ORTHOPEDIC CORRECTION OF GROWING RETROGNATHIC HYPERDIVERGENT PATIENTS

A Dissertation

by

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ABSTRACT

The purpose of this prospective study was to determine whether dental intrusion is effective in treating growing retrognathic hyperdivergent patients without negatively affecting the roots and periodontal structures. The sample consisted of 17 (7 males and 10 females) consecutively treated patients who were 13.2 ±1.1 years old at the start of treatment (T1) and treated for 25.3 ± 9.3 months (T2). The maxillary posterior teeth (premolars and molars) were all intruded using a rigid segmental appliance. Two maxillary and two mandibular MSIs (immediately loaded with 150gr coil springs) were used for the intrusion mechanics and vertical control. A matched control group was used to evaluate the skeletal changes that occurred during treatment. CBCT records, taken at T1 and at the end of the orthopedic phase (T2) were used to evaluate the treatment effects. The results showed significant ($p<.05$) intrusion (2.5 ± 1.7 mm) of the maxillary dentition in the treated group. The mandibular plane angle closed 2° ±1.7° and the SNB angle increased 1.5° ±1.5°. True forward rotation of the treated sample was significantly ($p<.05$) greater (1.8°) than in the controls. The treated group showed greater superior and less posterior condylar growth than the controls, but the difference was not statistically significant. All of the maxillary roots showed statistically significant amounts of external apical root resorption (EARR), ranging from 0.67 mm to 1.21 mm. Pointed roots showed the greatest amounts of resorption, followed by bent roots, normal shaped roots, and roots with open apices, which showed the least EARR. Alveolar crest heights between first molar and second premolar decreased significantly (0.38 ± 0.6 mm) over time, and

the distance between the bone and the CEJ increased significantly (0.52 ± 0.9 mm) only on the distal aspect of the maxillary second premolar. The overall MSI failure rate was 4.6%. It can be concluded that segmental intrusion of the posterior teeth with light forces and skeletal anchorage is effective for treating growing retrognathic hyperdivergent patients. The mechanics produced a significant true forward mandibular rotation, with minimal loss of crestal bone height and clinically acceptable EARR of the teeth that were intruded.

DEDICATION

This thesis is dedicated to my wife Daniela and our three loving children, Paulina, Andrea and Roberto, who always supported me in this journey. I loved to see you all greeting me with a smile after each one of my trips, even after my absences from many family occasions. Daniela, thanks for standing beside me in this ride, you are my daily energy and inspiration to be a better person. Kids, it was because of you that I was motivated to continue and not give up in this long journey. I love you all with my whole heart.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

Large numbers of orthodontic patients would benefit greatly if the development of the vertical dimensions could be predictably controlled. Reportedly, only 48% of the US population has an ideal overbite relationship (0-2 mm), and approximately 3.3% of the population has a moderate to severe open-bite malocclusion.[1] As reported by McNamara,[2] excessive development of the vertical dimension (commonly found in open bite patients), especially the anterior facial height, is commonly found in Class II malocclusions. While the prevalence of the problem has not been precisely quantified, many of the subjects with open-bite malocclusions might be expected to be hyperdivergent and retrognathic.

Retrognathic hyperdivergent patients are among the most difficult for orthodontists to treat due to the complexity of their malocclusion. Retrognathic hyperdivergent patients were initially categorized as having vertical dysplasia[3] and have since been called by a variety of names. Most investigators have referred to them as skeletal open bites.[4, 5] Schudy[6] was the first to characterize them as hyperdivergent, which more accurately reflects their skeletal phenotype.

