-term skeletal changes with rapid maxillary expansion. Only three articles were finally met all the inclusion criteria. Two of them measured the anteroposterior changes. According to Lagrevere, A point was more detruded (-1.05° when compared with control group); in RME-treated group, no significant changes were found for the anteroposterior

position of the maxilla and mandible; both maxilla and mandible presented similar changes when compared with the control group.

Some Other Effects of Maxillary Expansion

Ceylan et al (1996) studied the effect of rapid maxillary expansion on 14 patients with different level of hearing loss (one minimal, 11 mild, 2 severe), and found hearing was significantly improved during the active widening period, but this improvement was reversed after 4.5 months retention. Usumez et al (2003) reported the nocturnal enuresis in seven of total eights children was improved 74.2% after 3 to 6 mm of expansion using acrylic RME device.

Cho et al (2010) examined the pulp vitality using electric pulp tester (EPT) and Endo Ice (cold testing) in 25 adolescents who had undergone rapid palatal expansion with Hyrax expander. The authors found all the pulps of the examined teeth were vital after the retention phase of expansion; it was also observed that one individual maxillary first molar did response temporarily. Gurel et al (2009) investigated 25 patients who were treated with the splint-type tooth-and-tissue-borne bonded expanders. Obvious bleeding

was observed in 11 of 25 patients during appliance removal, and bacteremia was detected in 32% (8/25) patients. But no statistically significant relationship between the bleeding and bacteremia incidence was found. For the at-risk patients, the authors recommended to be aware of the possibility of bacterial endocarditis when this type of bonded expander is considered.

Development of Maxillary Expansion Appliances

In our daily practice, rapid and slow maxillary expansion appliances are the two commonly used types of maxillary expansion appliances. Karaman(2002) reported the effects of nitanium maxillary expander appliances in three dimensions for the 16 patients with averaging age 13.8 years and mandibular plane angle 40.75°. The author found that the mandibular plane angle and lower facial height increased 1.0°, and 1.1 mm, respectively; upper first molar and incisors were extruded.

Liou (2005) designed the double-hinged maxillary expander to "expand and rotate each half of the maxilla outward for greater anterior displacement with less risk of bone resorption behind the maxillary tuberosities."

Recently, Lee et al (2010) introduced a miniscrew-assisted rapid-palatal expander (MARPE) used to treat one 20-year-old patient with severe mandibular prognathism. This expander successfully increased the maxillary basal bone width and nasal width for 2.4 and 2.5 mm, respectively.

Treatment Timing for Rapid Maxillary Expansion

Baccetti et al (2001) compared the posteroanterior cephalographic changes of a sample of total 42 patients received Haas expander with a sample of total 20 untreated control subjects. After active phase of expansion, the authors found the change of lateronasal width in the early-treated group (CVM 1 to 3, 29 subjects) was 1.1 mm wider than the late-treated group (CVM 4 to 6, 13 subjects) with statistical significance. The long-term results showed that the early-treated group induced more pronounced transverse skeletal change than the late-treated group. No data that compared the long-term effects for the two groups were provided. It should also be noticed that the sample size of the late-treated group is small, and the sample sizes of the early and late control groups were not matched the early and late-treated groups.

Rapid Maxillary Expander and Class III Elastics for the Correction Of Class III Malocclusion

Haas (1965) pointed that "the forward displacement of the maxilla" seemly made the Class II or convex skeletal patterns worse but improved the Class III or concave skeletal patterns. He also stated that:

"The anterior migration of the maxilla in many instances corrects the anterior crossbite completely. If more antero-posterior correction is necessary, the loosened maxilla comes forward easily in response to the pull of vigorous Class III elastics".

Adams et al (1972) studied the dentofacial effects produced by intermaxillary forces applied on total seven monkeys (Macaca Mulatta). Class III elastics applied on two young monkeys (equivalent human age 5 to 8 years old), three adults (equivalent human age over 20 years old) received Class II elastics, one received Class II elastics on one side and Class III on another side. Casted gold splints were constructed for the both maxillary and mandibular arches.

The author is not aware of any research with adequate design and sample size that has been done so far to study the skeletal and dental effects of applying Class III elastic traction to bonded maxillary expanders in human being.

Conclusion of the Literature Review

The incidence of Class III malocclusion is less than 5% in Caucasian population. Reverse pull headgear (RPHG) is commonly modality to address skeletal Class III discrepancy by moving maxilla downward and forward. Most studies agree the optimal timing for the treatment of reverse pull headgear is around the eruption of maxillary incisors. For the patients with skeletal Class III malocclusion with permanent dentition, treatment options are very limited except orthognathic surgical correction. Rapid maxillary expansion in conjunction with Class III elastics was reported to treat skeletal Class III patients appeared in anecdotal case reports only. So far there is no study with adequate design and sample size that specifically focused on this treatment modality has been conducted.

REFERENCES

Adams, CD, Meikle, MC, Norwick, KW and Turpin, DL. Dentofacial remodelling produced by intermaxillary forces in Macaca mulatta. Arch Oral Biol. 1972 Nov; 17(11): 1519-1535.

Akkaya, S, Lorenzon, S and Ucem, TT. A comparison of sagittal and vertical effects between bonded rapid and slow maxillary expansion procedures. Eur J Orthod. 1999 Apr; 21(2): 175-180.

Baccetti, T, Franchi, L, Cameron, CG and McNamara, JA, Jr. Treatment timing for rapid maxillary expansion. Angle Orthod. 2001 Oct; 71(5): 343-350.

Baccetti, T, Franchi, L and McNamara, JA, Jr. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. Angle Orthod. 2002 Aug; 72(4): 316-323.

Campbell, PM. The dilemma of Class III treatment. Early or late? Angle Orthod. 1983 Jul; 53(3): 175-191.

Ceylan, I, Oktay, H and Demirci, M. The effect of rapid maxillary expansion on conductive hearing loss. Angle Orthod. 1996; 66(4): 301-307.

Cha, KS. Skeletal changes of maxillary protraction in patients exhibiting skeletal class III malocclusion: a comparison of three skeletal maturation groups. Angle Orthod. 2003 Feb; 73(1): 26-35.

Chang, JY, McNamara, JA, Jr. and Herberger, TA. A longitudinal study of skeletal side effects induced by rapid maxillary expansion. Am J Orthod Dentofacial Orthop. 1997 Sep; 112(3): 330-337.

Chen, F, Wu, L, Terada, K and Saito, I. Longitudinal intermaxillary relationships in class III malocclusions with low and high mandibular plane angles. Angle Orthod. 2007 May; 77(3): 397-403.

Cho, JJ, Efstratiadis, S and Hasselgren, G. Pulp vitality after rapid palatal expansion. Am J Orthod Dentofacial Orthop. 2010 Feb; 137(2): 254-258.

Chung, CH and Font, B. Skeletal and dental changes in the

sagittal, vertical, and transverse dimensions after rapid palatal expansion. Am J Orthod Dentofacial Orthop. 2004 Nov; 126(5): 569-575.

Davis, W and Kronman, J. Anatomical changes induced by splitting of the midpalatal suture. Angle Orthod. 1969; 39(2): 126-132.

Dellinger, EL. A preliminary study of anterior maxillary displacement. Am J Orthod. 1973 May; 63(5): 509-516.

Ellis, E, 3rd and McNamara, JA, Jr. Components of adult Class III malocclusion. J Oral Maxillofac Surg. 1984 May; 42(5): 295-305.

Franchi, L, Baccetti, T and McNamara, JA. Postpubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances. Am J Orthod Dentofacial Orthop. 2004 Nov; 126(5): 555-568.

Gallagher, RW, Miranda, F and Buschang, PH. Maxillary protraction: treatment and posttreatment effects. Am J Orthod Dentofacial Orthop. 1998 Jun; 113(6): 612-619.

Gurel, HG, Basciftci, FA and Arslan, U. Transient bacteremia after removal of a bonded maxillary expansion appliance. Am J Orthod Dentofacial Orthop. 2009 Feb; 135(2): 190-193.

Haas, AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. Angle Orthod. 1961 31(2): 73-90.

Haas, AJ. The treatment of maxillary deficiency by opening the midpalatal suture. Angle Orthod. 1965; 35(3): 200-217.

Haas, AJ. Palatal expansion: Just the beginning of dentofacial orthopedics. Am J Ortho. 1970; 57(3): 219-255.

Hagg, U, Tse, A, Bendeus, M and Rabie, AB. Long-term follow-up of early treatment with reverse headgear. Eur J Orthod. 2003 Feb; 25(1): 95-102.

Heymann, GC, Cevidanes, L, Cornelis, M, De Clerck, HJ and Tulloch, JF. Three-dimensional analysis of maxillary

protraction with intermaxillary elastics to miniplates. Am J Orthod Dentofacial Orthop. 2010 Feb; 137(2): 274-284.

Igleburger, GF. Rapid maxillary expansion in the Macaca Mulatta monkey studied by means of antero-posterior cephalometric roentgenograms with metallic implants [master's thesis]. Columbus: The Ohio State University; 1970.

Isci, D, Turk, T and Elekdag-Turk, S. Activation-deactivation rapid palatal expansion and reverse headgear in Class III cases. Eur J Orthod. 2010 May 9.

Jackson, GW, Kokich, VG and Shapiro, PA. Experimental and postexperimental response to anteriorly directed extraoral force in young Macaca nemestrina. Am J Orthod. 1979 Mar; 75(3): 318-333.

Jacobson, A, Evans, WG, Preston, CB and Sadowsky, PW. Mandibular prognathism. Am J Orthod. 1974 66: 140-171.

Johnson, JS, Soetamat, A and Winoto, N. A comparison of some features of the Indonesia occlusions with those two other ethnic groups. Br J Orthod. 1978; 5: 183-188.

Joondeph, DR. Early orthodontic treatment. Am J Orthod Dentofacial Orthop. 1993 Aug; 104(2): 199-200.

Karaman, AI. The effects of nitanium maxillary expander appliances on dentofacial structures. Angle Orthod. 2002 Aug; 72(4): 344-354.

Kim, JH, Viana, MA, Graber, TM, Omerza, FF and BeGole, EA. The effectiveness of protraction face mask therapy: a meta-analysis. Am J Orthod Dentofacial Orthop. 1999 Jun; 115(6): 675-685.

Kim, Y. Anterior openbite and its treatment with multiloop edgewise archwire. Angle Orthod. 1987; 57(4): 290-321.

Knaup, B, Yildizhan, F and Wehrbein, H. Age-related changes in the midplalatal suture. A histomorphometric study. J Orofac Orthop. 2004; 65(6): 467-474.

Kokich, VG. Age changes in the human frontozygomatic suture from 20 to 95 years. Am J Orthod. 1976 Apr; 69(4): 411-430.

Lagravere, MO, Major, PW and Flores-Mir, C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. Angle Orthod. 2005 Nov; 75(6): 1046-1052.

Lee, KJ, Park, YC, Park, JY and Hwang, WS. Miniscrew-assisted nonsurgical palatal expansion before orthognathic surgery for a patient with severe mandibular prognathism. Am J Orthod Dentofacial Orthop. 2010 Jun; 137(6): 830-839.

Lew, KK and Foong, WC. Horizontal skeletal typing in an ethnic Chinese population with true Class III malocclusions. Br J Orthod. 1993 Feb; 20(1): 19-23.

Lin, J and Gu, Y. Preliminary investigation of nonsurgical treatment of severe skeletal Class III malocclusion in the permanent dentition. Angle Orthod. 2003 Aug; 73(4): 401-410.

Lin, J and Gu, Y. Lower second molar extraction in correction of severe skeletal class III malocclusion. Angle Orthod. 2006 Mar; 76(2): 217-225.

Lindenfeldar, GW. The use of metallic implants to study the effects of induced rapid maxillary expansion in the Macaca Mulatta monkey by means of lateral cephalograms [master's thesis]. Columbus: The Ohio State University; 1970.

