STABILITY OF MINI-SCREW ASSISTED ORTHOPEDIC CORRECTION OF

GROWING RETROGNATHIC HYPERDIVERGENT PATIENTS

A Thesis

by

ALEC J. RICE

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Chair of Committee,	Peter Buschang
Committee Members,	Phillip Campbell
	Reginald Taylor
	Byron Benson
Head of Department,	Larry Bellinger

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ABSTRACT

Purpose: To determine if non-surgical posterior dental intrusion produces stable orthodontic and orthopedic correction in growing retrognathic hyperdivergent patients. The primary aim of this study was to compare the vertical dental and skeletal changes that occurred during treatment and after treatment to untreated control subjects. Methods: The sample included of 14 subjects (5 males and 9 females), who were 13.4 ± 0.7 years pre-treatment (T1), 16.8 ± 1.3 years post-treatment (T2), and 20.4 ± 0.9 years at long-term recall (T3). During the initial orthopedic phase, 150 gram Niti coil springs were attached to two palatal mini-screw implants (MSI's) for maxillary intrusion, and two buccal mandibular MSI's were used for posterior mandibular vertical control. Full orthodontic therapy was initiated to correct the malocclusion during the orthodontic phase. Patients were recalled a minimum of 1 year post-treatment (mean recall 3.6 ± 1.6 years) for stability records. The subjects were compared to matched untreated controls. Results: During treatment and retention, the maxillary and mandibular molars underwent 2.8 mm and 3.7 mm of relative posterior intrusion, respectively. The maxillary incisor was extruded 2.85 mm during treatment, while the untreated control incisor erupted only 1.25 mm. Orthopedic changes included a reduction in the MPA (3.25°), an increase in SN-Pg (2.4°), an increase in S-N-B (2.1°), and a 5 mm relative reduction in anterior facial height. With the exception of the maxillary incisor (0.6 mm of relative intrusion post-treatment), post-treatment dental and orthopedic changes were not statistically significant between the treated and control subjects. Conclusions: Except for maxillary

incisor position, the substantial dental intrusion and associated orthopedic corrections

that occurred during treatment remained stable post-treatment.

DEDICATION

I would like to dedicate this thesis to my loving family. Their unending love and support have made this journey incredible.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Introduction

Retrognathic hyperdivergent patients are a unique patient population that have been viewed by orthodontists as one of the most challenging demographics to treat due to the complexity of their dental malocclusions and vertical skeletal growth patterns. Many of these patients can develop anterior open bite malocclusions which are often classified as skeletal open bites[1, 2], have weaker than average masticatory musculature [3-5], and experience a variety of esthetic and functional difficulties. Orthodontists are often sought after for services related to the malocclusions associated with this phenotype; however, orthodontic treatment can produce both functional and esthetic dental, skeletal, and soft tissue changes. A variety of orthodontic treatment approaches have been explored throughout the literature for this complex dysmorphology with mixed results and an even greater variability is observed when analyzing the long-term stability for this patient population. The focus of this literature review is to introduce the retrognathic hyperdivergent phenotype, discuss common dysmorphologies typically associated with this population, evaluate previous orthodontic and orthognathic treatment modalities, and analyze the long-term stability associated with various treatment approaches.

Retrognathic Hyperdivergent Characteristics

The retrognathic hyperdivergent (hereafter referred to as RH) patient can greatly benefit from proper orthodontic treatment due to these subjects exhibiting a variety of both functional and esthetic limitations. The prevalence of class II malocclusions has been well documented throughout the literature. Proffit et al. [6] suggested that class II malocclusions are present in approximately 15% of adolescents according to data from the NHANES III study. It has also been documented that approximately 75% of class II's exhibit relative mandibular retrognathism and convex profiles which can be viewed as esthetic limitations [7, 8]. In a study completed by Czarnecki et al[9], 1300 dental professionals were surveyed on the topic of profile attractiveness. The results indicated that convex profiles with retrusive chins were the least favorable while straighter profiles with more prominent chins were the most desirable. In a similar study, Spyropoulos[1] found that lay people and dental professionals alike viewed altering a retrusive profile to a straighter, less retrusive profile increased facial attractiveness.

In addition to antero-posterior esthetic limitations, excessive vertical dysplasia is also common in RH patients including mandibular face height (measured from lower lip to menton) which has been documented by Naini et al to be perceived as unattractive by lay people and orthodontists[10]. These previous studies signify that the RH phenotype has legitimate esthetic concerns; however, this population also demonstrates important functional limitations. Weaker than normal bite forces, smaller masticatory muscles,

and the potential for respiratory impairments have all been linked to this HR phenotype [11-16]. These limitations can lead to additional compensations on both a dentoalveolar and skeletal level.

Skeletal and Dental Compensations

Retrognathic hyperdivergent patients have complex three-dimensional skeletal, soft tissue, and dental compensations. This unique phenotype has been documented as having consistent differences from the "normal" class I population [17]. It is important for orthodontists to understand the underlying characteristics of these patients in order to properly treat the diagnostic problems associated with these patients. These differences can be observed in both the maxilla and the mandible.

Maxillary components of retrognathic hyperdivergent patients tend to have more compensations on the dentoalveolar basis rather than the skeletal basis [18]. Many studies have compared hyperdivergent patients to normal controls and no significant differences have been observed for the maxillary skeletal measurements of palatal plane angle [3, 19, 20], anterior maxillary height[21-23], or posterior maxillary height[22]. A few studies have found deficits in the skeletal measurements of SNA, maxillary depth, and anterior maxillary height [19, 20, 24, 25]; however, the majority of studies agree that the primary maxillary differences for hyperdivergent patients compared to normal controls is the increased anterior and posterior dentoalveolar height [3, 21, 24, 26-28].

Based on these findings, it can be concluded that a primary maxillary compensation for hyperdivergence includes excessive vertical displacement of both the anterior and posterior maxillary dentition.

Compared to the maxilla, the mandible of retrognathic hyperdivergent patients exhibits a greater number and higher significance of differences when compared to normal control subjects. Various mandibular differences have been consistently documented including increases in the mandibular plane angle[3, 19, 24, 27], gonial angle[3, 19, 22, 28, 29], and anterior face height [19, 21, 28, 30]. Total posterior face height has been documented as normal for hyperdivergent patients, but ramus length is smaller than average[28, 30]. One of the most common differences for hyperdivergence includes the narrowing of the transverse dimension in both the maxilla and mandible [21, 31-36]. Typically, treatment for these patients involves maxillary expansion among other treatment modalities due to the narrowing of the transverse dimension. Now that the complexity of the RH phenotype has been addressed, it is important to understand the growth and development of these patients in order to dictate the treatment intervention best suited for this patient population.

Retrognathic Hyperdivergent Etiology

Comprehension of craniofacial growth is essential for orthodontists to truly understand the hyperdivergent retrognathic phenotype. The true etiology of most craniofacial

phenotypes can be classified as multi-factorial with a variety of genetic influences as well as environmental or functional adaptations. A multitude of genes have been linked to craniofacial traits. Phenotypic variations can be related to the amount of direct genetic control over a particular trait. The greater the direct genetic control over a trait results in less phenotypic variations and less direct genetic control provides a more diverse phenotype.

In addition to genetic predispositions for craniofacial phenotypes, environmental conditions can also play a large role in craniofacial growth. Jacob & Buschang [37] listed three broad environmental factors that have been associated with changes in malocclusion over time; oral habits, weakened masticatory muscle strength, and airway obstruction or interferences with normal breathing. The RH phenotype demonstrates morphological changes that are consistent with the environmental adaptations to the categories of weakened masticatory musculature and breathing interferences. Oral habits are thought to have less of a direct influence on this phenotype, but a combination of environmental influences is presumed to impact the growth and development of this patient population. The morphological changes for this phenotype can be attributed in part to growth adaptations, which is important to the orthodontic community. Buschang, Carrillo, and Rossouw [38] theorized that proper early intervention of the retrognathic hyperdivergent patient could lead to positive growth changes rather than the expected growth adaptations to these environmental limiting factors.