Hyperdivergent subjects exhibit both esthetic and functional problems. Orthodontists and lay people perceive excessive mandibular height (measured from lower lip to menton) as being unattractive.[7] Excessively convex profiles are considered to be less esthetically pleasing than straight profiles.[8-10] It has also been well established that hyperdivergent subjects present with functional and masticatory muscle deficiencies, as well as important respiratory impairments.[11-15] Importantly, research has shown that these types of patients have smaller masticatory muscles and weaker bite forces than normal and hypodivergent subjects.[12, 14, 16]

Morphologic Characteristics

Retrognathic hyperdivergent patients have complex three-dimensional skeletal, soft-tissue and dentoalveolar compensations that make them difficult to diagnose and treat. They show consistent differences when compared to normal Class I's.[17] Full understanding of the morphological compensations of these subjects is necessary in order to appreciate the magnitude of the problem. To better describe and understand these characteristics, the maxilla and the mandible are usually described separately. The specific maxillary characteristics of untreated retrognathic hyperdivergent subjects show that the primary maxillary problems of these subjects are dentoalveolar rather than skeletal,[18] and hyperdivergence does not appear to affect the palatal plane angle.[19-21] In addition, most studies that evaluated anterior maxillary height have reported no statistically significant differences between hyperdivergent subjects and normal controls, although a few have found deficits.[22-24] Posterior maxillary height also does not appear to be affected.[23] Maxillary length and the SNA (sella-nasion-Apoint) angle tend to be smaller - indicating a more posterior position - in hyperdivergent subjects classified based on open-bite, but not when the classification is skeletally based.[20, 21, 25, 26] Studies consistently show increased anterior and posterior dentoalveolar heights among hyperdivergent subjects.[19, 22, 25, 27-29] Thus, the primary maxillary problems of hyperdivergent subjects are dentoalveolar rather than skeletal.

More pronounced and a greater number of differences between untreated hyperdivergent and control subjects are seen in the mandible than in the maxilla. Most studies have reported retrognathic mandibles and steeper mandibular plane angles among hyperdivergent subjects.[19-22, 25, 28] Interestingly, while posterior facial height shows no consistent group differences, ramus height has most commonly been reported as being smaller among hyperdivergent subjects, and anterior face height is greater.[20, 22, 29, 30] In addition, the gonial angle is consistently larger than normal among hyperdivergent subjects.[19, 20, 23, 29, 31]

Studies of retrognathic hyperdivergent patients have also reported narrower transverse dimensions.[22, 32] Starting in the primary dentition, molar widths for both upper and lower dental arches tend to be narrower in Class II division 1 subjects than normal subjects.[33-37] Vertical growth patterns are closely related to the transverse growth of the maxilla and the mandible.[32]

With respect to bone structure, untreated hyperdivergent subject show smaller alveolar ridges, thinner cortical bone (maxilla and mandible), higher and thinner mandibular symphysis, and thinner anterior maxillary bone than normal and hypodivergent subjects.[38-41]

Identifying the problems early

Differences in the vertical dimensions of hyper- and hypodivergent subjects are well established by 6 years of age, making them easy to distinguish early. It is important for orthodontists to understand that the growth patterns of most hyperdivergent patients are established early, around four years of age.[42] Individuals who had higher mandibular plane angles between 6-15 years of age will have higher mandibular plane angles at 15 years of age.[43] Bishara and Jakobsen[44] showed that 82% of the five year olds classified as having long faces had long faces at 25 years of age. Approximately 64% of the hyperdivergent 6 year olds are still hyperdivergent at 15 years, with 25% worsening over time.[43] Approximately 75% of 10 year olds classified as hyperdivergent, within normal limits, or hypodivergent maintain their classifications through 15 years of age.[45]

Retrognathic features are not as evident as hyperdivergent characteristics during the early developmental stages. Adolescents classified as retrognathic at 14-16 years of age show only limited morphological differences at 6-7 years, whereas those classified as hyperdivergent shows numerous differences, especially in the mandible.[46] Hyperdivergent subjects also demonstrate less improvement of their skeletal relationships over time; their mandibular plane angles decrease only 0.3° between 6-15 years of age, compared with 2.5° and 4.0° decreases for average and hypodivergent subjects, respectively. The SNB (sella-nasion-basion) angle of hyperdivergent subjects increases only 0.2°, compared with 1.2° and 1.4° for average and hypodivergent subjects.