Liou, EJ. Toothborne orthopedic maxillary protraction in Class III patients. J Clin Orthod. 2005 Feb; 39(2): 68-75.

Liou, EJ and Tsai, WC. A new protocol for maxillary protraction in cleft patients: repetitive weekly protocol of alternate rapid maxillary expansions and constrictions. Cleft Palate Craniofac J. 2005 Mar; 42(2): 121-127.

Litton, SF, Ackermann, LV, Isaacson, RJ and Shapiro, BL. A genetic study of Class 3 malocclusion. Am J Orthod. 1970 Dec; 58(6): 565-577.

McNamara, JA. Orthodontics, Current Principles and Techniques. Graber, T, R Vanarsdall, Jr. and K Vig. 4th ed. St. Louise: Elsevier Mosby Inc.; 2005. Chap.13, Treatment of patients in the mixed dentition; p. 554-555.

Melsen, B. Palatal growth studied on human autopsy material. A histologic microradiographic study. Am J Orthod. 1975 Jul; 68(1): 42-54.

Merwin, D, Ngan, P, Hagg, U, Yiu, C and Wei, SH. Timing for effective application of anteriorly directed orthopedic force to the maxilla. Am J Orthod Dentofacial Orthop. 1997 Sep; 112(3): 292-299.

Miroue, MA and Rosenberg, L. The human facial sutures: A morphologic and histologic study of age changes [master's thesis]. Seattle: University of Washington; 1975.

Moon, YM, Ahn, SJ and Chang, YI. Cephalometric predictors of long-term stability in the early treatment of Class III malocclusion. Angle Orthod. 2005 Sep; 75(5): 747-753.

Mozayeni-Azar, M. *Post-treatment and Post-retention evaluation of protraction facemask therapy using traditional protraction facemask therapy using traditional cephalometrics* [master's thesis]. Cleveland: Case Western Reserve University; 2003.

Ngan, PW, Hagg, U, Yiu, C and Wei, SH. Treatment response and long-term dentofacial adaptations to maxillary expansion and protraction. Semin Orthod. 1997 Dec; 3(4): 255-264.

Pangrazio-Kulbersh, V, Berger, JL, Janisse, FN and Bayirli, B. Long-term stability of Class III treatment: rapid palatal expansion and protraction facemask vs LeFort I maxillary advancement osteotomy. Am J Orthod Dentofacial Orthop. 2007 Jan; 131(1): 7 e9-19.

Persson, M and Thilander, B. Palatal suture closure in man from 15 to 35 years of age. Am J Orthod. 1977 Jul; 72(1): 42-52.

Proffit, WR, Fields, HW, Jr. and Moray, LJ. Prevalence of malocclusion and orthodontic treatment need in the United States: estimates from the NHANES III survey. Int J Adult Orthodon Orthognath Surg. 1998; 13(2): 97-106.

Proffit, WR, Fields, HW and Sarver, DM. Contemporary orthodontics 4th. St. Louis, Mo., Mosby Elsevier; 2007.

498-502.

Sarver, DM and Johnston, MW. Skeletal changes in vertical and anterior displacement of the maxilla with bonded rapid palatal expansion appliances. Am J Orthod Dentofacial Orthop. 1989 Jun; 95(6): 462-466.

Schuster, G, Lux, CJ and Stellzig-Eisenhauer, A. Children with class III malocclusion: development of multivariate statistical models to predict future need for orthognathic surgery. Angle Orthod. 2003 Apr; 73(2): 136-145.

Tahmina, K, Tanaka, E and Tanne, K. Craniofacial morphology in orthodontically treated patients of class III malocclusion with stable and unstable treatment outcomes. Am J Orthod Dentofacial Orthop. 2000 Jun; 117(6): 681-690.

Uslu, O and Akcam, MO. Evaluation of long-term satisfaction with orthodontic treatment for skeletal class III individuals. J Oral Sci. 2007 Mar; 49(1): 31-39.

Usumez, S, Iseri, H, Orhan, M and Basciftci, FA. Effect of rapid maxillary expansion on nocturnal enuresis. Angle Orthod. 2003 Oct; 73(5): 532-538.

Wang, YC, Chang, PM and Liou, EJ. Opening of circumaxillary sutures by alternate rapid maxillary expansions and constrictions. Angle Orthod. 2009 Mar; 79(2): 230-234.

Wells, AP, Sarver, DM and Proffit, WR. Long-term efficacy of reverse pull headgear therapy. Angle Orthod. 2006 Nov; 76(6): 915-922.

Wendling, LK, McNamara, JA, Jr., Franchi, L and Baccetti, T. A prospective study of the short-term treatment effects of the acrylic-splint rapid maxillary expander combined with the lower Schwarz appliance. Angle Orthod. 2005 Jan; 75(1): 7-14.

Wenger, RT. *Evaluation of protraction facemask therapy using traditional morphometrics and procrustes analysis* [master's thesis]. Cleveland.: Case Western Reserve University; 1998.

Wertz, R. Skeletal and dental changes accompanying rapid

midpalatal suture opening. Am J Ortho. 1970; 58(1): 41-66.

Wertz, R and Dreskin, M. Midpalatal suture opening: a normative study. Am J Orthod. 1977 Apr; 71(4): 367-381.

Williams, MD, Sarver, DM, Sadowsky, PL and Bradley, E. Combined rapid maxillary expansion and protraction facemask in the treatment of Class III malocclusions in growing children: a prospective long-term study. Semin Orthod. 1997 Dec; 3(4): 265-274.

Yoshida, I, Ishii, H, Yamaguchi, N and Mizoguchi, I. Maxillary protraction and chincap appliance treatment effects and long-term changes in skeletal class III patients. Angle Orthod. 1999 Dec; 69(6): 543-552.

Zentner, A, Doll, GM and Peylo, SM. Morphological parameters as predictors of successful correction of Class III malocclusion. Eur J Orthod. 2001 Aug; 23(4): 383-392.

STATEMENT OF THE THESIS

Can the treatment protocol (bonded rapid maxillary expander followed by Class III elastics to full fixed mandibular appliance) for the patients with skeletal Class III malocclusion and permanent dentition have significant skeletal and dental changes? This study is designed to answer this question.

The purpose of this study is to examine the skeletal and dental changes after the patients received this treatment protocol. The following hypothesis will be tested:

a) Null hypothesis: there is no significant skeletal and dental change compared to the untreated matched Class III (or Class I)subjects;

b) Alternative hypothesis: there is (are) significant skeletal and dental change(s) compared to the untreated matched (or Class I) subjects.

If null hypothesis is rejected, there would have significant skeletal and/or dental change(s).

MANUSCRIPT

Effects of Rapid Maxillary Expansion Followed By Inter-Maxillary Elastic Traction on Skeletal Class III Patients with Permanent Dentition

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MANUSCRIPT DRAFT

Title: Effects of Rapid Maxillary Expansion Followed by Inter-maxillary Elastic Traction on Skeletal Class III Patients with Permanent Dentition

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Introduction: Skeletal Class III patients can be effectively treated using orthopedic forces for young adolescents, or surgical correction for adults. However, the best treatment protocol for post-adolescents remains unclear. **Material and Methods**: This study compared 43 consecutively treated Class III patients using a bonded expander and class III elastic traction to a full-bonded lower arch to 43 untreated subjects from the Bolton collection matched on race, gender, and age. Nineteen linear and 12 angular variables were measured on the before (T1) and after (T2) lateral cephalograms, and 14 variables were measured from superimposition of T1 and T2 on cranial base, maxilla, and mandible. A p value ≤ 0.05 was used

to assign statistical significance. **Results**: Statistically significant differences were found on superimposition for horizontal movement of A-point (0.63 ± 1.48 mm forward), upper first molars (1.24 ± 2.32 mm mesially), B point (1.27 ± 2.98 mm backward), and lower incisors (1.42 ± 2.65 mm lingually). Importantly, no differences between treatment and controls were found for the ratio of posterior and anterior facial height or mandibular plane angle. **Conclusions**: This treatment protocol produced clinically and statistically significant improvements in the occlusion of post-adolescent class III patients, and could be considered as an acceptable option for selected patients.

INTRODUCTION

The incidence of Class III malocclusion is less than 5% in the Caucasian population,[1] but is more prevalent in Asian populations.[2, 3] Most of orthodontists agree that treatment of skeletal Class III malocclusion is challenging,[4-6] primarily because of the unpredictable and potentially unfavorable nature of mandibular growth in patients with this skeletal pattern.

It was reported that about 32% to 63% of skeletal Class III malocclusions present with a retruded maxilla or a combination of a retruded maxilla and excessive growth of the mandible.[7] Therefore, reverse pull headgear (RPHG) is one of the most commonly used orthopedic modalities for moving the maxilla downward and forward in young patients.[7-13] Merwin et al recommended correcting skeletal Class III malocclusions with reverse pull headgear around the eruption of maxillary incisors to achieve optimal results.[14] Results on orthopedic treatment of Class III patients suggest that this intervention reduces the likelihood of orthognathic surgical correction in the permanent dentition.[13] Baccetti et al concluded that rapid maxillary expansion before the pubertal peak produces more pronounced skeletal transverse

change. [15] Since orthopedic treatment has not been as effective after eruption of the permanent dentition as in the mixed dentition, orthodontic camouflage treatment or surgical orthodontics are often considered the best treatment options in this older age group.

In addition to increases in the transverse dimension, both bonded and banded rapid maxillary expanders result in an increase in SNA and forward and downward movement of A-Point, [16-20],[21] even though some controversies existed.[22, 23] Previously reported effects on vertical dimension of rapid maxillary expansion include increases in posterior facial height resulting in backward rotation of the mandible and increased anterior facial height.[19, 21] Some studies also have suggested that bonded rapid maxillary expanders with occlusal coverage minimize the downward displacement of the maxilla associated with banded expander.[24] Others have even suggested an intrusive effect on the maxillary posterior molars.[25]

There have been some case reports on the use of rapid maxillary expansion followed by Class III elastics for Class III patients in the permanent dentition.[17, 19, 26] Adams et al also found the skeletal and dental effects of Class III

elastics applied on the casted splints in two Macaca mulatta,however, no controls were used.[27]

This retrospective case control study is the first one aimed to examine the skeletal and dental changes in post-adolescent patients with skeletal Class III malocclusion treated with a bondable rapid maxillary expander and Class III elastic traction anchored to a full fixed mandibular edgewise appliance.

MATERIALS AND METHODS

This study was approved by the Case Western Reserve University Institutional Review Board (See Appendix A). All the patients enrolled in this study had skeletal Class III malocclusion, and all of their permanent teeth fully erupted. Sample size calculations using an estimated effect size of one degree and 0.5 mm with a standard deviation of one degree and 0.7 mm[21] suggested that a minimum of 21/34 subjects would be needed to find a statistically significant difference if alpha was set at 0.05 and beta at 0.20.[28]

The sample for the Treatment Group and Control group

Forty three consecutively treated patients were identified from the treatment charts at one private office (GRW)

All these patients met the following inclusion criteria: Permanent dentition with no deciduous tooth present; Skeletal Class III malocclusion with or without anterior crossbite; ANB <0, Wits <-2mm; Adequate lateral cephalographs at Time one (T_1, before treatment) and Time two (T_2, after treatment, the full brackets were debonded) were present and all pertinent landmarks were distinguishable. Exclusion criteria were as follows: Congenitally missing or having teeth extracted at the beginning of treatment; Cleft lip and cleft palate or other craniofacial anomalies.

Treated patients were matched with untreated subjects from the Bolton collection[29] on race, gender, age, Angle Classification, ANB, and anterior facial height.

Treatment Protocol

All patients in this study received the same treatment protocol developed by one of the senior authors (GRW): Rapid maxillary expansion with a full coverage bonded expander followed by Class III elastic forces attached to the expander and a fully bonded mandibular arch. Pretorqued preangulated edgewise brackets with .022" Roth prescription were used (Figure 2 and Figure 3).