Early Intervention of Hyperdivergent Retrognathic Patients

It is important for dental professionals and orthodontists to recognize and understand the growth pattern of retrognathic hyperdivergent patients early in childhood to ensure a greater number of treatment options for these subjects including less invasive non-surgical options. Many documented orthodontic techniques for treatment of these patients may not be possible or as effective once the subject has completed skeletal growth of the maxillo-mandibular complex, thus early intervention of growing patients can be beneficial. The growth patterns of most hyperdivergent patients are established around 4 years of age, making diagnosis of hyperdivergence easily recognizable for dental professionals by the age of 6 [39, 40]. Bishara and Jakobsen [41] documented that 82% of 5 year old patients classified as having long faces also had a long face classification at 25 years of age. Additional studies have added that steeper mandibular plane angles between the ages of 6-15 were found to have high mandibular planes at 15 years of age [39]. Approximately 64% of hyperdivergent 6 year olds remained hyperdivergent by the age of 15 with 25% documented as worsening in the degree of hyperdivergence over time [39]. As children age, skeletal patterns become more predictable. According to Jacob and Buschang [37], approximately 75% of 10 year old children classified as hyperdivergent, within normal limits, or hypodivergent maintained the same skeletal divergence pattern through the age of 15 years old. These studies provide evidence that the RH phenotype can be diagnosed early and rarely self-corrects with time.

Mandibular retrognathism is not as predictable in young children as the vertical skeletal divergence. Limited mandibular morphologic relationships have been found between retrognathic adolescent patients and the same patients in early childhood; however, a relationship for hyperdivergence was more predictable than retrognathism [40]. Unlike mandibular retrognathism which can become less severe with growth and age, little improvement of hyperdivergence can be expected in untreated populations. Hyperdivergent subjects have been shown to decrease their mandibular plane angle by an average of only 0.3 degrees between the ages of 6-15 which is significantly less of a change compared to the average decreases of 2.5 and 4.0 degrees for normal and hypodivergent subjects respectively [37]. Similar findings have been observed when comparing the SNB measurement changes from 6 years old to 15 years old. Hyperdivergent subjects demonstrated a minimal increase of 0.2 degrees in the SNB measurement while average subjects increased SNB by 1.2 degrees and hypodivergent subjects increased by 1.4 degrees [37]. The limited change of hyperdivergent tendencies in untreated children discourages the assumption that the skeletal pattern will digress toward the average population with age, thus treatment of these patients during their active growth years can be beneficial if skeletal or orthopedic changes can be obtained.

Treatment Options for Retrognathic Hyperdivergent Phenotypes

Many attempts and treatment modalities have been utilized throughout the literature to treat the hyperdivergent retrognathic phenotype. A common theme among the literature for treatment of these patients is the need for antero-posterior chin advancement to reduce facial convexity and the need for vertical control due to the predilection for vertical hyperplasia[42]. The extent of the vertical hyperplasia varies from patient to patient; however, many of these vertically hyperplastic retrognathic patients exhibit anterior open bites, sometimes referred to as skeletal open bite malocclusions[43, 44]. According to Proffit et al. [6], only 48% of the American population has an ideal overbite relationship documented as 0-2mm of anterior incisal overbite. In addition, 3.3% of the same population is classified as having a moderate to severe open-bite malocclusion [6]. Orthodontic treatment of retrognathic hyperdivergent patients often involves treatment of a multitude of common problems associated with this phenotype as previously discussed including vertical, anterior-posterior, and transverse discrepancies.

Evidence has been provided that supports the notion that a lack of vertical control during orthodontic treatment could increase the mandibular plane angle, thus exacerbating the negative vertical growth pattern of the retrognathic hyperdivergent patient [45-48]. Since traditional orthodontic treatment can lead to backward rotation of the mandible [49], an unwanted result for the RH population, it can be concluded that vertical control

is the primary concern for orthodontic treatment of the retrognathic hyperdivergent phenotype[50-53].

Extraoral and Intraoral Appliances

A variety of both extraoral and intraoral appliances have been used as common treatment techniques for this patient population. Extraoral appliances have included high-pull head gear, vertical-pull chin cup, and acrylic splints with a high-pull head gear component. Additional removable appliances such as active vertical correctors, posterior bite blocks, and magnetic splints have also been used for treating this patient population; however, many of these appliances require strict patient compliance for adequate treatment results. The results of these appliances have documented some success with dental correction of malocclusions, but minimal positive change was noted from a soft tissue perspective [54-57]. The most common extraoral approach, the high-pull head gear, does exhibit a degree of vertical control [58]; however, mandibular forward rotation is not observed, primarily due to compensations from the mandibular dentition. As the maxillary molars are held vertically by a compliant head gear patient, the mandibular molars compensate by super-erupting; thus, negating any forward rotation of the mandible or added chin projection[48, 58].

In an effort to minimize the need for bulky extraoral appliances, other means of intraoral orthodontic techniques were explored for the RH patient. Many of these treatments rely

on inter-arch elastics for much of the dentoalveolar changes, but these movements can often be detrimental to the vertical pattern of this particular patient population. A combination of anterior vertical elastics (maxillary anterior dentition to mandibular anterior dentition) and class II vector elastics (maxillary anterior dentition to mandibular posterior dentition) have frequently been used to increase the incisal overbite relationship and eliminate any presence of anterior open bites. However, the vector for these dental movements frequently results in unwanted backwards rotation of the mandible and opening of the mandibular plane angle. In addition, incisor extrusion has historically been documented as an extremely unstable orthodontic movement which will be discussed in greater detail later in this literature review. [24]

Posterior Vertical Control

Due to the instability of vertically displacing the anterior incisors and the patient compliance issues associated with bulky extraoral appliances, orthodontic focus shifted to controlling the vertical component of the posterior dentition. Ideal orthodontic treatment should address not only dental correction, but orthodontists also have the ability to address functional and esthetic soft tissue goals as well. Bjork and Skieller [59] were the first to relate mandibular rotation to chin position and condylar growth. They discovered that both the amount and direction of condylar growth were strongly correlated with rotation. Their research demonstrated that forward mandibular rotation (counter clockwise if subject is facing to the right in profile) produced a greater chin

projection and a decrease in gonial angle. In contrast, traditional orthodontic treatment

approaches in studies by Phan et al [45] and Mair & Hunter [47] both indicated that class

II retrognathic patients demonstrated a tendency for "backward rotation" or clockwise

mandibular rotation during treatment. The class II retrognathic patients in these studies

had treatment that resulted in a greater inferior displacement of pogonion, statistically

significant increases in the mandibular plane angle, excess eruption of the mandibular

molars, and added profile convexity which all lead to a negative effect on the soft and

hard tissue profiles of the retrognathic hyperdivergent patient. The theory behind

vertical control of the posterior dentition allows for a more favorable soft tissue change

as the mandible is allowed to rotate in a counterclockwise manner, increasing chin

projection and decreasing the mandibular plane angle instead of the conventional

clockwise or "backward" rotation which adds to the vertically retrognathic problems

associated with this patient population [56, 60].

Orthognathic Surgery

One common method for achieving maximum vertical and anterior-posterior control for

this patient population and achieving desired forward mandibular rotation is

orthognathic surgery. Surgical correction for this patient population requires a high

degree of complexity for the oral surgeon, orthodontist, and patient alike. The typical

orthognathic surgical plan for this patient population varies patient to patient; however,

RH surgical treatment plans commonly involve multi-jaw, multi-piece procedures

sometimes including maxillary LeFort osteotomies with maxillary expansion, posterior maxillary impaction and/or anterior maxillary down-graft creating clockwise rotation of the maxilla, mandibular advancement by way of bilateral sagittal split osteotomies, and mandibular counterclockwise rotation to reduce the mandibular plane divergence and increase chin projection potentially with an added esthetic genioplasty procedure [61-65]. Orthognathic surgical correction has produced excellent functional and esthetic results for the retrognathic hyperdivergent phenotype; however, many patients decline orthognathic surgical treatments potentially due to the associated morbidity/risks, invasiveness, discomfort, and/or financial limitations [66]. An added drawback to surgical correction for these patients includes the timing of treatment. Surgical treatment is routinely delayed until full skeletal maturity has been achieved, thus delaying full orthodontic and orthognathic treatment until the late teenage years for many of the hyperdivergent retrognathic patients [66]. Surgical options are commonly not feasible or unfavorable to many patients; therefore, acceptable alternative techniques that are less invasive and more cost effective are highly desired.