Etiology of the Retrognathic Hyperdivergent Phenotype

Craniofacial growth is not exclusively dependent on genetic factors. Most craniofacial, dentoalveolar, and occlusal traits show a quantitative, often normal, distribution of phenotypes. Genetic, epigenetic, and environmental influences can incorporate variation in craniofacial growth. The relative contribution of genes to phenotypic expression varies greatly, depending on the environments in which they are expressed. Traits showing greater phenotypic variation are either under less direct genetic control and/or mature (i.e. grow relatively) less rapidly than traits showing less phenotypic variation.

Habits, interferences with normal breathing and decreases in masticatory muscle strength are the three broad environmental factors that have been proposed to explain changes in malocclusion over time.[47] However, only the latter two factors appear to explain the development of the retrognathic hyperdivergent phenotype. Because the morphological changes represent adaptive growth responses, it can be presumed that growth responses would be possible with treatment.

Effects of habits

The literature does not support habits as a direct explanatory factor for the hyperdivergent phenotype. Thumbsucking, fingersucking, nail biting, tongue sucking and tongue thrusting have been shown to be the most prevalent habits of young children.[48] While the prevalence of digit-sucking is population specific, it decreases as the prevalence of dummy (pacifier) sucking increases.[49]

Studies show that finger habits help to explain the Class II maxillary problems, but not the retrognathic hyperdivergent phenotypes, whose malocclusions are primarily due to mandibular dysmorphology. An early study performed on 7-16 year old children with persistent thumbsucking habits showed greater tendencies for open-bite malocclusions, a propensity toward Class II molar and canine relationships, proclined upper incisors, and a longer maxilla, but no effects on the mandibular or palatal plane angles.[50] During the primary dentition, there is a high prevalence of cross-bites among children in the primary dentition who suck their fingers or pacifiers as a result of maxillary constriction.[51-53] However, most cross-bites self-correct if the habit is stopped before the transition to the early mixed dentition, and most children with finger habits after the transitional dentition do not exhibit cross-bites after 9 years of age.[54, 55]

Effects of interference with normal breathing

There is a substantial amount of evidence to suggest that interference with normal breathing must be considered as a primary environmental factor explaining the development of retrognathic hyperdivergent dysmorphology. The morphological similarities that have been reported for subjects with enlarged tonsils, allergic rhinitis, and enlarged adenoids lead to the conclusion that chronic airway interference produce similar phenotypes.

Harvold and colleagues (1981) were able to establish a causal relationship between mode of breathing and changes in craniofacial morphology in their classic primate experiments.[56] Compared to control monkeys, those with blocked nasal airways developed steeper mandibular planes and larger gonial angles. The changes were most pronounced in the animals that maintained a low postural position of the mandible. Interestingly, when the blockages were removed, growth reverted back toward their normal, more horizontal, pattern.

Clinically, the relationship between airway and growth disturbances has been perhaps best established for patients with enlarged adenoids. Linder-Aronson[57] was among the first to report systematic differences between children with enlarged adenoids and nose breathing controls. They reported that children with enlarged adenoids have increased lower anterior facial heights, larger gonial angles, narrow maxillary arches, retroclined incisors, and larger mandibular plane angles. Other studies in children with enlarged adenoids have confirmed increased vertical mandibular growth tendencies, along with retroclinced mandibular incisors, smaller SNB angles, larger mandibular plane angle, and larger lower face heights.[58-60]

Linder-Aronson (1974)[61] studied children one year after adenoidectomies. The report showed that the majority (≈75%) of children changed to nasal breathing. When compared to controls, they showed improvements in the mandibular plane angle, maxillary arch widths and changes on incisor inclination. The mandible also showed growth adaptations after adenoidectomy, by assuming an even more horizontal direction than in controls.[62, 63] Kerr et al.,[59] who followed 26 children five years after adenoidectomies, showed changes in their mode of breathing and a normalization of growth, with a more anterior direction of mandibular growth and forward true rotation of the mandible. Interestingly, it appears that the timing of the adenoidectomies is an important factor in determining the growth response that occurs.[60]