The maxillary bonded expander consisted of A Hyrax-type jackscrew embedded in the acrylic. The acrylic extended to cover the palatal sides of the posterior teeth and the occlusal surfaces. Buccally, the acrylic was also extended completely to the buccal gingival margins to maximize retention and to minimize the risk of decalcification. The acrylic coverage of the expander extended mesially to the mesial of the first premolars. Two archwire tubes with elastic hooks were placed in the acrylic opposite the first molar to allow Class III elastics and partial maxillary appliances to be used if desirable. Wire occlusal rests were placed over the occlusal of the maxillary second molars if present to avoid extrusion (Figure 4). All the expanders were fabricated by one laboratory (Allesee Orthodontic Appliances, Sturtevant, Wisconsin 53177).

An activation schedule of one turn every other day was followed. Although the amount of expansion varied with the individual patient's situation, some expansion occurred in all cases prior to beginning the elastics. The lower arch was bonded with full fixed appliance after the expected expansion was achieved (Figure 2Figure 4). The inter-maxillary Class III elastics (3/8 inch, 4 ½ ounces or 127.6 grams) were added

bilaterally directed from the mandibular canines to elastic hooks embedded in the bonded expander after the expansion phase was nearly completed (Figure 3). Patients were required to wear Class III elastics full time except brushing and eating. This Horizontal overjet, measured from the middle of the maxillary incisal edge to labial of mandibular incisors, was used as an indicator of correction. One of the treatment goals was to gain positive horizontal overjet.

Image calibration

All radiographs were calibrated using previously described methods[30] and were printed on premium paper (Epson Glossy Photo Epson American, Inc.) using a high quality printer (Epson Stylus Photo R280 Inkjet Printer, Epson American, Inc.). All linear measures were adjusted for magnification using mediolateral distance (Control Images) or an imbedded scale (Treatment images).

Cephalogram Tracing and Superimposition

A 0.5 mm lead pencil was used to trace all cephalometric photographs on 0.003mm matte acetate papers (3M Unitek). All tracings and all superimpositions were done by one author (XZ), and verified by one senior author (GRW). Superimposition on

cranial base landmarks was used to determine measure changes in the maxilla and mandible.[31] Maxillary superimpositions were done to quantify the dental movements of upper central incisors and upper first molars.[32] Mandibular superimpositions were used to measure the horizontal and vertical dental movements of lower central incisors and lower first molars, and to quantify the amount of mandibular lengthening.[33, 34]

Data Capture and Management

Nineteen landmarks were identified on each tracing to calculate a total of 31 measurements (19 linear measurements and 12 angular measurements) (

Figure 1). A total of fourteen linear measurements were made on the superimpositions: Five on the overall, representing the anteroposterior movements of A point, B point and Pogonion point and the vertical movements of ANS, PNS; four on the maxillary, and four on the mandibular, representing the A-P and vertical movements of upper and lower incisors and molars, respectively. The mandibular lengthening was also measured on the mandibular superimposition.

All anteroposterior measurements were made on the average

occlusal plane, and vertical changes were measured perpendicular to this plane. Positive values were assigned for the downward and forward movements; negative values were assigned for the upward and backward movements. [34, 35] Cervical vertebral maturation scores were determined according to the methodology described by Baccetti et al.[36]

All the data were collected by one author (XZ). The demographic data were entered into Excel file directly. The data measured from individual cephalometric tracing and from superimpositions were entered into Data Editor of the Statistical Package for the Social Sciences Software (version 17.0.0; SPSS, Inc., Chicago Ill) directly. The linear measurements were made using a Fowler Sylac Ultra-Cal IV (Swiss) and directly transferred to the SPSS Data Editor using the OPTO-RS232 Simplex cable from Fowler Tools and Instruments (EDP# 13588, Sylvac S.A.) to minimize the data entry error. Angular measurements were made with a protractor (3M Unitek).

Reliability test

Fourteen subjects were randomly selected from the two groups to conduct the reliability tests. Cephalograms were re-printed, re-traced, re-superimposed, and re-measured by

same author (XZ) after an interval of at least of 2 weeks. The intraclass correlation coefficient (ICC) was used to estimate reliability.

Statistical Analysis

All the statistical analyses were performed using SPSS 17.0. Descriptive statistics were conducted to provide the clinical information of the bonded maxillary expanders and Class III elastics in treatment group (Table 2). Chi-square test was used to compare the difference of in cervical maturation scores between treatment and control groups (Table 1). Selected measurements were tested with paired T-tests. Linear Regression analysis (Enter) was used to identify the variables that could possibly predict the horizontal movement of A point measured on overall superimposition. A P-value of 0.05 was used to assign statistical significance.

RESULTS

The demographic data of the two groups as well as the clinical information of the treatment group were listed in Table 1and Table 2. The mean ANB of the treatment group was negative 0.20° (±1.4°) with a Wits value of negative 4.61(±2.01) mm, and the control group had a mean ANB of

1.3°(±2.5°) with a negative Wits value 1.80(±3.20) mm (Table 3 andTable 4).

The intra-class correlation coefficients between repeated angular/linear measurements on the cephalograms at T1 and T2 were from 0.896 to 0.998. As exceptions, the coefficients for the measurement of molar relationship at T1 and T2, were 0.627 and 0.762, respectively. For the reliability of the measurements on overall and regional superimpositions, the intra-class correlation coefficients were between 0.800 and 0.966.

The results for the cervical vertebral maturation scores implied the control group had relatively less skeletal maturation at Time one. There was 39.53% (17/43) of control subjects at stage of CVM 3, but only 30.23% (13/43) treatment subjects at this stage. More treatment subjects were at stage CVM 4(17/43, 39.53%) comparing the controls (10/43, 23.26%).

There were statistically significant differences on the means of cranial basal angle (NSBa), SNB, ANB, and IMPA between these two groups at Time one; the subjects in the treatment group had more acute cranial base angulation, more prognathic mandible, and more retroclined lower incisor angle comparing the control group. On average, the mean mandibular plane angle

(MPA) for the both groups was over 36 degree. At time two, there were no more statistically significant differences of the angles of SNB and ANB that presented at Time one (Table 3).

There were not statistical significant differences for the mid-face depth (Ar-A) between the two groups at both time points. On average the treatment group had more severe Class III pattern when compared the mandibular length (Ar-Gn and Ar-Pg) and maxillary-mandibular length difference (Ar-Gn_Ar-A_diff) as well as the mean Wits. In the vertical dimension, even though the mean anterior facial height and lower facial height for the treatment group were statistically larger than the control group, the ratio of posterior facial height to anterior facial height (PFH/AFH) maintained same between two groups at both time points. Dentally, the treated patients had more severe Class III pattern and open-bite tendency comparing the controls at Time one. At Time two, for the linear measurements related to the skeletal relationship between maxilla and mandible, the statistically significant differences that existed at Time one were maintained at T2 except Wits, OJ, OB, and molar relationship. The ratios of posterior facial height and anterior facial height in both

groups were increased, but these two groups had the same ratios, implying both group maintained the balanced posterior and anterior facial height ratio (Table 4).

The changes of ANB, Wits and Molar relationship between the two groups had statistically significant differences, indicating the significant improvement of Class III malocclusion in the treatment group. The changes of the lower anterior facial height, and anterior facial height as well as the posterior facial height (S_Go) in the treatment group were statistically larger than the control group (Table 5).

On average, the horizontal movement of A point in the treatment group (2.06±1.36 mm) was 0.63 mm larger than the control group (1.44±1.26mm) ($p<0.01$) with the 95% confidence interval from 0.17 to 1.08 mm. Twenty-one cases (21/43, 48.9%) in the treatment group had the horizontal movement of A point equal to or more than 2.0mm, but only 12 subjects (12/43, 27.9%) experienced that amount movement in the control group (data not provided on the listed tables). On average, the vertical movement of PNS was 0.70 mm more downward than the control group ($p<0.001$) with the 95% confidence interval from 0.31 to 1.10 mm. Horizontally, B point moved lingually 1.27 mm comparing the control group ($p< 0.01$) with the 95% CI from

-2.18 to -0.35 mm (lingually). Both the treatment group and control group had similar mandibular lengthening (Table 6).

All the following six selected variables were entered into the regression model with the R^2 equal to 0.336 and P value of 0.016: the total time of bonded expander in place (Bxp_Total_Time), CVM at Time one (CVM_T1), Expansion turns made (Exp_Turns), gender, total treatment time (Total_Tx_Time), Class III elastics wearing time (Class_III_Elas_Time). However, only the coefficients of CVM at T1 and total treatment time had statistical significance; the standardized coefficients were negative 0.301 (P=0.044) and 0.344 (P=0.024), respectively.

DISCUSSION

The study design and the nature of the samples

The goal of this study was to characterize the effects of using a bonded maxillary expander and Class III elastics to treat post-adolescent Class III patients with permanent dentition.

Many factors can influence the treatment outcome. These include the amount of expansion, the length of Class III elastics were used, family history of mandibular prognathism[37],

skeletal and chronological age, race, gender, compliance, and clinician skill. To control for some variation in variables, we included all the consecutively treated Caucasian cases treated by one clinician (GRW) using a consistent treatment protocol; [28] we also included an age and gender matched control group. However, due to the limited available longitudinal records of untreated Class III subjects in the Bolton Collection and the AAOF Craniofacial Growth Legacy Collection[38], it was not possible to match all 43 subjects with untreated skeletal Class III subjects. As a result, only 20 of 43 of the treated patients could be matched with a Class III untreated subject. The remaining 23 were matched with untreated Class I controls. Battagel[39] found that the Class III European Caucasian males demonstrated less forward growth of the maxilla and a more vertical growth pattern than the normal controls, and the facial growth of the Class III subjects continued after the age of 15 years. Kuc-Michalska et al.[40] also found that the pubertal peak in Class III Caucasian subjects was 5 months longer than the Class I subjects on average. Therefore, our results likely under-estimated the positive effects of this treatment protocol.

Anterior-posterior skeletal and dental changes

The observed skeletal and dental changes were small, but additive, and similar with the effects of Class III functional appliances in A-P dimension.[41] Combination of these changes corrects the Class III malocclusion. For example, the net change on ANB was 1.5 degree. This result came from a combination of increasing in SNA of 0.5 degree and decreasing in SNB of 1.1 degree. The ANB change was statistically significant but not in SNA or SNB.

Clinically we treat patients one at a time, so the range of response is important. We found a net treatment effect of 0.63 mm forward movement of A point; the range of movement was 0 to 6.23 mm, and almost half (48.9%) of the patients had more than 2.0mm horizontal movement, while in the control group, the maximum movement of A point was up to 5.44 mm, but only 27.9% subjects had more than 2.0 mm horizontal movement.

Currently there is no evidence to prove that either rapid maxillary expansion or applying Class III elastics alone in patients in the permanent dentition produces anterior movement of A point. We speculate that the skeletal changes found in this study were the additive responses caused by combining maxillary expansion with Class III elastic traction.