Skeletal Anchorage Techniques

With continuing advancements in orthodontic technology and mechanics, successful alternative treatment approaches have been developing. One of the most innovative recent developments in the field of orthodontics has been the introduction of skeletal anchorage by means of mini-screw implants (MSI's) or titanium mini-plates. These

forms of skeletal anchorage have been well accepted by the orthodontic community and have been shown to be clinically stable throughout treatment [67, 68]. Mini-screw implants have been a well documented form of anchorage throughout the literature, and many studies have used the MSI's for successful intrusion of teeth and vertical control [69-71]. These concepts have been applied in a number of case reports and clinical studies to actively intrude posterior teeth in hyperdivergent patients resulting in the added benefit of forward mandibular rotation and profile improvement [72-74].

An additional benefit of mini-screw implant anchorage compared to other extra-oral forms of anchorage or intra-oral elastics is the concept that MSI's are not dependent on patient compliance. Yao et al [75] compared mini-screw implant skeletal anchorage to high-pull head gear extraoral anchorage in hyperdivergent patients. The treatment results indicated that the MSI skeletal anchorage group had a significant intrusive effect on the maxillary molars while maxillary molar eruption was present in the high-pull head gear group. The results also demonstrated a reduction in the mandibular plane angle for the MSI group and an increase in the mandibular plane angle for the head gear group resulting in a negative profile impact. The authors cited greater control with the MSI skeletal anchorage group and the potential for poor patient compliance in the head gear group as a possible explanation for the treatment results. Overall, mini-screw implants have increased in popularity among the field of orthodontics, and a recent trend involves posterior intrusion studies for hyperdivergent patients. The majority of these studies focus on non-growing adult patients and treatment mechanics vary widely

between studies, but one study in particular demonstrated excellent dental and orthopedic results in a growing retrognathic hyperdivergent population.

Two Jaw MSI Based Posterior Intrusion of Growing RH Patients

The primary focus of this current study is based on a successful treatment approach conducted by Buschang, Carrillo, and Rossouw [38] who utilized orthodontic mini-screws to achieve posterior intrusion and mandibular orthopedic correction on growing retrognathic hyperdivergent patients. An important distinction between this study and other similar mini-screw intrusion studies were the factors of growth and two jaw vertical control. Growing patients have an important treatment distinction from non-growing patients for this treatment approach. In order to achieve the treatment effect of molar intrusion and mandibular forward rotation, non-growing adults require active posterior intrusion. In contrast, growing adolescents can have the same mandibular rotation by relatively intruding the posterior dentition (vertically holding the development of the posterior dentition with skeletal anchorage which provides a net intrusive effect and mandibular rotation by limiting normal vertical posterior eruption during treatment) [76]. In order to maximize treatment results and mandibular rotation, the Buschang et al [38] study provided intrusive forces to the maxillary posterior dentition, but also added vertical skeletal anchorage and relative intrusion to the mandibular posterior dentition. The clinical study included 17 (7 male and 10 female) consecutively treated patients with a mean age of 13.2 years old at the initiation of

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treatment (T1). All subjects presented with a class II malocclusion and retrognathia classified as at least 1 standard deviation below age and sex specific SNB measures [77]. The maxillary posterior teeth were treated using a segmental intrusion appliance. After maxillary expansion, 2 mini-screw implants (MSI's) were placed in the posterior palate lateral to the maxillary first molar and immediately loaded with 150gram Niti coil springs attached to the segmental intrusion appliance. Orthodontic brackets and segmental wires were utilized on the maxillary premolars and molars during the intrusive phase with no orthodontic appliances on the anterior canine to canine dentition to limit incisor extrusion. Mini-screw implants were also placed in the mandible located buccally between the mandibular second premolar and first molar. The MSI's were attached to the mandibular first molar orthodontic bracket with a stainless steel ligature to prevent mandibular molar eruption. Vertically holding the mandibular dentition with MSI skeletal anchorage prevented compensatory super-eruption of the mandibular molars during maxillary posterior intrusion; a negative result documented in previous posterior intrusion studies [74, 76, 78]. CBCT radiographs were acquired at treatment initiation (T1) and at the end of the orthopedic phase (T2) for skeletal and dental analysis. By controlling the vertical posterior dimensions of both the maxilla and mandible, the retrognathic hyperdivergent patients demonstrated beneficial dental, skeletal (orthopedic), and soft tissue changes including significant maxillary posterior intrusion of 2.5 ± 1.7mm, reduction in the mandibular plane angle of $2° \pm 1.7°$, and an SNB angle increase of $1.5° \pm 1.5°$. When compared to matched untreated control groups, the results were of even greater relevance. The maxillary molar was intruded

significantly during treatment while the maxillary molar continued to erupt in the control group; therefore, there was a net intrusion effect of nearly 4 mm. Similar results were observed as both the soft and hard tissue profiles became less convex in the treated group but increased in convexity in the untreated control group. All of these changes are indicative of a positive non-surgical skeletal treatment effect for this patient population; however, little is known about the relative stability of this treatment effect on growing individuals. With these successful functional and esthetic results achieved, the next discussion should include the long term stability of these findings. Are these dental and orthopedic results stable as these adolescent patients complete their growth phase or will they regress back to their retrognathic hyperdivergent tendencies? The literature supports varying levels of stability for many of these former orthodontic treatment techniques.

Stability of Retrognathic Hyperdivergent Orthodontic Treatments

The primary goal of orthodontic treatment should not only include functional occlusions and esthetic results, but also results that remain stable over the course of time. Orthodontic treatment for retrognathic hyperdivergent patients has been documented as one of the most difficult malocclusions to treat orthodontically due to the high prevalence of relapse post-treatment [3, 17, 79]. As previously discussed, many methods for orthodontic correction of RH patients have been documented with successful correction during treatment; however, few have demonstrated excellent long-

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term stability. Due to the vertical skeletal nature of this patient population along with

the posterior dento-alveolar excess, many retrognathic hyperdivergent patients present

with anterior open bite (AOB) malocclusions. A strong research emphasis has been

placed on anterior open bite correction due to the extremely variable long-term stability

results indicating a very high potential for relapse post-treatment. In a meta-analysis by

Greenlee and co-workers [80], anterior open bite long-term stability studies were

analyzed. The results demonstrated incisor overbite relapse rates spanning from 0% to

as high as 70%. With such as wide range of treatment outcomes, treatment throughout

the literature has attempted to isolate and minimize known unstable tooth movements

while counteracting with new mechanics that can lead to a more stable treatment result.

Unstable Orthodontic Tooth Movement

Retrognathic hyperdivergent patients, particularly those exhibiting anterior open bite

malocclusions, have historically been treated with incisor extrusion mechanics in order

to achieve a proper incisal overbite relationship; however, incisor extrusion has been

documented as one of the most unstable orthodontic movements. In a classic 1985

anterior open bite long-term stability study by Lopez-Gavito et al., [24] AOB patients

who had previously been treated with head gear extra-oral appliances and vertical

anterior elastics to increase incisal overbite were evaluated 10 years post-orthodontic

treatment. The long term stability data indicated that over 35% of the patients

previously treated had a 3 mm or greater anterior open bite at the 10 year follow-up with

an average of nearly 4.5mm of incisal overbite relapse. The instability of the vertical

dimension was also quantitated by Nemeth and Issacsson [81]. These authors analyzed

13 patients who had previously received orthodontic treatment for an anterior open bite

malocculsion but experienced a re-opening of the bite 1-6 years post-treatment. The

treatment mechanics for these patients involved forced incisor extrusion with anterior

elastics and class II elastics as needed. As these patient's final orthodontic treatment

(T1) and post-treatment (T2) cephalometric and plaster model measurements were

analyzed, the results indicated that the maxillary incisor intruded/relapsed post-treatment

in all 13 cases between 0.25mm and 7.00 mm. Interestingly, the mandibular incisors

were much more variable. In these same 13 patients the mandibular incisor extruded in

6 cases, remained the same in 6 cases, and intruded in 1 case post-treatment. The

posterior dentition also exhibited vertical changes. The maxillary first molar

erupted/extruded 0.50mm to 9.00mm and the mandibular first molar erupted/extruded

between 0.25mm and 3.00mm in 10 cases and remained unchanged vertically in 3 cases.