Although less well studied, chronically enlarged tonsils produce the same phenotype as enlarged adenoids. Behlfelt and colleagues,[64] who evaluated 73 ten year old children with enlarged tonsils, showed that they were more retrognathic, had longer anterior facial height, and larger mandibular plane angles than children who do not have enlarged tonsils. Furthermore, the skeletal features were directly related to the children's open mouth and lowered tongue postures.

Adults with other breathing disturbances such as sleep apnea produce similar morphological characteristics. Lowe and collaborators[65] showed that adult males with severe obstructive sleep apnea exhibited steep occlusal and mandibular plane angles, overerupted maxillary and mandibular teeth, larger gonial angles and anterior open bites. Andersson and Brattström[66] reported similar morphological patterns among 51 heavily snoring patients with and without apnea. More recently, it was shown that children with obstructive sleep apnea also have steeper mandibular plane angles, greater lower anterior face heights, and more retroclined incisors; five years after adenoidectomies/tonsillectomies none of the differences between apnea patients and controls were statistically significant.[67]

There are similar associations between allergic rhinitis and craniofacial development. Children 6-16 years of age with chronic perennial allergic rhinitis display more vertical and divergent facial growth patterns than controls, with the degree of hyperdivergence being directly related to the severity of the allergic rhinitis.[68] This is important because the prevalence of allergic rhinitis ranges between 10-20%; most patients with allergic rhinitis also have asthma.[69] Bresolin et al.[70] showed that mouth breathers have significantly longer anterior facial heights, larger mandibular plane angles, relatively greater mandibular than maxillary retrusion, larger gonial angles, higher palates, greater overjet, and narrower maxillas than nose breathers. Mouth breathers with perennial allergic rhinitis display deeper palates, retroclined lower incisors, smaller SNB and SNPg angles, increased overjet, increased lower face heights, larger gonial angles and larger mandibular plane angles than their siblings.[71] Harari et al.,[72] who compared 55 children with signs and symptoms of nasal obstruction to 61 normal nasal breathers, showed that the mouth breathers had larger mandibular plane angles, greater overjets, retrognathic mandibles, larger Y-axes, and narrower intermolar widths.

Effects of muscle weakening

Historically, reduced masticatory muscle forces provide the best explanation for the prevalence of hyperdivergent retrognathic phenotypes. Anthropological studies have consistently shown that the prevalence of malocclusion is much lower for subjects living under primitive conditions than for their counterpart eating processed foods.[73] Since individuals living under more primitive conditions eat harder foods that require greater muscular effort for communition,[74] they might be expected to have larger masticatory muscles and greater force output. Importantly, this association is not limited to dental malocclusion; maladaptive changes to technological advances have also been associated with larger inter-maxillary (i.e. mandibular plane) angles, larger gonial angles and narrower jaws. Comparisons of the present day Finns to Finnish samples from the 16th and 17th centuries showed that posterior, but not anterior, facial heights were significantly smaller in present day Finns; hyperdivergence was attributed to the softer foods in the present day diet, supporting the notion that craniofacial growth is regulated with masticatory stress.[75]

There are also numerous experimental studies showing differences in muscle strength, muscle morphology, and craniofacial growth between animals fed soft and hard diets. Various species of growing animals fed on soft diets show structural differences in their masticatory muscles, lower bite forces, alterations in condylar growth, narrower maxilla and differences in bony remodeling.[76-80] Remodeling of the gonial process has been directly related to the sizes of the masseter and medial pterygoid muscles;[81] resection of the masseter and pterygoid muscles results in alterations in condylar growth, mandibular length, and ramus height.[82]