We applied the Class III elastic forces parallel to the occlusal plane as close as possible to produce horizontal forward traction and to minimize the vertical traction. Inevitably, this Class III vector force moves the lower incisors lingually as we found in this study; B point moved lingually 1.27 mm more than the control group, and the lower incisors were retroclined 1.4 degrees more compared to controls. This finding seems consistent with the use of Class III elastics, but may also relate to the patient's unfavorable Class III growth pattern.[42] We observed some cases in the treatment group had thin mandibular symphysis; for these cases, it is critical to control the torque of the lower anterior teeth to keep the apices in place when Class III elastic force is applied.[43]

Vertical skeletal and dental changes

Some subjects in both groups had high mandibular plane angles (MPA) over 36°, and the mean for the treatment group 1.2° higher than controls. Our results showed that the mandibular plane angle had almost no change from Time 1 to Time 2. From the overall and maxillary superimpositions, the vertical movement of PNS and the upper first molar in the

treatment group were statistically significant (downward movement of 0.70 mm for PNS and 0.60 mm for upper first molars) more than the control group. These changes are consistent with the vertical component force from the Class III elastics applied on the maxillary bonded expander. This force tends to tip the posterior palatal plane downward[17], but since the Class III traction forces we applied parallel to the occlusal plane, this side effect was minimized. Moreover, the posterior facial height also increased significantly, and the ratio of posterior facial height and anterior facial heights was maintained, even though the absolute measurements on vertical dimension were significantly larger than the control group. As a result, this treatment protocol maintained the vertical dimension. Our results did not show a downward and backward rotation of the mandible[21]. This might be because bonded palatal expanders were used instead of banded expander. This is consistent with Sarver et al who found that the downward displacement that associated with the banded rapid palatal expansion appliance was minimized with the bonded expander[24], and Wendling et al who concluded that the acrylic-splint expander had a posterior "bite block effect" resulting maxillary molars intrusion[25].

Haas recommended not applying "vigorous Class III elastics" directly to the Class III patients with open-bite type skeletal pattern[19]. Despite the small amount of counterclockwise rotation the PNS and upper first molar in the treatment group, our results appear to support this protocol can be applied to the Class III patients with open-bite skeletal pattern with caution.

The treatment protocol and its possible mechanism

Based on studies of fusion of the midpalatal and the circum-maxillary sutures [44, 45, 46, 47, 48,49], it is likely that these sutures were patent in at least some of the patients allowing forward movement when the bonded maxillary expander was activated and Class III elastics traction applied.

A regression analysis showed the amount of horizontal movement of A point was negatively correlated to the skeletal maturation level at Time one and total treatment time. Interestingly, time in Class III elastics traction did not correlate with the movement of A point. Therefore, even though all patients were in the permanent dentition, more forward movement of the maxilla was observed in the skeletally immature patients. Also longer treatment time does not equate

to more favorable treatment effects.

To increase the anchorage of the expander, a tooth and tissue borne design was used. Even with increased anchorage in the treatment group, upper first molar moved 1.24 mm mesially and 0.60 mm occlusally in the treatment group more than the control group compared to controls. However, the Time two records were taken after the comprehensive full bonded treatment, so this dental movement might have occurred during the fixed appliance stage after the expander was removed.

CONCLUSIONS

Application of Class III inter-maxillary elastic force to full fixed mandibular appliances combined with a full coverage maxillary bonded expander during the expansion phase results in clinically and statistically forward movement of A-Point and en mass distal movement of the mandibular dentition.

Even though the treated patients had open-bite skeletal pattern, the vertical dimension was well controlled during treatment. The mandibular plane angle almost had no change. Statistically significant increases in anterior and posterior vertical facial heights were observed. However, the ratio of posterior and anterior facial height was maintained.

References

1. Gallagher RW, Miranda F, Buschang PH. Maxillary protraction: treatment and posttreatment effects. *Am J Orthod Dentofacial Orthop*. Jun 1998;113(6):612-619.
2. Lew KK, Foong WC, Loh E. Malocclusion prevalence in an ethnic Chinese population. *Aust Dent J*. Dec 1993;38(6):442-449.
3. Johnson JS, Soetamat A, Winoto NS. A comparison of some features of the Indonesian occlusion with those of two other ethnic groups. *Br J Orthod*. Oct 1978;5(4):183-188.
4. Dellinger EL. A preliminary study of anterior maxillary displacement. *Am J Orthod*. May 1973;63(5):509-516.
5. Kim JH, Viana MA, Graber TM, Omerza FF, BeGole EA. The effectiveness of protraction face mask therapy: a meta-analysis. *Am J Orthod Dentofacial Orthop*. Jun 1999;115(6):675-685.
6. McNamara JA. Treatment of patients in the mixed dentition. In: Graber T, Vanarsdall R, Jr., Vig K, eds. *Orthodontics, Current Principles and Techniques*. 4 ed. St. Louise: Elsevier Mosby Inc.; 2005:554-555.
7. Williams MD, Sarver DM, Sadowsky PL, Bradley E. Combined rapid maxillary expansion and protraction

facemask in the treatment of Class III malocclusions in growing children: a prospective long-term study. *Semin Orthod*. Dec 1997;3(4):265-274.

8. Ngan PW, Hagg U, Yiu C, Wei SH. Treatment response and long-term dentofacial adaptations to maxillary expansion and protraction. *Semin Orthod*. Dec 1997;3(4):255-264.

9. Yoshida I, Ishii H, Yamaguchi N, Mizoguchi I. Maxillary protraction and chincap appliance treatment effects and long-term changes in skeletal class III patients. *Angle Orthod*. Dec 1999;69(6):543-552.

10. Hagg U, Tse A, Bendeus M, Rabie AB. Long-term follow-up of early treatment with reverse headgear. *Eur J Orthod*. Feb 2003;25(1):95-102.

11. Franchi L, Baccetti T, McNamara JA. Postpubertal assessment of treatment timing for maxillary expansion and protraction therapy followed by fixed appliances. *Am J Orthod Dentofacial Orthop*. Nov 2004;126(5):555-568.

12. Wells AP, Sarver DM, Proffit WR. Long-term efficacy of reverse pull headgear therapy. *Angle Orthod*. Nov 2006;76(6):915-922.

13. Pangrazio-Kulbersh V, Berger JL, Janisse FN, Bayirli B. Long-term stability of Class III treatment: rapid

palatal expansion and protraction facemask vs LeFort I maxillary advancement osteotomy. *Am J Orthod Dentofacial Orthop*. Jan 2007;131(1):7 e9-19.

14. Merwin D, Ngan P, Hagg U, Yiu C, Wei SH. Timing for effective application of anteriorly directed orthopedic force to the maxilla. *Am J Orthod Dentofacial Orthop*. Sep 1997;112(3):292-299.

15. Baccetti T, Franchi L, Cameron CG, McNamara JA, Jr. Treatment timing for rapid maxillary expansion. *Angle Orthod*. Oct 2001;71(5):343-350.

16. Haas AJ. Rapid expansion of the maxillary dental arch and nasal cavity by opening the midpalatal suture. *Angle Orthod*. 1961;31(2):73-90.

17. Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. *Angle Orthod*. 1965;35(3):200-217.

18. Davis W, Kronman J. Anatomical changes induced by splitting of the midpalatal suture. *Angle Orthod*. 1969;39(2):126-132.

19. Haas AJ. Palatal expansion: Just the beginning of dentofacial orthopedics. *Am J Ortho*. 1970;57(3):219-255.

20. Wertz R, Dreskin M. Midpalatal suture opening: a normative study. *Am J Orthod*. Apr 1977;71(4):367-381.

21. Chung CH, Font B. Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. *Am J Orthod Dentofacial Orthop*. Nov 2004;126(5):569-575.

22. Wertz R. Skeletal and dental changes accompanying rapid midpalatal suture opening. *Am J Ortho*. 1970;58(1):41-66.

23. Lagravere MO, Major PW, Flores-Mir C. Long-term skeletal changes with rapid maxillary expansion: a systematic review. *Angle Orthod*. Nov 2005;75(6):1046-1052.

24. Sarver DM, Johnston MW. Skeletal changes in vertical and anterior displacement of the maxilla with bonded rapid palatal expansion appliances. *Am J Orthod Dentofacial Orthop*. Jun 1989;95(6):462-466.

25. Wendling LK, McNamara JA, Jr., Franchi L, Baccetti T. A prospective study of the short-term treatment effects of the acrylic-splint rapid maxillary expander combined with the lower Schwarz appliance. *Angle Orthod*. Jan 2005;75(1):7-14.

26. Haas AJ. Rapid palatal expansion: A recommmended prerequisite to Class III treatment. *Trans Eur Orthod Soc*. 1973:311-318.

27. Adams CD, Meikle MC, Norwick KW, Turpin DL. Dentofacial

remodelling produced by intermaxillary forces in Macaca mulatta. *Arch Oral Biol*. Nov 1972;17(11):1519-1535.

28. Hulley SB, Cummings SR, Browner WS, Grady DG, Newan TB. *Designing Clinical Research*. 3 ed. San Francisco: Lippincott Williams & Wilkins; 2007.

29. Hans MG, Broadbent BH, Jr., Nelson SS. The Broadbent-Bolton Growth Study--past, present, and future. *Am J Orthod Dentofacial Orthop*. Jun 1994;105(6):598-603.

30. Cohen JM. Comparing digital and conventional cephalometric radiographs. *Am J Orthod Dentofacial Orthop*. Aug 2005;128(2):157-160.

31. Elmajian K. *A Serial Study of Facial Growth as related to Cranial Base Morphology*. Seattle: Orthodontics, University of Washington; 1959.

32. Doppel DM, Damon WM, Joondeph DR, Little RM. An investigation of maxillary superimposition techniques using metallic implants. *Am J Orthod Dentofacial Orthop*. Feb 1994;105(2):161-168.

33. Bjork A. Variations in the growth pattern of the human mandible: longitudinal radiographic study by the implant method. *J Dent Res*. Jan-Feb 1963;42(1)Pt 2:400-411.

34. Mozayeni-Azar M. *Post-treatment and Post-retention evaluation of protraction facemask therapy using traditional protraction facemask therapy using traditional cephalometrics*. Cleveland: Department of Orthodontics, Case Western Reserve University; 2003.

35. Wenger RT. *Evaluation of protraction facemask therapy using traditional morphometrics and procrustes analysis*. Cleveland.: Department of Orthodontics, Case Western Reserve University; 1998.

36. Baccetti T, Franchi L, McNamara JA, Jr. An improved version of the cervical vertebral maturation (CVM) method for the assessment of mandibular growth. *Angle Orthod*. Aug 2002;72(4):316-323.

37. Sugawara J, Mitani H. Facial growth of skeletal Class III malocclusion and the effects, limitations, and long-term dentofacial adaptations to chincap therapy. *Semin Orthod*. Dec 1997;3(4):244-254.

38. AAOF. AAOF Craniofacial Growth Legacy Collection. 2008, 2009.

39. Battagel JM. The aetiological factors in Class III malocclusion. *Eur J Orthod*. Oct 1993;15(5):347-370.

40. Kuc-Michalska M, Baccetti T. Duration of the pubertal peak in skeletal Class I and Class III subjects. *Angle Orthod*. Jan;80(1):54-57.

41. Baik HS, Jee SH, Lee KJ, Oh TK. Treatment effects of Frankel functional regulator III in children with class III malocclusions. *Am J Orthod Dentofacial Orthop*. Mar 2004;125(3):294-301.

42. Proffit WR, White RP. *Surgical-orthodontic treatment*. St. Louis: Mosby-Year Book; 1991.

43. Phelps AE, Masri N. Location of the apex of the lower central incisor. *Am J Orthod Dentofacial Orthop*. Oct 2000;118(4):429-431.

44. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. *Am J Orthod*. Jul 1975;68(1):42-54.

45. Persson M, Thilander B. Palatal suture closure in man from 15 to 35 years of age. *Am J Orthod*. Jul 1977;72(1):42-52.

46. Knaup B, Yildizhan F, Wehrbein H. Age-related changes in the midplalatal suture. A histomorphometric study. *J Orofac Orthop*. 2004;65(6):467-474.

47. Miroue MA, Rosenberg L. *The human facial sutures: A morphologic and histologic study of age changes*. Seattle: Department of Orthodontics, University of Washington; 1975.

48. Kokich VG. Age changes in the human frontozygomatic suture from 20 to 95 years. *Am J Orthod*. Apr

1976;69(4):411-430.

49. Heymann GC, Cevidanes L, Cornelis M, De Clerck HJ, Tulloch JF. Three-dimensional analysis of maxillary protraction with intermaxillary elastics to miniplates. *Am J Orthod Dentofacial Orthop*. Feb 2010;137(2):274-284.