This study indicates that the maxillary incisors and maxillary molars experienced

significantly more vertical displacement post-treatment than the mandibular dentition.

The amount of incisor intrusion post-treatment mirrors the conclusions from the Lopez-

Gavito[24] study that forced vertical eruption of maxillary incisors is unstable. Age and

maturation status was not specified in this study; therefore, it is difficult to quantify

normal growth and expected eruption from actual dental relapse.   Additional studies

have verified the high relapse potential for forced anterior dental extrusion with elastics

in addition to unwanted opening of the mandibular plane [82-86] causing orthodontists

to search for an improved treatment technique that limits the use of anterior vertical elastics, especially when treating vertically hyperplasic patients.

Orthognathic Surgical Stability

Orthognathic surgery has often been considered the gold standard of care for severe skeletal and/or dental dysmorphias. As previously discussed, orthognathic surgery in combination with orthodontic treatment is a viable and successful treatment option for severe retrognathic hyperdivergent patients, especially those patients also presenting with skeletal anterior open bite malocclusions. The literature documents years of orthognathic surgical techniques for this patient population, but surgical correction is not immune to relapse post-treatment. Proffit and coworkers have documented a hierarchy of orthognathic surgical stability based on the surgical movements completed. Figure 1 represents this hierarchy from profit et al.[87]

The retrognathic hyperdivergent phenotype can differ greatly patient to patient as previously discussed; however, typical orthognathic surgical movements could include maxillary expansion and clockwise maxillary rotation (anterior down) which are near the most problematic and least stable surgical movements according to figure 1. In a LeFort I osteotomy surgical stability study by Denison et al. [88] 42.9% of the open-bite hyperdivergent subsample demonstrated clinically and statistically significant increases in facial height, increase in maxillary molar eruption, and decreases in overbite post-

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treatment. 12 of the 28 patients in this study experienced re-opening of the anterior open bite beyond incisal overlap during the post-retention [80, 88].   These results indicate that while orthognathic intervention may issue surgeons and clinicians a high level of skeletal and dental control, long-term stability needs to be monitored and improved. Many additional long-term surgical stability studies have been completed with results varying from 57% to 100% overbite stability post-treatment [88-96]. A hyperdivergent anterior open-bite stability meta-analysis by greenlee et al. [80] analyzed 9 surgical and 6 non-surgical long-term stability studies. The average mandibular plane angle was 42.2 indicating hyperdivergence. The results indicated that the mean overbite stability was 75.0% for the non-surgical group compared to 82.0% for the surgical group. The groups were not able to be matched pre-treatment and comparative effectiveness cannot be accurately concluded, but the results show greater than 75% stability for both groups. While this percentage is relatively high, clinically and statistically significant relapse remains present in both surgical and non-surgical treatment groups; therefore, additional measures need to be taken to improve post-treatment stability. Patients and clinicians alike have to take into account the cost, invasiveness, recovery, and potential morbidity/mortality of surgical intervention when exploring treatment options, which often leads to patients declining surgical treatment. Therefore, orthodontists must have proper non-surgical treatment modalities that provide similar dental, functional, and esthetic results that remain stable.

Non-Surgical RH Treatment Stability

Various non-surgical treatments have been documented in the literature for hyperdivergent retrognathic patients and limited long-term stability studies have been conducted. These studies differ from this proposed study due to factors such as treatment approach, study design, patient growth status, and/or lack of control groups. Table 1 cites multiple non-surgical long-term stability studies focusing on anterior open bite correction of hyperdivergent patients. The patient population, study design, stability and treatment interventions differ widely between each study; however, the inconsistent results of non-surgical hyperdivergent correction indicates the need for a more reliable non-surgical treatment approach.

Stability for these non-surgical treatments varies widely from 63-100% stability, but few non-surgical treatments address the dental, skeletal, and soft tissue goals of the RH patient. The introduction of mini-screw implants for skeletal anchorage and the concept of mandibular autorotation to reduce the hyperdivergence and profile convexity is a new treatment with little knowledge about the long-term stability. The aims of this current study will address the long-term stability of intrusion and mandibular autorotation in order to dictate if this treatment is a suitable alternative to surgical correction for retrognathic hyperdivergent patients.

CHAPTER II

STABILITY OF MINI-SCREW ASSISTED ORTHOPEDIC CORRECTION OF

GROWING RETROGNATHIC HYPERDIVERGENT PATIENTS

Introduction

Due to the complexity of their malocclusions and vertical skeletal growth patterns,

retrognathic hyperdivergent patients are among the most difficult to treat. Because these

patients exhibit a variety of esthetic and functional difficulties, treatment is required.

Orthodontists and lay people alike perceive excessive lower facial height as being

unattractive[10] and have viewed excessively convex profiles as less esthetically

pleasing than straighter profiles[1, 9, 97, 98]. The muscle weakness that characterizes

hyperdivergent patients is a concern because it is affects occlusal contacts, occlusal

support, and masticatory performance[99-101].

In order to improve the functional and esthetic characteristics of this complex patient

population, both surgical and non-surgical orthodontic treatment modalities have been

utilized. Surgical correction has consistently demonstrated superior results because it

provides both dental and skeletal improvements[80]. However, many patients decline

orthognathic surgical treatments due to the associated morbidity/risks, invasiveness,

discomfort, and/or financial constraints[66]. In addition, surgury cannot be performed

until full skeletal maturity has been achieved, which often delays treatment until the

early adulthood[66]. Since surgical options are often not feasible or viewed unfavorably to by patients, alternative less invasive and more cost effective techniques are highly desired.

While traditional non-surgical orthodontic treatment approaches effectively correct their dental malocclusions, they do not adequately address the skeletal and soft-tissue treatment objectives of retrognathic, hyperdivergent, patients. Most non-surgical approaches fail to control the vertical dimension during treatment, often leading to negative skeletal and esthetic outcomes[57, 102]. Vertical control of retrognathic hyperdivergent patients depends on true mandibular rotation, which is the primary determinant of the anterior-posterior position of the chin in both treated and untreated individuals. [59, 103] Since untreated growing children show a close association between true mandibular rotation and vertical changes in dental position, treatments aimed at reduce vertical skeletal dysplasia, reducing profile convexity and improving esthetics should focus on the vertical control of the dentition [37, 51, 52, 76, 103].

Based on these notions, a recent novel treatment approach was developed utilizing maxillary and mandibular mini-screw assisted control of the vertical dimension to achieve both dental and orthopedic corrections[38]. Along with correction of the malocclusion, this new approach produced beneficial orthopedic changes including significant decreases in the mandibular plane angle, increases in the SNB angle,

increases in chin projection, decreases in facial convexity, and control of vertical facial height.

While the treatment results were positive, the long-term stability of this approach in growing patients remains to be established. Greenlee et al[80] documented highly variable long-term stability for hyperdivergent open-bite patients ranging from 57-100% stability for surgical corrections and 30-100% stability for non-surgical corrections. Due to the extreme variation in stability leading to unpredictable long-term treatment outcomes, additional studies are needed in order to document a treatment modality that can provide functional, esthetic, reliable, and stable results for this dynamic patient population.

The purpose of the present study was to determine if the orthodontic and orthopedic correction produced with non-surgical posterior dental intrusion is stable when performed on growing retrognathic hyperdivergent patients. The primary aim was to analyze the vertical dental and skeletal changes that occur during treatment, and a minimum of one year after treatment, by comparing the changes to untreated control subjects.

Materials and Methods

Study Design and Population

The study sample was drawn from 17 retrognathic hyperdivergent patients who were previously treated in the graduate orthodontic clinic at Texas A&M University Baylor College of Dentistry. All subjects met the following inclusion criteria 1) end on or greater bilateral Class II molar and canine relationships, 2) SNB angle one standard deviation or more below the age and gender specific values, [77] 3) lower anterior facial height (ANS-Me) greater than age and gender specific mean values,[77] and 4) premolars fully erupted.