Humans with weak jaw muscles have been directly linked with hyperdivergent growth tendencies. Similarly, adults with larger mandibular plane angles and children with vertical growth patterns exhibit low bite forces.[12, 14, 16, 83] In addition, a decreased masticatory muscle function has been shown to be associated with increased dentoalveolar height.[84, 85] Skeletal hyperdivergence has also been directly related to reduced muscle size, low EMG activity, and reduced muscle efficiency.[86-88]

To clearly demonstrate the relationship between muscle function and hyperdivergence, one can observe the reports on patients with muscular dystrophy and spinal muscular atrophy. Kreiborg and colleagues[89] showed the effects that muscular dystrophy had on the craniofacial growth of a 12.5 year old girl. Subsequent research has shown that subjects with Duchenne and myotonic muscular atrophy,[90, 91] as well as spinal muscular atrophy,[87, 92] have significantly weaker masticatory muscles, and show the same constellation of features presented by retrognathic hyperdivergent subjects, including narrow and deep palates, increased anterior facial heights, larger gonial angles, and steeper mandibular planes.

Importantly, strengthening of the masticatory muscles produces morphological changes opposite of those produced by weakened muscles. Hyperdivergent patients who underwent chewing exercises show greater true forward mandibular rotation than untreated hyperdivergent subjects, and even greater rotation than subjects treated with vertical-pull chincups.[93] Ingervall and Bitsanis[94] also showed that masticatory muscle training produces significant increases in bite forces and greater than expected forward rotation of the mandible.

Mandibular posture and facial morphology

It is important to consider mandibular posture when trying to explain why airway blockages and weakened muscles produce the same retrognathic hyperdivergent phenotype. There is substantial indirect evidence supporting the concept that muscle strength relates to posture. Kuo and Zajac provided a biomechanical analysis proving that muscle strength is a limiting factor in standing posture.[95] In addition, muscle strength has been related to posture in patients with chronic lumbar pain and is one of the main causes for postural instability in Parkinson's disease.[96, 97] Most importantly, muscle exercises (strengthening) are also commonly used to correct postural deviations.[98, 99] One study provides direct experimental support for the relationship between posterior mandibular rotation and reduced muscle function.[85]

By definition, mouth breathers must move their mandibles in order to breathe, and it is more efficient to lower than protrude or laterotrude the mandible. For this reason, it is much easier to understand why the mandible is typically lowered in individuals with airway obstruction. Experimental obstruction of the upper airway results in lowered resting posture of the mandible, and a 5 degree increase in the cranio-cervical extension.[100]

It can be summarized from the evidence presented that if the lower mandibular posture is maintained (i.e., if it is habitual), and especially if the subject has growth potential, then the dentition, dentoalveolar complex, and mandible might be expected to adapt to the new position. Lower mandibular posture immediately produces a mandibular plane angle increase, as well as a decrease in the posterior to anterior lower facial height ratio. Over time, lowered posture causes an increase in anterior face height and supraeruption of the dentition. Whether or not the anterior teeth overerupt depends, at least in part, on whether the tongue is postured between the teeth (or not), in which case an open bite would be produced. The incisors, especially of the mandible, adapt to this mandibular position by retroclination. Retroclination and overeruption cause changes in symphyseal morphology and increased crowding. Lowered mandibular and tongue posture lead to a narrow maxillary arch with possible cross-bites. A lowered posture leads to changes in the mandible's remodeling pattern and a more posteriorly directed condylar growth, which, in turn, lead to shorter ramus height and increases in the gonial angle.