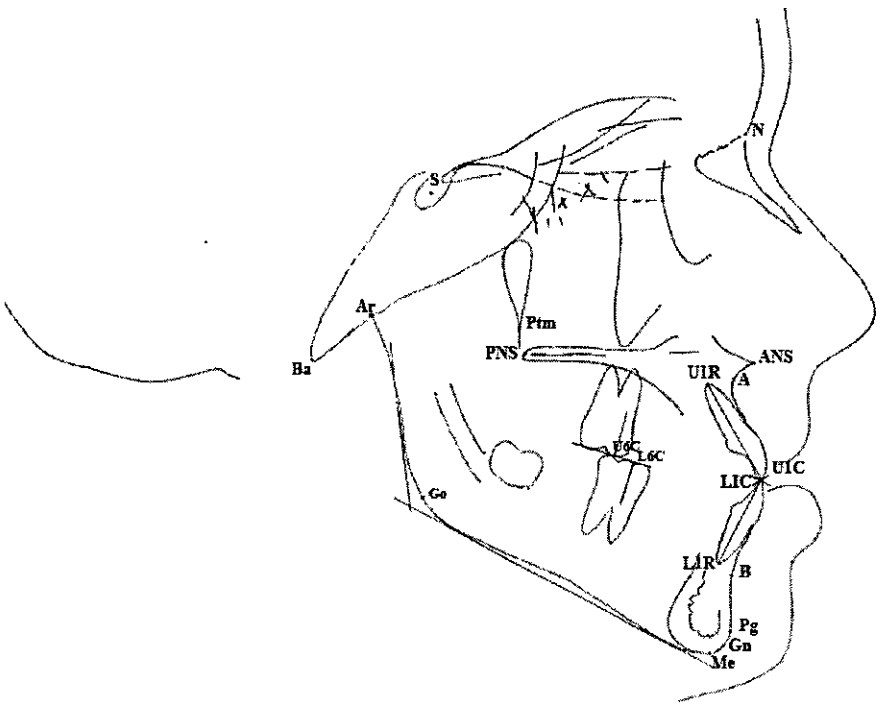


Figure 1 Nineteen cephalometric landmarks used in this study
S (Sella), N (Nasion), ANS, A (A point), B (B point), Pg (Pogonion), Gn (Gnathion), Me (Menton), Go (Gonion), Ar (Articulare), PNS, Ptm (Pterygomaxillary fissure), UIR (Root apex of upper central incisor), UIC (most incisal point of upper central incisor), LIC (most incisal point of lower central incisor), L1R (Root apex of lower central incisor), L6C (buccal groove of lower first molar), U6C (Mesiobuccal cusp tip of upper first molar)



Figure 2 Bonded expander, lower fixed appliance and Class III elastics in place (Courtesy of Dr. Gary R Wolf)

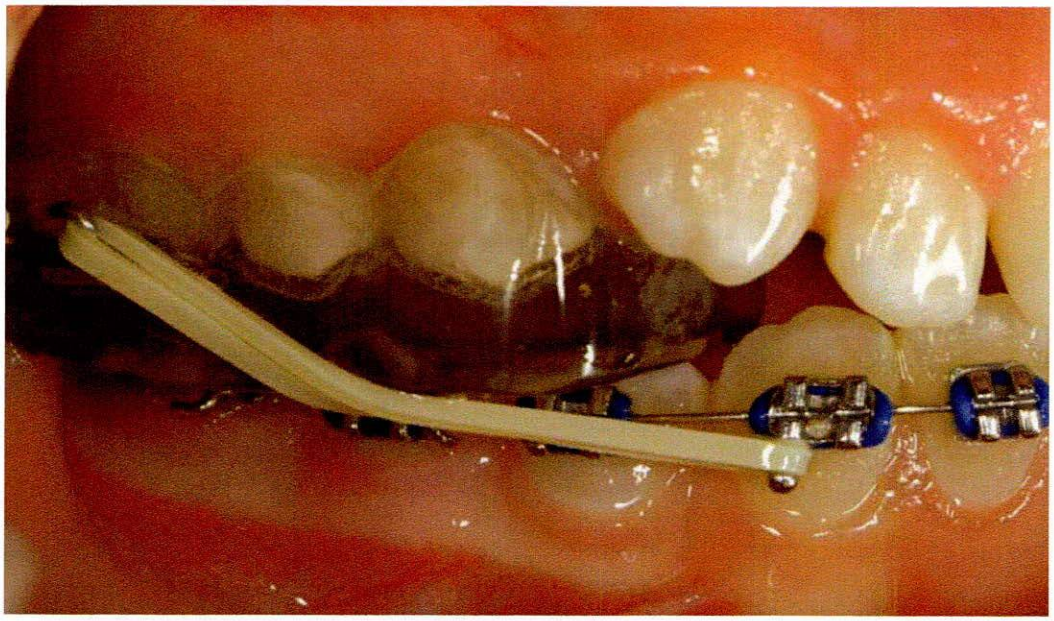


Figure 3 Right side view of the inter-maxillary Class III elastics (Courtesy of Dr. Gary R Wolf)

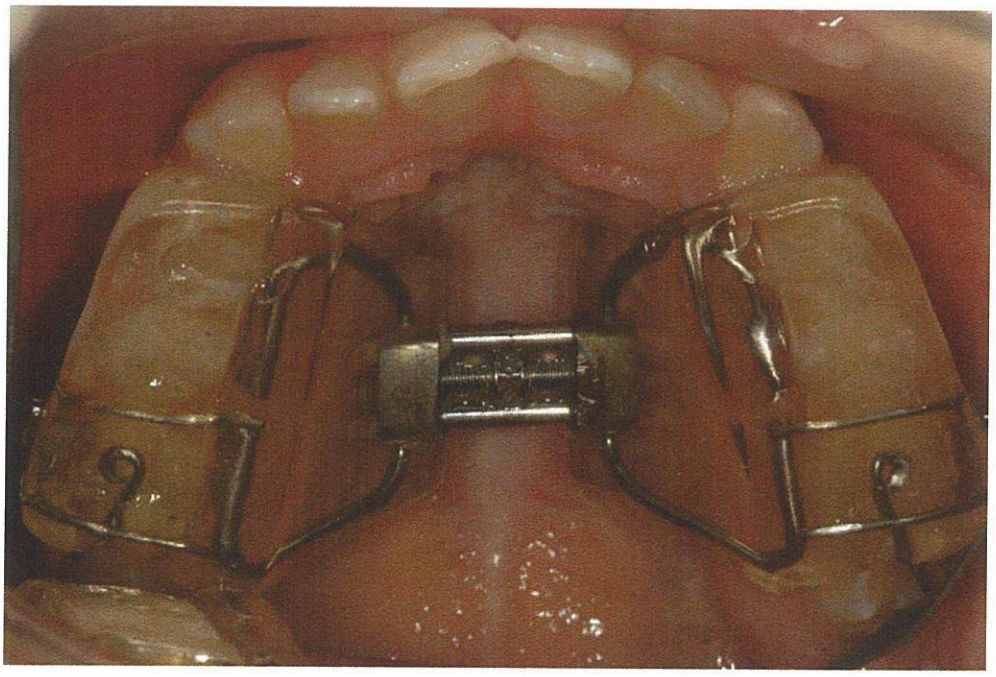


Figure 4 Bondable expander used in this study (Courtesy of Dr. Gary R Wolf)

Table 1 Demographic data of the treatment group and control group

	Control Group (N=43)	Treatment Group (N=43)
	Mean ± SD	Mean ± SD
Age at T1 (yrs)	13.90 ± 1.86	13.82 ± 1.81
Age at T2 (yrs)	16.70 ± 1.83	16.73 ± 1.76
Observing/TX Time (yrs)	2.80 ± 0.49	2.92 ± 0.31
Number of Males	20	20
Number of Females	23	23
Cervical Maturation Score Time One	3.9	4.0
Cervical Maturation Score Time Two	5.0	5.3 *

* Pearson Chi-squre test P value 0.033

Table 2 Clinical information for the treated group (N=43)

	Mean	Minimum	Maximum
Bonded expander activation time (months)	3.0±0.9	0.3	6.4
Bonded expander stabilization time (months)	4.1±1.0	1.4	7.1
Total Time of bonded expander in place (months)	7.1±1.3	3.3	9.9
Class III elastics(months)	4.9±1.2	2.6	7.4
Amount of expansion(mm)	9.3±1.5	4.5	13.0

Table 3 Comparison of angular measurements for control and treatment samples at time one and time two

Angular measurements (degree)	Time One		Time Two	
	Control Group (N=43)	Treatment Group (N=43)	Control Group (N=43)	Treatment Group (N=43)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD
NSBa	132.0 ± 5.7	129.5 ± 4.9 *	131.8 ± 5.6	129.3 ± 5.2 *
SNA	79.6 ± 3.8	79.7 ± 4.0	79.7 ± 3.6	80.3 ± 4.2
SNB	78.2 ± 4.1	79.9 ± 3.6 *	79.0 ± 4.2	79.7 ± 3.7
ANB	1.3 ± 2.5	-.2 ± 1.4 ***	.7 ± 2.9	.6 ± 1.6
Ar_Go_Gn	130.2 ± 5.3	132.3 ± 4.6	130.2 ± 5.6	131.2 ± 5.1
SN_SPg	65.6 ± 3.9	65.2 ± 4.1	65.0 ± 3.8	65.8 ± 4.0
SN_MP	36.7 ± 5.0	37.9 ± 5.2	36.3 ± 5.6	38.0 ± 5.4
SN_PP	9.0 ± 4.0	8.0 ± 2.6	9.1 ± 4.0	7.9 ± 3.2
SN_OP	17.1 ± 4.4	16.9 ± 4.1	16.3 ± 5.1	15.4 ± 5.2
SN_U1	102.6 ± 8.3	104.6 ± 7.1	104.3 ± 7.4	106.1 ± 7.3
U1_L1	132.6 ± 8.3	134.0 ± 8.3	132.5 ± 8.6	134.8 ±10.3
IMPA	86.7 ± 7.3	82.5 ± 6.3 **	86.1 ± 7.7	81.1 ± 8.0 **

* P value < 0.05 ** P<0.01 *** P<0.001

Table 4 Comparison of linear measurements for control and treatment samples at Time One and Time Two

Linear Measurements (mm)	Time One		Time Two	
	Control Group (N=43)	Treatment Group (N=43)	Control Group (N=43)	Treatment Group (N=43)
	Mean±SD	Mean±SD	Mean±SD	Mean±SD
Ar_A	78.75 ± 4.47	79.04 ± 4.77	80.66 ± 4.35	81.35 ± 5.08
Ar_ANS	82.92 ± 4.56	83.67 ± 5.13	84.81 ± 4.68	86.01 ± 5.10
Ar_Gn	101.10 ± 5.69	105.57 ± 5.54 ***	105.35 ± 6.38	110.40 ± 6.34 ***
Ar_Pg	99.30 ± 5.51	103.98 ± 5.38 ***	103.43 ± 6.27	109.11 ± 6.68 ***
Ar_Go	39.76 ± 3.61	41.78 ± 5.34 *	42.53 ± 3.64	45.03 ± 5.38 *
Go_Pg	71.66 ± 4.58	73.43 ± 4.29	74.24 ± 5.36	76.34 ± 4.51
Ar_SN	18.14 ± 3.78	17.08 ± 3.24	18.11 ± 3.23	17.56 ± 3.18
Ar_PTM	31.89 ± 2.63	32.78 ± 5.54	32.60 ± 2.43	32.60 ± 3.26
Ar_Gn_Ar_A_Diff	22.36 ± 3.92	26.53 ± 3.14 ***	24.69 ± 4.62	29.04 ± 4.12 ***
Wits	-1.80 ± 3.20	-4.61 ± 2.01 ***	-2.49 ± 4.08	-2.80 ± 1.99
N_ANS	49.14 ± 3.19	50.29 ± 2.95	50.50 ± 3.66	52.14 ± 3.06 *
ANS_Me	62.28 ± 4.08	65.20 ± 5.10 **	64.51 ± 4.15	69.25 ± 5.37 ***