All subjects were treated by the same clinician. Maxillary and mandibular mini-screw implants (MSIs) were used for posterior vertical control. The maxillary posterior teeth were treated using a segmental intrusion appliance. After maxillary expansion with a rapid palatal expander (RPE), 2 MSIs were placed in the posterior palate lateral to the maxillary first molars and immediately loaded with 150 gram Niti coil springs attached to the RPE. While orthodontic brackets and segmental wires were used on the maxillary premolars and molars during the intrusive phase, no appliances were used on the anterior six teeth in order to minimize incisor extrusion. Buccal MSIs were also placed in the mandible between the second premolars and first molars. The MSIs were ligated to the mandibular first molar orthodontic bracket with a stainless steel ligature to prevent

eruption. After adequate posterior intrusion had been achieved, the remaining dentition was bonded and the malocclusion was corrected. Post-treatment (T2) records were obtained upon completion of orthodontic treatment.

All of the treated subjects received a maxillary full coverage thermoplastic (Essix) retainer and a mandibular bonded lingual retainer spanning from canine to canine. The mandibular lingual retainers included a 0.030 inch stainless steel orthodontic wire intimately fit to the mandibular canines and incisors. The distal ends of the mandibular lingual retainers were micro-etched and bonded to the lingual surface of the mandibular canines. The maxillary retainers were thermoformed from 0.75 mm (0.030 inches) copolyester Essix sheets (Dentsply Raintree Essix, New Orleans, Louisiana, USA) to a thickness of 0.015 inches. They were fabricated and placed on the same day the fixed appliances were removed, and extended to include the second molars. Each patient was instructed to wear the maxillary retainer full-time, except during meals, for 6 months and then at night only, indefinitely. The two patients who declined mandibular bonded retainers were provided maxillary and mandibular thermoplastic retainers.

The current study pertains to 14 of the original 17 subjects (5 males and 9 females). Three subjects failed to be recalled due to inability to obtain accurate contact information, geographical change, or incomplete records. The subjects were 13.4 ± 0.7 years pre-treatment (T1), 16.8 ± 1.3 years post-treatment (T2), and 20.4 ± 0.9 years at long-term recall (T3). Average total treatment time (T1-T2) was 3.5 ± 0.9 years and the

post-treatment (T2-T3) duration was 3.6 ± 1.6 years. The post-treatment records (T3) were taken at least 12 months after active orthodontics because that is when the majority of posterior intrusion and incisal overbite relapse occurs, with minimal changes occurring 12-36 months post-treatment [104]. The Institutional Review Board (IRB) committee of Texas A&M University Baylor College of Dentistry reviewed and approved this study prior to subject recruitment (2014-0750-BCD-FP).

The same investigator collected all of the long-term (T3) records in the graduate orthodontic clinic at Texas A&M University Baylor College of Dentistry (TAMBCD) which included:

- Three extraoral (facial profile, facial repose, facial smiling) and six intraoral photographs (maxillary occlusal, mandibular occlusal, intraoral center maximum intercuspation, right buccal, left buccal, and overjet)
- Maxillary and mandibular alginate impressions for plaster models
- Clinical measurements for overjet (measured buccal of mandibular incisor to lingual of maxillary incisor at the area of greatest distance) and overbite (measured incisal of maxillary incisor to incisal of mandibular incisor at the area of most shallow overbite)
- Clinical exam evaluating the presence of any crossbites, open bites, and molar and canine relationships.
- A Cone Beam Computed Tomography (CBCT) image was acquired using an iCAT machine (Imaging Sciences International, Hatfield, Pa) under

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the following conditions: 1) 13 cm vertical collimation, 2) 0.3 mm voxel

size, 3) head strap utilized instead of standard chin cup for soft tissue

accuracy.

Each subject was asked to complete a three-item questionnaire at the start of the long-

term records appointment. The following three questions and was answered using a 10

cm Visual Analog Scale (VAS):

1) How satisfied are you with your current orthodontic treatment results? (VAS

anchored with "not satisfied" and "extremely satisfied")

2) How well did you follow your retainer wear instructions? (VAS anchored with

"never wore" and perfect wear")

3) How much do you feel your teeth or bite has changed since your braces were

removed to now? (VAS anchored with "extreme change" and "no change")

Measurements

Lateral cephalographs were rendered from the CBCT data volumes at; pre-treatment

(T1), post-treatment (T2), and long-term recall (T3). Each CBCT rendering was

oriented using the midsaggital and Frankfort horizontal (porion to orbitale) planes.

Lateral cephalographs were rendered using the right side of the skull and a portion of the

left extending to the medial border of the left orbit. The cephalometric renderings were

digitized by the same examiner using Dolphin Imaging (Patterson Technology, Chatsworth, CA).

In order to estimate expected growth changes, the subjects were compared to untreated control subjects of similar age, gender, molar classification, and pre-treatment mandibular plane angle. The controls were drawn from records collected by the University of Montreal Growth Study (Human Growth and Research Center, University of Montreal, Montreal, Canada). The control tracings were imported into the Dolphin Imaging system for digitization.

The following cephalometric landmarks, as defined according to Riolo et al.[77], were digitized by the same examiner (Figure 1). Maxillary first molar mesiobuccal cusp (U6), mandibular first molar mesiobuccal cusp (L6), maxillary central incisor incisal edge (U1), mandibular central incisor incisal edge (L1), sella, nasion, porion, orbitale, anterior nasal spine, posterior nasal spine, pogonion, gnathion, menton, gonion, condylion, A point, and B point.

The following antero-posterior and vertical measurements were obtained from the cephalometric landmarks:

- Skeletal antero-posterior measures: mandibular protrusion (S-N-B) and chin projection (SN-Pg).

- Vertical skeletal measures: mandibular plane angle (S-N/Go-Me) and total anterior face height (N-Me).

- Vertical dental measures: maxillary molar (U6 ⊥ ANS-PNS), maxillary incisor (U1 ⊥ ANS-PNS), mandibular molar (L6 ⊥ Go-Me), mandibular incisor (L1 ⊥ Go-Me), Overbite (U1 incisal tip to L1 incisal tip).

All radiographs were digitized by the same examiner. Intra-examiner reliability was measured by choosing five subjects initially and re-digitizing the radiographs. The intra-examiner reliability is less than 0.5 mm error. Ten additional radiographs were re-digitized following the study to determine an overall intra-examiner reliability for the study.

Statistical Analysis

Treatment (T1-T2), post treatment (T2-T3), and overall long-term changes (T1-T3) were evaluated. SPSS version 22 (SPSS Inc., Chicago IL) was used to analyze the data. The skewness and kurtosis statistics indicated that the distributions were not normal. As such, the central tendencies and dispersions were described with medians and interquartile ranges. Mann-Whitney U tests were used for statistical comparisons between the treatment and control groups. Due to age differences between control and treated subjects at T3, the post-treatment changes were annualized for statistical comparisons. The statistical significance level was set at .05 for all comparisons.

Results

Dental Changes

The treated group showed approximately -0.45 mm of active maxillary first molar intrusion during treatment, while the controls exhibited 2.85 mm of maxillary molar eruption over the same time period (Table 2). This group difference was statistically significant. During the post-treatment phase, the maxillary molars erupted slightly more in the treated than control group, but the difference was not statistically significant. Overall, from the initiation of treatment to the long-term follow-up, there was a statistically significant -2.8 mm vertical difference in the maxillary first molar movement between the treated and control groups.

The mandibular molars erupted 0.65 mm during treatment and 2.90 mm in the control group, which was a statistically significant difference. There were minimal changes post-treatment, with the treatment and control groups showing less than 0.5 mm of eruption and no significant group difference. Overall, the treated mandibular molar exhibited 3.7 mm of relative intrusion, which was a statistically significant vertical treatment effect.

During treatment, the maxillary incisor was extruded 2.85 mm, while the control incisor erupted significantly less (1.25 mm). Post-treatment, the maxillary incisor remained vertically unchanged in the treated group and erupted 0.6 mm in the control group. There

was a 2.65 mm overall change of the maxillary incisor in the treated group compared to 1.40 mm change in the control group, a difference that was statistically significant.