Treatment Elements and Influencing Factors

Due to the complex dental and skeletal compensations that retrognathic hyperdivergent cases present with, there has been a variety of treatment approaches that have been implemented to try to correct such malocclusions. It has been well established that vertical control is difficult and problematic especially for retrognathic hyperdivergent patients; treatment of such patients remains a challenging task for orthodontists.[101, 102] A lack of vertical control during orthodontic treatment exacerbates the negative effects of these characteristics. In fact, there is evidence supporting the notion that traditional orthodontic treatments cause an increase in the mandibular plane angle.[103-106] Since orthodontic treatment can worsen the problem by rotating the mandible backwards,[107] vertical control may be the single most important factor when treating hyperdivergent patients.[6, 108-111]

Treatment mechanics

Common treatment mechanics for patients with excessive vertical growth tendencies include high-pull headgear, acrylic splints with high-pull headgear, active vertical correctors, posterior bite-blocks with and without magnets and vertical pull chin-cups. Although most of these treatment alternatives are effective in correcting the dental malocclusion, most do not have a positive impact on chin projection and soft-tissue profiles.[112-119] Importantly, all of these approaches are highly dependent on patient compliance to be effective, and compliance has been shown to be variable and difficult to measure during orthodontic treatment.[120-122]

Established treatment mechanics thus appear to be impeding the improvement of the profile in cases requiring chin projection and forward rotation of the mandible. Unfortunately for these patients, increases in vertical dimensions can be attributed to growth as well as a result of orthodontic treatment.[116] A recent report by Phan et al,[103] showed that treated subjects with Class II Division 1 malocclusions had greater inferior displacement of pogonion, increased occlusal movement of the mandibular molars and a significant increase in the mandibular plane angle. Such results emphasize the difficulty of controlling the vertical displacement of the mandible during orthodontic treatment. Mair and Hunter[105] also reported that Class II, Division 1 individuals have more vertical mandibular displacement during treatment than matched controls. The backward rotation of the mandible commonly caused by treatment mechanics makes profile correction difficult and prevents the improvement of chin projection, a fact especially important in retrognathic hyperdivergent patients whose profiles need to be improved.

Extraoral appliances

All extraoral appliances are dependent on patient compliance, making them unpredictable and highly variable in their results. Dental relationships can be successfully improved using appliances such as the high-pull headgear, one of the most common appliances used to control the vertical dimension.[123] Importantly, the deficiency of this appliance comes when measuring the skeletal changes created in retrognathic hyperdivergent patients. Reports have shown that changes in the mandibular plane are not favorable when treating patients with high pull headgear, because it negates any possibility of positive mandibular autorotation.[106, 123] The inability to control dentoalveolar compensations, especially of the lower molars, following the intrusion of the upper molars makes it difficult to obtain the desired effect on chin projection and mandibular autorotation.[114, 115] Other major disadvantages of headgears relate to the direction of force application onto the arch; headgears are unable to intrude a complete segment of the dentition, which in the majority of these cases is desired to achieve a forward rotation of the mandible.

To minimize the vertical development of the maxillary dentition, a maxillary splint has been typically used with the high pull headgear. Splints help to intrude the maxillary molars more effectively than head gears without a splint, but they do not prevent the mandibular molars from compensating by over erupting.[115] However, mandibular molar eruption can be maintained by other appliances discussed in the following section, which also depend on patient compliance.

Of the common extraoral treatment approaches, the most effective for controlling dentoalveolar heights and increasing chin projection has been the vertical pull chin-cup.[124-131] Sankey et al.[127] treated growing patients with high-pull chin cup and a bite block and compared these patients to untreated controls. They reported significant effects in the treated group. They showed important effects in the mandible, such as gonial angle decrease, the chin advancing forward twice as much than controls and a true mandibular rotation. Iscan and colaborators,[129] also reported that chin cup patients had a significant decrease in mandibular plane and gonial angle and improved jaw relationships. Interestingly, a later prospective randomized study by Torres et al.,[130] did not find any significant effects on skeletal changes between treated and untreated controls.

Orthodontic mechanics and intraoral appliances

A clear understanding of reciprocal forces and their clinical application is imperative in order to move teeth in the desired direction. The multiloop edgewise archwire technique (MEAW) is an approach recommended to intrude posterior teeth and close the anterior open bite.[132, 133] Treatment with this approach requires 100% patient compliance and depends on full time anterior vertical elastics used to intrude the posterior teeth.[132] With these types of mechanics, the occlusal planes move toward each other by extrusion of anterior teeth.[133] The correction is thus due to anterior and posterior dentoalveolar compensations, making it difficult to obtain clinically significant amounts of mandibular plane closure and forward chin projection.