N_Me	110.43 ± 5.80	114.58 ± 6.64 **	114.17 ± 6.52	120.33 ± 6.70 ***
S_Go	67.67 ± 4.95	70.18 ± 6.24 *	70.79 ± 5.19	74.28 ± 6.25 **
PFH_AFH_Ratio	.61 ± .04	.61 ± .04	.62 ± 0.05	.62 ± 0.04
L1_APg	1.69 ± 2.07	2.31 ± 2.15	2.21 ± 1.97	1.43 ± 2.17
OJ	2.22 ± 1.74	1.11 ± 1.14 ***	1.83 ± 1.90	1.62 ± 0.78
OB	2.28 ± 1.86	.76 ± 1.20 ***	1.92 ± 2.10	1.72 ± 0.76
Molar_relationship	-.91 ± 1.90	-3.23 ± 1.84 ***	-1.52 ± 2.17	-.94 ± 1.37

* P value < 0.05 ** P<0.01 *** P<0.001

Table 5 Paired T-tests results for selected linear and angular measures of clinical importance (N=43)

Measurements	Control Group (C2-C1)	Treatment Group (T2-T1)	P value	Treatment effect
	Mean ± SD	Mean ± SD		Mean ± SD
ANB(°)	-0.6 ± 0.9	0.9 ± 1.1	.000 ***	1.5 ± 1.3
Wits(mm)	-0.69 ± 1.39	1.82 ± 1.75	.000 ***	2.50 ± 2.45
Molar_relationship(mm)	-0.61 ± 1.62	2.23 ± 1.44	.000 ***	2.84 ± 2.14
Ar_A(mm)	1.91 ± 1.73	2.31 ± 1.91	.181	0.40 ± 1.94
Ar_Pg(mm)	4.13 ± 3.30	5.12 ± 3.58	.084	0.99 ± 3.69
Ar_Gn(mm)	4.25 ± 3.32	4.83 ± 3.67	.283	0.58 ± 3.48
SN_MP(°)	-0.4 ± 1.6	0.2 ± 1.9	.186	0.6 ± 2.7
ANS_Me(mm)	2.23 ± 2.18	4.04 ± 2.92	.000 ***	1.82 ± 2.83
N_Me(mm)	3.74 ± 3.47	5.75 ± 3.89	.000 ***	2.00 ± 3.46
S_Go (mm)	3.12 ± 2.53	4.10 ± 2.75	.019 *	0.98 ± 2.62
SN_U1(°)	1.6 ± 4.0	1.4 ± 7.9	.905	-0.2 ±10.0
IMPA(°)	-0.5 ± 3.1	-1.4 ± 7.6	.543	-0.8 ± 8.7

* P<0.05 ** P<0.01 *** P< 0.001 † Treatment effect=(T2-T1)-(C2-C1)

Table 6 Paired T-test results for the measurements made on the overall and regional superimpositions (mm)

N=43	Control Group (C2-C1)	Treatment Group (T2-T1)	P value	Treatment Effect (T2-T1)- (C2-C1)
	Mean ± SD	Mean ± SD		Mean ± SD
Overall Superimposition				
A point horizontal	1.44 ± 1.26	2.06 ± 1.36	0.008 **	0.63 ± 1.48
ANS vertical	1.16 ± 1.59	1.68 ± 1.52	0.091	0.53 ± 1.99
PNS vertical	1.18 ± 1.25	1.88 ± 1.31	0.001***	0.70 ± 1.28
Pg horizontal	3.15 ± 2.52	2.92 ± 2.75	0.655	-0.23 ± 3.36
B horizontal	2.69 ± 2.32	1.42 ±2.16	0.008 **	-1.27 ± 2.98
Maxillary Superimposition				
Upper 1 horizontal	.94 ± 0.81	1.04 ± 1.39	0.600	0.10 ± 1.29

Upper 1 vertical	1.14 ± 1.12	1.76 ± 1.83	0.072	0.62 ± 2.21
Upper 6 horizontal	1.59 ± 1.04	2.84 ± 2.30	0.001***	1.24 ± 2.32
Upper 6 vertical	1.67 ± 1.16	2.26 ± 1.62	0.023 *	0.60 ± 1.65
Mandibular				
Superimposition				
Articulare	5.06 ± 3.67	5.35 ± 3.87	0.614	0.29 ± 3.69
Lower 1 horizontal	.12 ± 0.76	-1.30 ± 2.44	0.001 ***	-1.42 ± 2.65
Lower 1 vertical	-1.36 ± 1.43	-2.48 ± 2.86	0.030 *	-1.12 ± 3.27
Lower 6 horizontal	.65 ± 1.03	-.03 ± 1.09	0.004 **	-0.68 ± 1.47
Lower 6 vertical	-1.26 ± 1.60	-1.96 ± 2.50	0.126	-0.70 ± 2.96

* P value < 0.05 ** P<0.01 *** P<0.001

APPENDIX 1 IRB APPROVAL

Case Western Reserve University
Institutional Review Board

NOTICE OF EXEMPTION (#4)

Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects.

This protocol is exempt under the #4 category because this involves existing retrospective de-identified data. Prospective data are NOT included in this exemption. De-identified pre-existing data to be collected on 02/04/2009 and after are NOT covered by this exemption.

PLEASE NOTE THAT THIS ONLY APPLIES TO EXISTING DATA.

THE RI MUST ENSURE DATA REMAIN COMPLETELY DE-IDENTIFIED.

If you wish to change the protocol in any way, you must an addendum request PRIOR to implementing any protocol change.

Responsible Investigator: Gary Wolf

Department: Dental Orthodontics

IRB Protocol Number: 20090106

Title: Skeletal and Dental Effects of Bonded Rapid Maxillary Expansion Followed by Fixed Appliance and Elastics on Skeletal Class III Patients with Permanent Dentition

Co-Investigator: Xingzhong Zhang

Exemption Date: February 3, 2009

The Institutional Review Board (IRB) has deemed the above protocol EXEMPT under 45 Code of Federal Regulations (CFR) part 46.101(b)(4). The IRB will not conduct subsequent reviews of this protocol.

Any changes to the protocol that put it under the purview of the IRB would require a formal application to, and approval of, the IRB prior to implementation of the change IRB applications are available at the CWRU IRB Pages, or from the Office of Research Compliance (ORC) at Sears Library Building, #657.

APPENDIX 2 ROW DATA

Table 7 Supplemental demographic information of the patients included in the treatment group

ID	DOB	Gender	Angle Classification	TG at T1			TG at T2		
				T1	Film/Digital	T1Age	T2	Film/Digital	T2Age
1	10/04/1991	M	III(I)	11/26/2003	F	12.15	08/21/2006	D	14.88
2	07/24/1984	M	III	12/29/1997	F	13.43	10/10/2000	F	16.21
3	05/11/1983	M	III	12/03/1997	F	14.57	11/20/2000	F	17.53
4	07/14/1992	M	III	07/12/2005	D	12.99	11/04/2008	D	16.31
5	12/12/1984	F	III	02/15/1999	F	14.18	02/01/2002	F	17.14
6	03/11/1976	F	III	11/10/1994	F	18.67	06/17/1996	F	20.27
11	03/06/1986	F	III	10/30/1997	F	11.65	10/02/2000	F	14.58
12	08/05/1987	F	III	4/19/1999	F	11.70	4/23/2002	F	14.72
13	05/22/1986	M	III	01/26/1999	F	12.68	02/20/2002	F	15.75
14	08/14/1986	M	III	03/02/1999	F	12.55	01/09/2002	F	15.41
15	11/13/1980	F	III	09/04/1996	F	15.81	10/12/1999	F	18.91
16	11/06/1990	F	III	04/29/2003	F	12.48	08/15/2006	D	15.77
17	12/20/1984	M	III	11/14/2000	F	15.90	08/25/2003	F	18.68
18	09/29/1981	F	III	09/02/1999	F	17.92	09/10/2002	F	20.95
19	07/02/1987	M	III	11/20/2001	F	14.39	12/22/2004	D	17.48
20	1/14/1993	F	III	2/28/2006	D	13.12	10/27/2008	D	15.78
25	07/26/1983	M	III	08/17/1999	F	16.06	05/01/2002	F	18.77
26	08/03/1984	M	III	1/4/1999	F	14.42	12/17/2001	F	17.37
27	12/17/1991	M	III	2/20/2006	D	14.18	12/22/2008	D	17.02

28	07/23/1987	F	III	01/30/2002	F	14.52	04/06/2005	D	17.71
29	10/26/1988	F	III	11/18/2002	F	14.06	09/25/2005	D	16.91
31	01/29/1980	M	III	3/23/1998	F	18.15	4/9/2001	F	21.19
32	12/27/1990	F	III	09/17/2003	F	12.72	03/15/2006	D	15.21
33	08/20/1985	M	III	5/29/1998	F	12.77	6/19/2001	F	15.83
34	03/21/1988	M	III	07/02/2003	F	15.28	03/01/2006	D	17.94
35	12/13/1990	F	III(I)	08/16/2005	D	14.67	06/26/2008	D	17.54
38	04/06/1991	F	III	1/2/2003	F	11.74	11/7/2005	D	14.59
39	08/04/1986	M	III	3/16/1999	F	12.61	01/30/2002	F	15.49
40	01/27/1989	F	III	1/25/2000	F	10.99	2/5/2003	F	14.02
41	08/19/1991	F	III	08/02/2005	D	13.95	07/08/2008	D	16.89
45	10/06/1989	M	III	06/18/2002	F	12.70	08/23/2005	D	15.88
46	06/25/1991	F	III	05/11/2005	D	13.88	07/29/2008	D	17.10
47	05/15/1983	F	III	6/30/1998	F	15.13	3/27/2001	F	17.87
49	04/15/1983	F	III	12/29/1995	F	12.71	10/12/1998	F	15.49
50	12/08/1987	F	Open bite III	5/24/2000	F	12.46	2/24/2004	F	16.21
52	11/24/1981	M	III	12/18/1995	F	14.06	9/13/1998	F	16.80
53	09/13/1986	M	III	2/14/2000	F	13.42	2/4/2003	F	16.39
54	07/06/1994	F	III	08/24/2005	D	11.13	02/27/2008	D	13.65
56	06/16/1994	F	III	04/27/2006	D	11.86	03/03/2009	D	14.71
57	07/21/1994	M	III	07/12/2006	D	11.98	05/19/2009	D	14.83
58	04/03/1992	F	III	06/29/2006	D	14.24	05/18/2009	D	17.12
59	12/12/1991	F	III	03/13/2006	D	14.25	05/28/2009	D	17.46
60	02/07/90	M	III	01/10/2006	D	15.92	04/20/2009	D	19.20