The vertical position of the mandibular incisor did not change significantly during treatment (-0.05 mm), and it erupted slightly post-treatment (0.30 mm). The overall vertical change was only 0.40 mm. The control group showed 3.30 mm of vertical eruption, which was significantly more than the overall change of the treated group.

Skeletal Changes

During treatment, the treated group had a 2.80° decrease of the mandibular plane angle, while the control group remained relatively unchanged (Table 3). The difference was statistically significant. The MPA did not change significantly during the post-treatment phase for the treated or control group. Overall, the mandibular plane angel was reduced 3.25° in the treated group and 0.48° in the control group, which was statistically significant.

Chin projection (SN-Pg) was significantly increased (1.85°) in the treated group, but was not increased in the control group resulting in a statistically significant difference. Post-treatment, the chin projection increased slightly more in the treated group (0.60°) than control group (0.12°), but the difference was not significantly significant. The overall

change in chin projection increased 2.40° in the treated group and 0.52° in the control group.

Initially, the S-N-B angle increased significantly more in the treated group (1.1°) than in the control group (0.15°). A slight increase in S-N-B was noted post-treatment in the treated group, and no change was observed in the controls. The post-treatment group difference was not statistically significant. Overall, there was a statistically significant increase of the S-N-B angle in the treated group (2.10°) and only minimal change in the control group (0.28°).

Lower anterior face height increased significantly in both the treated and control groups during treatment. However, the treated group showed significantly less vertical growth, with a net difference of 5 mm. Both groups showed minimal changes in lower anterior face height during the post-retention phase. The overall difference in lower anterior face height was a statistically significant net decrease of 4.2 mm, with less growth in the treated group than the control group.

Patient Survey Results

Treatment satisfaction (question 1) among the patients was 8.4 ± 1.8, indicating a roughly 84% overall satisfaction rate. They rated their retainer wear (question 2) at 4.9 ± 2.9, indicating less than 50% compliance with their prescribed retainer wear. Patients

also reported an average post-treatment bite stability (question 3) of 7.5 ± 1.9,

suggesting a self-reported 75% stability post-treatment.

The only statistically significant correlation among the three survey questions was

between the degree of treatment satisfaction and the amount of retainer wear (r=.579,

p=.030), indicating that more retainer wear resulted in greater treatment satisfaction.

Patients reported retainer wear was not significantly correlated to patient reported post-

treatment bite change (r=.304), and patient satisfaction was not correlated to post-

treatment bite change (r=.131).

Discussion

Treatment Effect

This non-surgical orthodontic approach produced substantial orthopedic changes of

vertical skeletal dimensions. The treated subjects demonstrated a 2.8° decrease of the

MPA, while the control subjects remained relatively unchanged over the same time

period. Previous MSI/plate intrusion studies reported similar to MPA reductions,

ranging from 0.9° to 3.3° [76, 105-111]. However, previous intrusion studies pertained

to non-growing adults who required substantially more intrusion, which could affect

long-term stability. Vertical skeletal control in the present study was greater than

previously reported by most other non-surgical treatment approaches. Studies involving

headgears or vertical-pull chin-cups have documented MPA changes ranging from a 0.3°

increase to a 1.4° decrease during treatment [30, 103, 112-115]. The only exception is a 1978 study by Pearson [83], who documented a 3.9° decrease of the MPA using a vertical-pull chin-cup, which could not be replicated by another vertical-pull chin-cup study [114]. The MPA decrease in the present study was also comparable to surgical changes used to correct hyperdivergent anterior open bites, which reported decreases in the MPA ranging from 0.3° to 3.4° [65, 116-118].

Facial height (N-Me) was also substantially improved with this new approach. In the present study, facial height increased 5 mm less in the treated group than the control group. Kuroda et al[117], who compared non-surgical intrusion of adult patients to two-jaw orthognathic surgery in hyperdivergent anterior open bite patients, showed a 3.8 mm decrease in facial height (N-Me) for the surgical group and a 4.0 mm decrease for the non-surgical group. These surgical findings are slightly less than those observed in the current study, indicating that non-surgical vertical control via mandibular autorotation in growing patients provides a potent approach for reducing facial height.

Mandibular rotation also produced significant antero-posterior (AP) skeletal improvements. Vertical posterior control during treatment allowed the mandible to rotate forward, which has shown to be the most important determinant of chin position [38, 51, 52, 76, 83, 103]. Chin projection for the retrognathic subjects in the present study was improved by approximately 1.5°. Previous adult posterior intrusion studies have shown similar SNB increases, ranging from 1.3° to 1.9° [76, 105-111]. The AP skeletal results

also compare favorably with those obtained with various orthognathic procedures that autorotate the mandible. For example, Mojdehi et al. [116] who analyzed hyperdivergent patients treated surgically with maxillary impaction and clockwise maxillary rotation, reported a 2.0° increase in the SNB angle due to mandibular autorotation. Fontes et al. [118], who analyzed hyperdivergent anterior open bite patients treated with mandibular bilateral sagittal split osteotomies, also found a 2.0° increase of the SNB angle. Together, these results indicate that the present non-surgical technique can be used to produce substantial vertical and AP orthopedic effects in growing children.

Vertical control of the posterior dentition is the key for achieving non-surgical orthopedic skeletal changes and profile improvements. Hyperdivergent patients typically present with excessive vertical dentoalveolar dimensions, primarily due to overeruption of the maxillary posterior teeth [18]. In order to produce meaningful mandibular autorotation and increase chin projection in actively growing adolescents, it is necessary to control the vertical positions of both the maxillary and mandibular posterior dentition. The maxillary first molars were actively intruded only 0.45 mm during treatment, which amounts to a dramatic treatment effect when compared to the 2.85 mm of maxillary molar eruption that occurred over the same time span in the untreated control group. The relative vertical molar difference is over 3 mm of relative intrusion for the treated group during orthodontic treatment.

Surprisingly, the mandibular molars demonstrated similar amounts of relative intrusion. Although not actively intruded during treatment, vertical eruption of the mandibular molar was impeded by anchoring the mandibular molar to the buccally placed MSIs. The mandibular molar erupted 0.65 mm during treatment, which probably occurred before the mandibular MSIs were placed. The mandibular molars of the control group erupted approximately 2.90 mm, producing a total net difference of nearly 6 mm of vertical intrusive change between the maxillary and mandibular posterior dentition, which allowed the mandible to rotate in a favorable antero-posterior and vertical direction.

The maxillary incisor was extruded 2.85 mm during treatment, which was significantly more than the 1.25 mm of maxillary incisor eruption that occurred in the control group. Despite efforts to limit incisor extrusion through segmental posterior intrusion mechanics, significant maxillary incisor extrusion still occurred during the orthodontic finishing phase. This shows that the maxillary molars were not sufficiently intruded during the orthopedic phase in the present study, requiring extrusion during the orthodontic phase. In order to avoid maxillary incisor extrusion, the maxillary molars should be intruded to the incisor plane of occlusion.

The mandibular incisor was maintained in virtually the same position throughout treatment (-0.05mm). The control group showed an overall eruption of 3.3 mm, resulting in nearly 3 mm of relative mandibular incisor intrusion in the treated group. The relative mandibular incisor intrusion that occurred was probably related to orthodontic leveling

of the curve of Spee, in combination with vertical skeletal control of the mandibular

molars during treatment. The vertical posterior control resulted in mandibular

autorotation and anterior bite deepening, thus limiting the need for mandibular incisor

extrusion to achieve proper overjet and overbite. Overall, proper control of the dental

vertical dimension was obtained except for the maxillary incisor, which also correlated

with post-treatment stability.

Post-Treatment Stability

Post-treatment results showed that most of the orthodontic and orthopedic changes were

stable. During the post-treatment phase, all of the vertical positions of the molars and

mandibular incisors did not relapse. The eruptive changes that occurred were

comparable to those of the untreated controls. The maxillary incisor, which was

significantly extruded (2.85 mm) in during treatment, remained unchanged post-

treatment, while it erupted an additional 0.60 mm the control group. This lack of

expected incisor eruption in the treated sample produced a net vertical relapse of the

maxillary incisor post-treatment. Forced incisor extrusion has historically been shown to

be unstable [24], which is why posterior segmental intrusion mechanics were used in this

study in an attempt to reduce maxillary incisor extrusion. It is theorized that additional

maxillary molar intrusion in this study could have led to less maxillary incisor extrusion

and, potentially, a more stable outcome.