Intraoral appliances are commonly used to control for excessive vertical dental development. Common intraoral appliances such as bite blocks, magnets and active vertical correctors (AVC) are primarily used for the intrusion of upper and lower posterior teeth.[116, 118, 134-142] The goal of all these appliances is to apply an intrusive force to the posterior segments in order to produce a forward rotation of the mandible. Magnetic appliances and AVC have been shown to produce significant intrusion of posterior teeth.[134, 137-140] Importantly, the shearing forces produced by the magnets have also produced negative side effects in the transverse dimension, such as crossbites.[136, 137] In animal models, the use of bite blocks, with or without magnets, to apply intrusive forces to teeth has produced root resorption and ankylosis.[134] In addition, bite blocks rotate the mandible posteriorly, which could possibly produce adverse growth and remodeling changes, such as a tendency to increase the gonial angle.[43, 116, 135] Such treatment could be detrimental to existing hyperdivergent skeletal dysmorphology. Another major disadvantage with these types of treatment approaches (bite blocks, magnets, and AVC) is patient compliance, due primarily to the design of the appliances.

As shown, a treatment approach that could intrude posterior teeth without extruding the anterior teeth will create a forward rotation of the mandible, a better chin projection and potential improvement of the patient's profile. Many hyperdivergent and mandibular retrognathic patients could benefit from this type of approach. As previously shown, none of the common treatment approaches can predictably control the vertical dimension of patients. While some of these treatment approaches have shown intrusion of posterior teeth, the skeletal and profile changes produced usually do not meet the objectives desired by the patient or the orthodontist.

Based on this review, it has been almost impossible to improve the soft-tissue and hard tissue profiles of hyperdivergent phenotype patients with orthodontic treatment alone. These types of cases often present with a combination of skeletal problems and supraerupted posterior teeth that most likely will require maxillofacial surgery.[143-147] Surgery, which could include complex multi-jaw and multi-piece procedures presents an enormous challenge to the surgeon, the orthodontist and the patient. One of the main limitations for this treatment approach is the patient's skeletal maturity. Growth of vertical craniofacial dimension is completed after transverse and sagittal growth. To prevent post-surgical growth changes and maximize post-treatment stability, surgery to correct vertical discrepancies has to be postponed until the patient is skeletally mature and growth in this dimension has been completed. Finally, the economic implications for the patient sometimes make surgery an unreachable goal.

More novel and less invasive treatment approaches include the use of skeletal anchorage provided primarily by titanium mini-plates and miniscrew implants (MSI) as anchorage for intruding teeth.[148-155] From the different methods for skeletal anchorage, MSIs are the most commonly used by orthodontists and provide excellent anchorage for controlling the vertical positions of the teeth. Overall, MSIs are well accepted by orthodontists and have been shown to remain clinically stable throughout orthodontic treatment.[156-160] Multiple case reports and limited clinical studies of MSIs have shown them to be successfully used for the intrusion of the dentition and resulting mandibular rotation in adults.[161-169]

Importantly, achieving molar intrusion and mandibular rotation in adults are not the same as in growing children. Non-growing individuals require active dental intrusion to produce mandibular autorotation, with the rotation axis being close to the condyle. In contrast, growing patients require only relative intrusion (holding the vertical development of the maxillary and mandibular dentition) to produce true mandibular rotation (orthopedic change of the mandible), with the axis of rotation located more anteriorly, somewhere between the incisors and premolars. In addition, the intrusive mechanics must be applied directly to the posterior teeth as a segment, rather than to the entire arch connecting anterior and posterior teeth, which has been the most common method previously used. To date, there has been only one retrospective study reporting the effects of intrusion miniscrew mechanics on growing individuals, but the lower dentition were not well controlled for, so treatment effects were less than expected.[168] There have been no prospective clinical investigation regarding the effects these mechanics have on growing individuals using miniscrew implants as anchorage for vertical control of the maxillary and mandibular dentition.