Table 8 Matched untreated subjects from the Bolton-Brush Growth Study

ID	ID#	Bolton_ID	Angle Classification	Gender	DOB	T1Age	T2Age	ML_C1	ML_C2
61	C1	B0277	I	M	1/5/1918	12.04	15.05		86.1
62	C2	B0482	I	M	5/7/1916	13.11	15.11	87	90.9
63	C3	B2414	III	M	11/3/1916	15.06	18.06		
64	C4	B0522	III	M	3/5/1917	13.02	16.02	mi	87.8
65	C5	B2480	I	F	1/27/1931	14.05	17.00	89.1	91.1
66	C6	B1382	I	F	2/22/1928	18.34	20.28	88.5	87.2
71	C11	B1306	III	F	2/7/1919	12.01	15.03	85	82.8
72	C12	B0224	III	F	11/28/1917	12.05	15.06	mi	85.4
73	C13	B2671	I	M	11/18/1916	13.03	15.08	89.8	
74	C14	B0464	III	M	7/26/1917	12.10	15.10	mi	89.7
75	C15	B2565	I	F	2/9/1917	16.02	19.03	90.4	93.1
76	C16	B3328	III	F	4/12/1917	13.02	16.01		
77	C17	B0403	III	M	3/8/1914	16.02	18.02	mi	90
78	C18	B1047	III	F	1/28/1917	18.03	21.08	89.2	86.4
79	C19	B0288	I	M	6/3/1916	14.11	17.10		
80	C20	B1101	I	F	9/29/1924	13.00	16.01	87	84.4
85	C25	B1534	III	M	2/26/1917	15.99	19.10	100.3	100.6
86	C26	B0168	III	M	12/25/1916	14.04	17.04	83	87.7
87	C27	B2603	I	M	9/21/1927	14.00	17.00	mi	89.5
88	C28	B3427	III	F	8/31/1921	14.09	17.10	85.2	94
89	C29	B4317	III	F	1/27/1931	14.04	16.11	mi	mi
91	C31	B0996	I	M	9/20/1927	18.03	21.01		

92	C32	B3484	III	F	10/16/1926	13.00	15.00	91.3	93.5
93	C33	B0137	I	M	11/7/1916	13.05	16.00	23.5?	88.6
94	C34	B4318	I	M	3/18/1931	15.02	18.00		
95	C35	B0223	I	F	4/16/1923	14.65	17.64	80.8	86.9
98	C48	B3254	III	F	7/30/1923	12.02	15.00	84	90.2
99	C39	B3746	I	M	12/28/1939	13.01	16.01	94	94
100	C21	B1249	III	F	4/21/1919	11.09	14.00	87.5	83.7
101	C41	B1432	I	F	4/29/1930	14.02	17.01	82.8	85
105	C45	B2656	III	M	10/15/1929	13.00	16.00	91.6	86.2
106	C46	B1883	III	F	4/3/1930	14.00	17.09	88	84
107	C47	B2479	III	F	1/8/1926	14.99	17.85	86.4	91
109	C49	B2034	I	F	1/2/1928	13.00	16.00	91.6	92.3
110	C50	B0379	I	F	7/21/1917	12.10	16.10	mi	85
112	C52	B0381	I	M	7/15/1926	14.10	17.09	89.2	90
113	C53	B0771	I	M	8/3/1917	13.09	16.09	83	82.9
114	C54	B1378	I	F	5/13/1923	11.11	13.11	87	91.3
116	C56	B2462	III	F	3/18/1932	11.05	14.00	84.10	84.00
117	C57	B2900	III	M	7/11/1924	12.00	14.09	91.70	91.70
118	C58	B1916	I	F	7/24/1931	14.00	17.01	74.00	80.30
119	C59	B1336	I	F	10/5/1916	14.07	17.07	89.50	88.40
120	C60	B2668	I	M	11/10/1922	16.00	19.00	85.30	90.70

Number of Class III subjects 20, Class I subjects 23

Table 9 Randomly selected sample for the reliability test (N=14)

Treated group			Control group			
Case ID	Gender	DOB	Bolton ID			
T3	M	05/11/1983	B0224	C12	F	11/28/1917
T11	F	03/06/1986	B2565	C15	F	08/10/1921
T25	M	07/26/1983	B1101	C20	F	09/29/1924
T32	F	12/27/1990	B1432	C41	F	04/29/1930
T35	F	12/13/1990	B1883	C46	F	04/03/1930
T40	F	01/27/1989	B0379	C50	F	07/21/1917
T41	F	08/19/1991				
T54	F	07/06/1994				

Table 10 Reliability test for the angular measurements at T1 (N=14)

	1st Measurement	2nd Measurement	Paired difference	Correlation	Sig
	Mean ± SD	Mean ± SD	Mean ± SD	(Cronbach's Alpha)	
NSBa	128.59±4.06	128.30±3.80	0.29±1.22	0.976	.000
SNA	81.01±2.78	81.10±2.94	-0.09±0.64	0.987	.000
SNB	79.89±2.31	79.93±2.58	-0.04±0.73	0.977	.000
ANB	1.13±1.86	1.17±1.77	-0.04±0.61	0.971	.000
S_N_Pg	80.88±2.23	80.75±2.28	0.13±0.64	0.979	.000
SN_PP	7.39±2.41	8.06±2.34	-0.68±0.93	0.961	.000
SN_OP	17.62±3.13	17.20±3.56	0.42±1.88	0.914	.000
SN_MP	37.61±3.61	37.84±3.35	-0.24±0.83	0.986	.000
SN_SPg	65.01±2.20	65.13±2.31	-0.12±0.58	0.983	.000
Ar_Go_Gn	132.07±2.92	132.19±2.70	-0.12±1.59	0.913	.000
SN_U1	103.74±5.18	104.36±5.24	-0.61±2.18	0.954	.000
U1_L1	133.99±7.25	133.49±7.20	0.50±2.67	0.965	.000
IMPA	84.39±6.90	84.56±7.12	-0.16±2.30	0.972	.000

Table 11 Reliability test for the linear measurements at T1 (N=14)

	1st Measurement	2nd Measurement	Paired difference	Correlation	Sig
	Mean ± SD	Mean ± SD	Mean ± SD	(Cronbach's Alpha)	
Wits	-3.56±2.22	-2.95±2.99	-0.61±1.61	0.896	.000
SBa	44.03±3.79	44.98±4.00	-0.95±1.51	0.961	.000
SN	66.53±4.48	66.76±4.54	-0.23±0.45	0.997	.000
S_A	58.05±5.26	58.05±5.38	0.00±0.82	0.994	.000
S_U1	58.61±5.63	58.52±5.81	0.09±1.05	0.991	.000
Ar_SN	16.55±3.69	16.69±3.69	-0.14±0.50	0.995	.000
Ar_PTM	31.75±3.53	31.64±3.05	0.10±1.28	0.961	.000
Ar_ANS	85.20±6.77	84.57±6.85	0.63±1.79	0.982	.000
Ar_A	79.95±6.46	80.31±6.54	-0.36±0.72	0.997	.000
Ar_Pg	103.23±6.28	103.22±6.35	0.01±1.26	0.990	.000
Ar_Gn	104.90±6.57	105.6.6125±6.61	-0.35±0.90	0.995	.000
Ar_Gn_Ar_A_Diff	24.95±3.28	24.94±3.48	0.01±0.68	0.990	.000
Ar_Go	41.80±5.52	42.07±5.16	-0.27±1.37	0.983	.000
Go_Pg	73.05±4.97	73.18±4.90	-0.13±0.69	0.995	.000
ANS_SN	50.79±3.22	51.43±3.22	-0.65±0.45	0.995	.000
PNS_SN	44.52±3.87	44.74±3.89	-0.23±0.75	0.991	.000
N_ANS	50.81±3.21	51.50±3.23	-0.69±0.51	0.994	.000

ANS_Me	65.21±4.85	65.01±5.12	0.20±0.84	0.993	.000
N_Me	114.61±6.60	115.45±6.88	-0.83±0.62	0.998	.000
S_Go	70.46±6.92	70.91±6.94	-0.45±1.05	0.994	.000
L1_APg	2.03±1.78	1.96±1.85	0.07±0.53	0.978	.000
OJ	1.24±1.44	1.30±1.59	-0.06±0.31	0.989	.000
OB	1.52±1.62	1.63±1.49	-0.12±0.39	0.984	.000
Molar_relationship	-1.92±1.68	-2.17±1.71	.251±1.77	0.627	.043

Table 12 Reliability test for the angular measurements at T2 (N=14)

	1st Measurement	2nd Measurement	Paired difference	Correlation	Sig
	Mean ± SD	Mean ± SD	Mean ± SD	(Cronbach's Alpha)	
NSBa	128.30±4.24	128.68±4.02	-0.38±1.95	0.941	.000
SNA	81.42±2.96	80.94±2.73	0.48±0.95	0.971	.000
SNB	79.99±2.79	79.47±2.53	0.52±0.62	0.986	.000
ANB	1.43±1.52	1.47±1.64	-0.04±0.66	0.955	.000
S_N_Pg	81.19±2.88	80.72±2.65	0.46±0.61	0.988	.000
SN_PP	7.68±2.97	8.20±2.84	-0.52±0.69	0.986	.000
SN_OP	16.47±4.33	17.43±3.45	-0.96±2.00	0.930	.000
SN_MP	37.84±4.80	38.34±4.70	-0.50±0.83	0.992	.000
SN_SPg	65.58±3.16	65.65±3.05	-0.07±0.75	0.985	.000
Ar_Go_Gn	131.34±3.70	130.96±4.02	0.38±1.19	0.976	.000
SN_U1	105.50±5.61	105.40±5.34	0.10±1.51	0.981	.000
U1_L1	133.92±7.34	133.76±6.86	0.16±2.66	0.964	.000
IMPA	82.69±5.97	83.46±7.04	-0.76±2.77	0.953	.000

Table 13 Reliability test for the linear measurements at T2 (N=14)

	1st Measurement	2nd Measurement	Paired difference	Correlation	Sig
	Mean ± SD	Mean ± SD	Mean ± SD	(Cronbach's Alpha)	
Wits	-2.86±2.13	-2.61±2.15	-0.25±0.84	.960	.000
SBa	44.36±3.48	45.95±3.42	-1.58±1.98	.910	.000
SN	67.74±4.32	67.98±4.19	-0.24±0.54	.996	.000
S_A	59.06±5.25	58.73±5.17	0.33±0.87	.993	.000
S_U1	60.11±5.84	59.54±5.65	0.57±0.82	.995	.000
Ar_SN	16.76±3.68	16.90±3.57	-0.13±0.80	.988	.000
Ar_PTM	32.15±3.25	32.07±3.42	0.09±1.50	.947	.000
Ar_A	81.64±6.01	81.84±6.24	-0.21±1.09	.992	.000
Ar_ANS	86.63±5.61	86.42±6.39	0.21±1.76	.978	.000
Ar_Pg	107.03±5.56	106.70±5.86	0.33±1.10	.991	.000
Ar_Gn	108.99±5.82	109.01±6.08	-0.02±1.31	.988	.000
Ar_Go	44.45±4.84	44.69±4.91	-0.24±1.22	.984	.000
Go_Pg_M2	75.00±4.90	75.27±5.04	-0.26±0.67	.995	.000
ANS_SN	52.52±2.92	53.18±2.72	-0.66±0.73	.983	.000
PNS_SN	45.86±3.88	46.45±3.88	-0.58±0.99	.983	.000
N_ANS	52.59±2.87	53.26±2.68	-.67±0.75	.982	.000
ANS_Me	68.40±4.62	68.53±4.53	-0.13±0.80	.992	.000

N_Me	119.74±5.61	120.64±5.31	-0.90±0.80	.995	.000
S_Go	73.95±6.28	74.30±6.34	-0.35±0.57	.998	.000
Ar_Gn_Ar_A_Diff	27.35±3.64	27.17±3.82	0.18±0.83	.987	.000
L1_APg	1.63±1.39	1.78±1.63	-0.14±0.51	.970	.000
OJ	1.99±0.71	2.05±.054	-0.06±0.33	.928	.000
OB	2.29±1.07	2.42±1.02	-0.13±0.35	.971	.000
Molar_relationship	-.62±1.11	-.72±1.76	0.10±1.29	.762	.007

Table 14 Reliability test for Overall superimposition (N=14)