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The maxillary and mandibular molars continued to erupt post-treatment as expected in this growing patient population (0.95 mm maxillary molar and 0.50 mm mandibular molar); however, the treatment group did not erupt significantly more than the control subjects, demonstrating relative molar stability. Molar intrusion has been documented as relatively stable throughout the literature including a study by Baek et al. [104], which showed 0.45 mm of vertical relapse 3 years post-treatment after intruding maxillary molars 2.39 mm. These patients were all adult patients with no expected molar eruption post-treatment, but the molar relapse rate was quantified at 18.8%. Similar studies have reported adult molar intrusion stability ranging from 10.4% − 30% relapse [70, 105].

The orthopedic treatment results showed a high level of stability. The vertical and antero-posterior skeletal measurements showed the same changes as the control subjects post-treatment. Chin projection, facial height, and the S-N-B angle continued to slightly increase post-treatment. Most importantly, the mandibular plane angle increased only $0.15°$ post-treatment after the $2.8°$ MPA reduction during treatment. These results indicate a very stable skeletal treatment effect, which is not common among all hyperdivergent treatments. Fontes et al[118], who analyzed the long term stability of bilateral sagittal split osteotomies used to correct anterior open bite malocclusions showed that the MPA decreased $3.7° \pm 2.4°$ with surgical correction, but then increased $1.1°$ during the orthodontic finishing phase. 4.5 years post-surgery, the MPA opened an additional $1.1°$ indicating a 60% rotational relapse after surgical correction for the mandibular plane angle [118]. Similarly, Fischer et al. [91] analyzed the two year

stability of double jaw surgical intervention of anterior open bite hyperdivergent

patients. Double jaw surgery allowed for greater rotational control of the dento-skeletal

complex, as these subjects experienced an average MPA decrease of 4.0° and an SNB

increase of 4.0°, substantially more than non-surgical and single jaw surgery procedures.

However, 17 of the original 58 patients (29.3%) presented with an anterior open bite at

the two year follow-up, with statistically significant relapse of the MPA (1.4° of

backward rotation) and the maxillary incisor (27.3% vertical relapse). While surgery

remains a positive treatment approach for hyperdivergent retrognathic patients, similar

results with arguably higher stability can be obtained using non-surgical methods

without the added treatment expenses, discomfort, and morbidity/mortality risk. In

addition, non-surgical patients are able to have their malocclusions corrected during their

adolescent years instead of delaying treatment until full skeletal maturity, which allows

patients to have the benefits of improved occlusal function and esthetics throughout their

formative years. Early non-surgical intervention can produce esthetic, functional, and

stable results on a dental and skeletal level similar to surgical correction if the posterior

vertical dimension is managed properly.

Clinical Implications

Intervention in growing retrognathic hyperdivergent patients provides substantial

vertical control and produces significant skeletal changes with only minimal need for

active intrusive forces. Compared to non-growing adult posterior intrusion, much less

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active molar intrusion is necessary in the growing patients to produce similar orthopedic effects. Non-growing individuals require active forces and great mechanical control to adequately achieve dental intrusion, with the rotational axis of the mandible being located near the condyle. In contrast, growing adolescent patients require only relative intrusion to produce true mandibular rotation with orthopedic changes. This is partially due to the axis of mandibular rotation being located more anteriorly in growing patients, which is more favorable for effective chin projection [18, 38].

To have the greatest vertical control and treatment effect, proper treatment timing is essential. To obtain the greatest treatment effect over the shortest time period, it is recommended to initiate vertical control with skeletal anchorage approximately one year prior to adolescent peak growth velocity. This is also when peak eruption occurs and peak adolescent growth displacement is closely associated with peak eruption[18, 37]. Posterior control should be established early in treatment and controlled in both jaws throughout treatment in order to prevent compensatory super-eruption of the opposing dentition, an effect observed in previous intrusion studies [76]. Care should be taken to limit maxillary incisor orthodontic extrusion due to the high susceptibility for relapse documented in this study and previous literature [24], which can be accomplished by intruding maxillary posterior dentition to the level of the incisor occlusal plane when possible.

In addition, methods of retention could be improved, especially if the anterior teeth have to be extruded. All treated subjects in the present study received a maxillary full coverage thermoplastic (Essix) retainer and a mandibular bonded lingual retainer spanning from canine to canine. Two patients declined mandibular bonded retainers and were provided maxillary and mandibular thermoplastic retainers. Normal vertical eruption of the posterior molars and lack of vertical eruption of the maxillary incisors compared to untreated control subjects was noted post-treatment, which indicates that thermoplastic maxillary retainers do not adequately hold the vertical dimension in these hyperdivergent patients. Sauget et al. [119], who compared occlusal contacts at debond and 6 months post-treatment in patients retained with Hawley retainers and thermoplastic (Essix) retainers, showed that the Hawley retention group had greater areas of occlusal contact 6 months post-treatment because the molars were allowed to vertically erupt uninhibited. The thermoplastic group showed less settling. This study provides weak comparison evidence of vertical control for thermoplastic retainers; however, maxillary incisor vertical retention has not been addressed in the literature. Neither thermoplastic nor Hawley retainers provide vertical control of the maxillary incisors. Ideally, the maxillary incisors should have a natural horizontal undercut area to allow the thermoplastic material to vertically stabilize them and prevent relapse. However, the anatomy of the maxillary incisors provides little surface area for vertical resistance. Future retention studies could bond a composite lingual attachment near the cingulum of the maxillary incisors to increase vertical resistance for the vacuformed retainers. This would allow the maxillary thermoplastic retainers to intimately lock onto

the dentition while providing vertical retention control for relapse prone anterior open

bite patients.

CHAPTER III

CONCLUSIONS

Substantial orthodontic and orthopedic treatment effects were observed for growing

retrognathic hyperdivergent patients. No evidence of orthodontic or orthopedic relapse

was present when compared to untreated control patients except for the maxillary

incisor. Posterior relative intrusion can be achieved with minimal intrusive forces in

growing patients. Posterior skeletal vertical control in both jaws is crucial for

maximizing mandibular autorotation benefits. Maxillary incisor extrusion was the least

stable orthodontic movement in this study and should be limited as much as possible.

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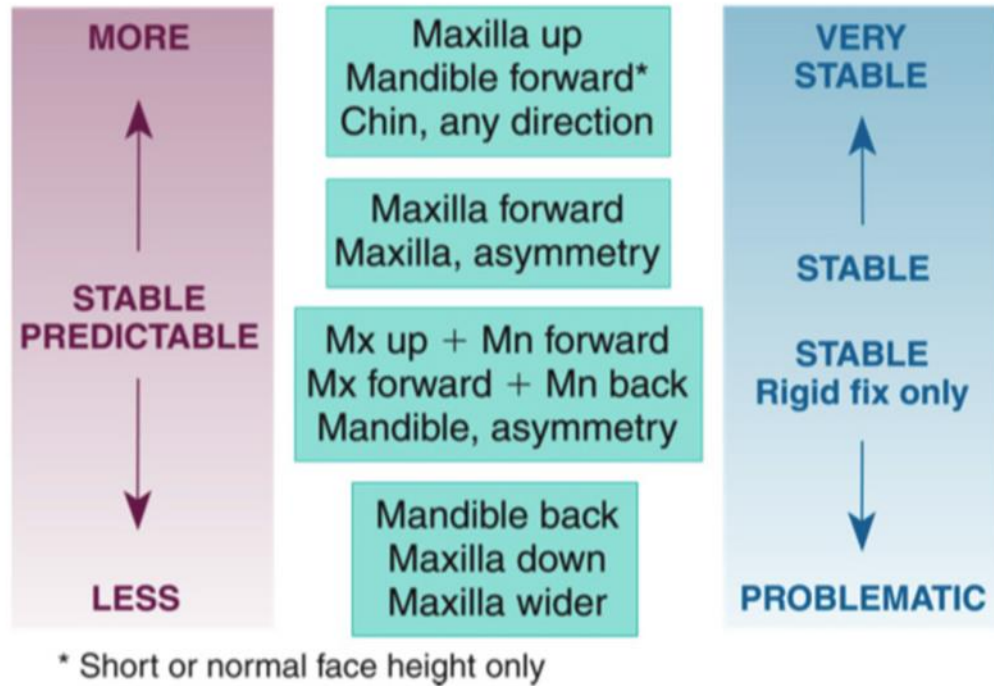
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**Surgical-Orthodontic Treatment:
A Hierarchy of Stability**

MORE	Maxilla up Mandible forward* Chin, any direction	VERY STABLE
STABLE PREDICTABLE	Maxilla forward Maxilla, asymmetry	STABLE
	Mx up + Mn forward Mx forward + Mn back Mandible, asymmetry	STABLE Rigid fix only
LESS	Mandible back Maxilla down Maxilla wider	PROBLEMATIC

* Short or normal face height only

Figure 1: Surgical Stability Hierarchy from Proffit et al[120]
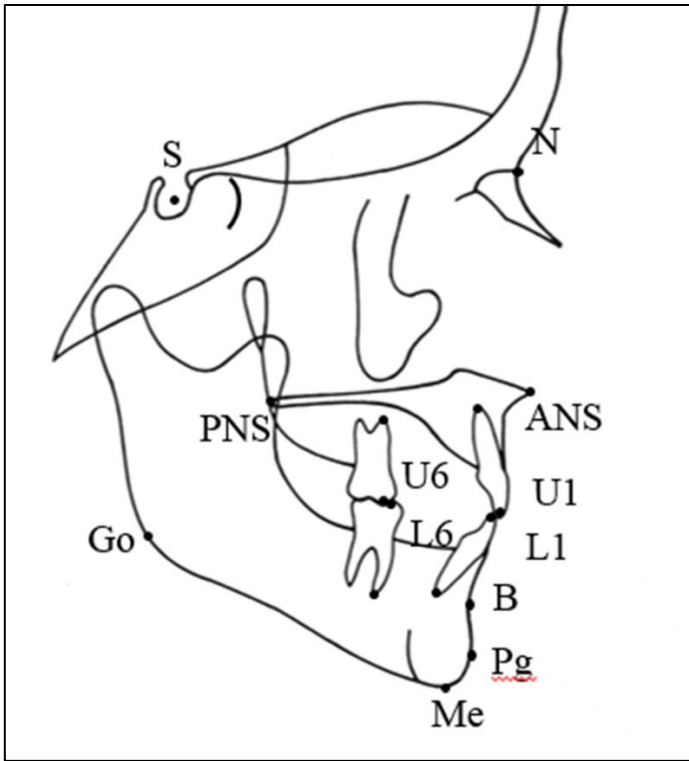
Figure 2: Cephalometric Landmarks
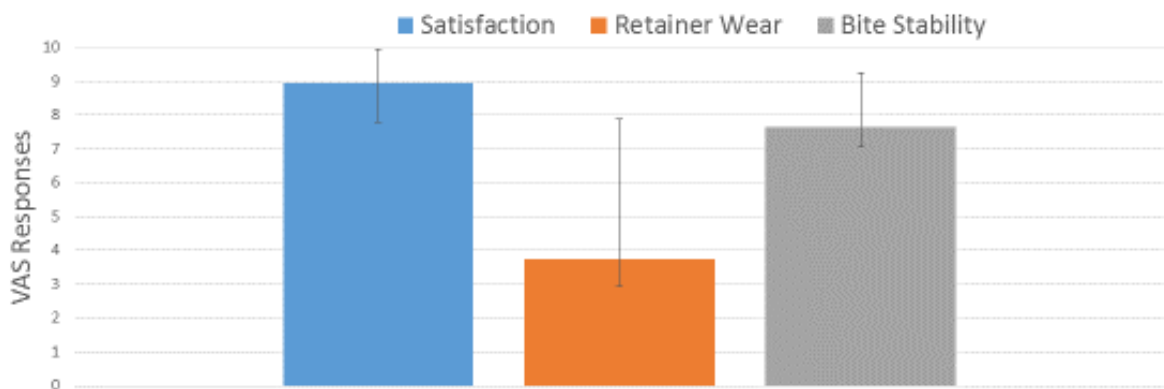
Figure 3: Medians and interquartile ranges for patient responses to post-retention questions pertaining to their treatment satisfaction, retainer wear, and post-treatment bite stability

APPENDIX B

Table 1: Non-Surgical Hyperdivergent AOB Correction Stability Studies

Study	Intervention	Growing Patients	OB Stability (total vertical change – T2-3 change)	Difference from this study
Nelson & Nelson [121]	Elastics/therapy	No	63%	Tx, non-growing
Katsaros & Berg [122]	Functional/EXT's	Yes	100%	Tx
Kucukkeles et al.[123]	Elastics/reverse CoS	No	75%	Tx, Non-growing
Kim et al.[124]	Elastics/reverse CoS	Both	87%	Tx
Sugawara et al.[105]	Miniplate anchors	No	82%	Non-growing, sample size, intrude L6's only
Janson et al.[125]	Elastics/EXT's	Yes	68%	Tx
Remmers et al.[82]	HG/elastics/functionals	Yes	90%	Tx

TABLE 2: Treatment, Post-Treatment, and Total Vertical Dental Changes of the Maxillary and Mandibular Molars and Incisors. *Indicates statistical significance at the p=.05 level

	TREATMENT GROUP			CONTROL GROUP			
	50th	25th	75th	50th	25th	75th	Probability
Treatment (T1-T2)							
U6 ⊥ PP	-0.45	-1.83	0.70	2.85	1.70	4.33	<.001*
U1 ⊥ PP	2.85	1.43	4.23	1.25	-0.20	2.10	.006*
L6 ⊥ MP	0.65	-0.95	2.20	2.90	2.05	3.68	.001*
L1 ⊥ MP	-0.05	-1.43	1.48	2.80	1.00	3.80	.001*
Post-treatment (T2-T3)							
U6 ⊥ PP	0.95	0.18	1.48	0.35	-0.15	0.98	.231
U1 ⊥ PP	0.00	-0.88	0.40	0.60	-0.20	0.90	.029*
L6 ⊥ MP	0.50	-0.45	0.95	0.25	-0.10	1.25	.899
L1 ⊥ MP	0.30	-0.80	0.53	0.50	0.00	0.80	.083
Total Change (T1-T3)							
U6 ⊥ PP	0.50	-1.95	1.78	3.30	1.35	4.50	<.001*
U1 ⊥ PP	2.65	1.83	3.33	1.40	0.80	3.00	.042*
L6 ⊥ MP	0.00	-0.30	1.93	3.70	2.13	4.95	<.001*
L1 ⊥ MP	0.40	-1.90	1.85	3.30	1.20	4.20	<.001*

TABLE 3: Treatment, Post-Treatment, and Total Skeletal Changes   *Indicates statistical significance at the p=.05 level

	TREATMENT GROUP			CONTROL GROUP			
	50th	25th	75th	50th	25th	75th	Probability
Treatment (T1-T2)							
MPA	-2.80	-3.73	-0.90	-0.08	-1.01	0.49	<.001*
SN-Pg	1.85	0.28	2.45	0.29	-0.13	1.41	.020*
S-N-B	1.10	0.48	2.05	0.15	-0.39	0.77	.001*
N-Me	3.70	0.35	6.28	8.74	4.49	11.37	.010*
Post-treatment (T2-T3)							
MPA	0.15	-3.00	1.30	-0.23	-0.76	0.35	.775
SN-Pg	0.60	-0.68	1.60	0.12	-0.59	0.56	.267
S-N-B	0.30	-0.85	1.43	-0.04	-0.54	0.37	.339
N-Me	0.25	-1.30	2.10	1.16	-0.12	1.93	.189
Total Change (T1-T3)							
MPA	-3.25	-6.10	1.55	-0.48	-1.31	0.64	.038*
SN-Pg	2.40	-0.43	4.40	0.52	-0.33	1.57	.066
S-N-B	2.10	-0.05	3.60	0.28	-0.94	0.82	.027*
N-Me	4.70	-1.05	6.55	8.99	5.12	13.48	.001*