	1st Measurement	2nd Measurement	Paired difference	Correlation	Sig
	Mean ± SD	Mean ± SD	Mean ± SD	(Cronbach's Alpha)	
Nasion_H	.78±0.64	.53±0.38	0.24±0.53	.658	.032
Nasion_V	.01±0.77	-.13±0.47	0.14±0.75	.452	.156
ANS_H	1.31±1.90	1.69±1.78	-0.39±2.10	.524	.097
ANS_V	1.82±1.58	1.46±1.53	0.36±1.12	.852	.001
A_H	1.33±0.85	1.18±1.26	0.15±1.29	.902	.000
A_V	1.86±2.12	2.56±2.24	-0.70±1.22	.914	.000
PNS_H	.20±1.37	.57±1.13	-0.37±1.34	.573	.069
PNS_V	1.40±1.38	1.80±1.61	-0.40±0.88	.905	.000
B_H	1.10±1.53	.95±1.22	0.15±1.15	.915	.000
B_V	2.85±3.00	2.66±3.20	0.19±2.13	.867	.001
Pg_H	2.02±2.21	2.11±2.06	-0.09±1.52	.904	.000
Pg_V	4.09±4.37	3.94±4.00	0.15±1.86	.948	.000

Table 15 Reliability test for maxillary and mandibular superimposition

	1st Measurement	2nd Measurement	Paired difference	Correlation (Cronbach's Alpha)	Sig
	Mean ± SD	Mean ± SD	Mean ± SD		
Maxillary Superimposition					
U1_H_max	1.04±1.31	.57±1.10	0.48±0.98	.800	.003
U1_V_max	1.97±1.62	2.01±1.46	-0.04±1.00	.882	.000
U6_H_max	2.09±1.86	1.74±1.93	0.36±1.30	.867	.000
U6_V_max	2.35±1.65	1.80±1.39	0.56±0.60	.960	.000
Mandibular Superimposition					
Ar_mand	4.69±3.32	4.67±3.85	0.03±1.31	.966	.000
L1_H_mand	-0.91±1.81	-.78±1.58	-0.13±0.79	.943	.000
L1_V_mand	-2.52±2.27	-2.33±2.02	-0.19±1.02	.941	.000
L6_H_mand	0.28±1.43	0.54±1.48	-0.27±1.15	.814	.002
L6_V_mand	-2.14±2.28	-1.81±1.65	-0.34±1.49	.838	.001

Table 16 Cervical vertebral maturation score at Time One and Two

		Time One		Time Two	
		Control Group	Treatment Group	Control Group	Treatment Group
CVM	2	2 (4.65%)	0(0%)		
	3	17(39.53%)	13 (30.23%)	1 (2.33%)	0 (0%)
	4	10 (23.26%)	17 (39.53%)	14 (32.56%)	4 (9.30%)
	5	12 (27.91%)	13 (30.23%)	13 (30.23%)	21(48.84%)
	6	2 (4.65%)	0 (0%)	15 (34.88)	18 (41.86%)
Total		43	43	43	43

Table 17 Variables entered/removed for Regression analysis

Model	Variables Entered	Variables Removed	Method
1	BxP_Total_Time, CVM_T1, Exp_turns, Gender, Total_Tx_Time, Class_III_Elas_Time[a]	.	Enter

a. All requested variables entered.

Table 18 Regression Model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.580[a]	.336	.226	1.20006

a. Predictors: (Constant), BxP_Total_Time, CVM_T1, Exp_turns, Gender, Total_Tx_Time, Class_III_Elas_Time

Table 19 Information of the whole Model (ANOVA[b])

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	26.275	6	4.379	3.041	.016[a]
	Residual	51.845	36	1.440		
	Total	78.120	42			

b. Dependent Variable: A_H_overall_Cor_TG

Table 20 Coefficients[a] for the Regression analysis

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	7.351	2.267		3.243	.003
	CVM_T1	-.521	.249	-.301	-2.091	.044
	Gender	-.643	.385	-.238	-1.671	.103
	Exp_turns	.000	.032	.001	.008	.994
	Class_III_Elas_Time	.021	.216	.018	.096	.924
	Total_Tx_Time	-1.511	.641	-.344	-2.356	.024
	BxP_Total_Time	.202	.198	.192	1.020	.314

a. Dependent Variable: A_H_overall_Cor_TG

b. Predictors: (Constant), BxP_Total_Time, CVM_T1, Exp_turns, Gender, Total_Tx_Time, Class_III_Elas_Time

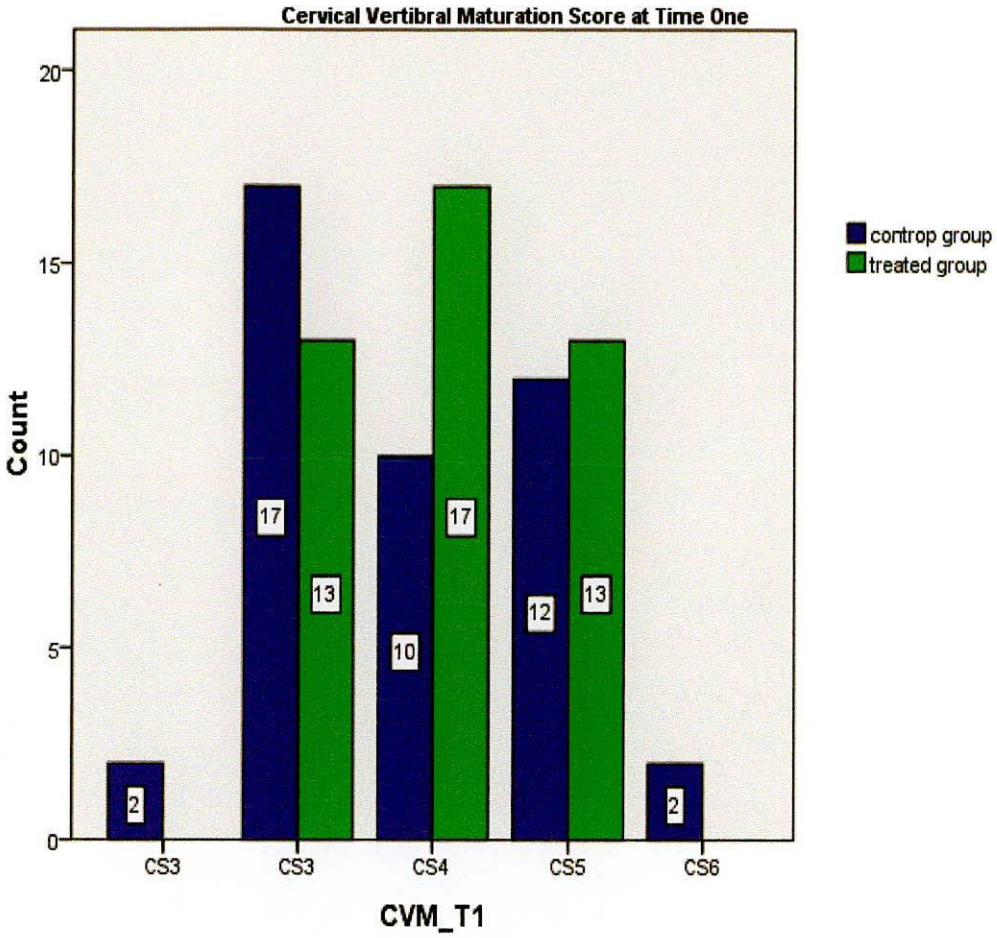


Figure 5 Cervical vertebral maturation score at Time One

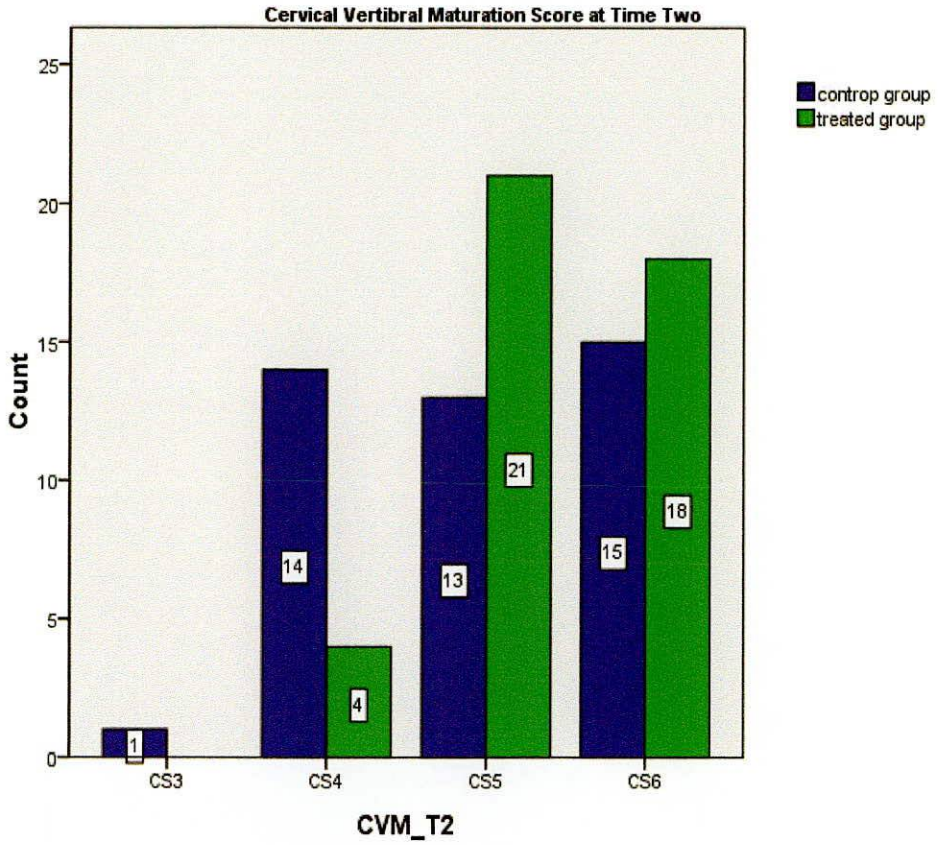


Figure 6 Cervical vertebral maturation score at Time Two

GLOSSARY

Note: The following glossary was modified from the theses of Wenger and Mozayeni-Azar (1998; 2003)

1. **The landmarks used for the cephalometric analysis** (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.

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

LIR: 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 midsagittal plane.

Pg: 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.

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

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

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 this study.

DESCRIPTIVE MEASUREMENTS

MAXILLARY SKELETAL MEASUREMENTS

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 MEASUREMENTS

SNB. The angular measurement between the Sella-Nasion and Nasion-B point.

SN to Pogonion. The angular measrrement 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 RELATIONSHIP

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 MEASUREMENTS

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 (according to the definition from American Board of Orthodontics).

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).

MAXILLARY DENTAL MEASUREMENTS

Upper 1 to SN. The posterior inferior angle formed between the intersection of long axis of the maxillary central incisor and Sella-Nasion.

MANDIBULAR DENTAL

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

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

Overjet. 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.

3. Superimposition Measurements

OVERALL

Nasion horizontal. The change in the linear position of Nasion between Time one and Time two, measured parallel to the average occlusal plane.

ANS horizontal. The change in the linear position of

anterior nasal spine between Time one and Time two, measured parallel to the average occlusal plane.

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

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

A point vertical. The change in the linear position of A-point between Time one and Time two, measured perpendicular to the average occlusal plane.

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

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

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

B point vertical. The change in the linear position of B point between Time one and Time two, measured perpendicular to the average occlusal plane

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

Pogonion vertical. The change in the linear position of Pogonion between Time one and Time two, measured perpendicular to the average occlusal plane.

MAXILLA

ANS horizontal. The change in the linear position of anterior nasal spine between Time one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, 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 one and Time two, measured parallel to the average occlusal plane from the mandibular superimposition.

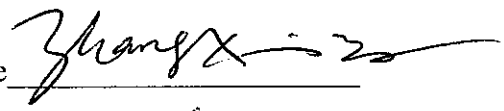
Lower 6 vertical. The change in the linear position of the mesiobuccal groove of the mandibular first molar between Time one and Time two, measured perpendicular to the average occlusal plane from the mandibular superimposition.

Articulare. The change in the linear position of Articulare between Time one and Time two, measured parallel to the average axis of the condyle.

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