Hyperdivergence, Retrognathism and Mandibular Rotation

Schudy[6, 170] was among the first to emphasize the importance of vertical growth for understanding AP chin position. More recently, moderate relationships have been reported between the anteroposterior and vertical mandibular changes that occur during growth, suggesting that most individuals who become more hyperdivergent over time also become more retrognathic.[171]

It has been well established that most of the mandible's surface changes during growth. The condyle grows and the cortical bone remodels. These are adaptions to changing functional relationships as the mandible alters its position and increases its size.[108, 172] The ramus grows and remodels primarily in a superior and posterior direction; it undergoes greater changes than the corpus of the mandible.[172-176] The condyle exhibits greater growth than most other aspects of the mandible.[172, 174] While bone is being resorbed along the lower border between gonion and the molars, it is typically being added below the symphyseal region. The superior aspect of the symphysis drifts superiorly and posteriorly. These growth and modeling changes have been related to the type of true mandibular rotation that occurs.

Traditionally, orthodontists have evaluated the rotation of the lower mandibular border relative to either the Frankfort horizontal or the anterior cranial base (sella-nasion). Rotation of the mandibular plane is not the actual rotation that occurs, but the rotation that appears to be occurring. Importantly, what appears to be occurring is actually not occurring because the lower border of the mandible remodels. In order to understand rotation, it is necessary to distinguish between the rotation of the mandibular plane and the actual rotation of the mandible that occurs. The modeling camouflages or covers up the true rotation that actually occurs. For example, Spady et al.[177] showed that almost 5 deg of true forward rotation occurred between 6-15 years of age, but there was less than 1 deg of change of the mandibular plane angle.

Hyperdivergent patients undergo significantly less (23-43%) forward true rotation than hypodivergent patients.[178] Untreated patients normally undergo forward or counterclockwise (as viewed by the observer when the patient is facing to the right) rotation. Average true rotation ranges between approximately 0.4-1.3°/yr,[173, 177-182] with greater rates reported during childhood than adolescence.[177, 181, 182] Substantially greater amounts of true rotation occur during the transition between the primary and early mixed dentition, than between the early mixed and early adulthood,[182] implying that the dentition plays a fundamental role.

It is known that the tip of the chin undergoes little or no modeling.[108, 173-175, 177] True mandibular rotation has repeatedly been shown to be the most important determinant of the anteroposterior position of the chin in untreated[175] and treated subjects.[183, 184] There are only three possible ways to explain the forward or backward movements of the chin in untreated growing subjects. These are condylar growth changes, glenoid fossa changes, and true mandibular rotation. True mandibular rotation has repeatedly been shown to be the most important determinant of the anteroposterior position of the chin in untreated[175] and treated subjects.[183, 184]

True mandibular rotation is important because it is directly related to chin position, and indirectly related to various other growth and remodeling changes that occur. Strong associations have been reported between true mandibular rotation, the amount of condylar growth and the condylar growth direction.[173-176, 179] Forward rotators show more condylar growth, oriented in a more anterior direction than backward rotators. The lower mandibular border of forward rotators tends to show bony apposition anteriorly and resorption posteriorly, which is not the remodeling pattern exhibited by backward rotators.[173, 180] True mandibular rotation also produces compensatory changes in the eruptive paths of teeth, with the molars erupting more than the incisors in forward rotators and the incisors erupting more among backward rotators.[173] The mandibular incisors and molars tend to retrocline and tip distally in backward rotators; they procline and tip mesially in forward rotators.[108, 173]

Mandibular growth and modeling adapt to treatment-imposed changes in mandibular position, following similar patterns exhibited by untreated individuals. Growing individuals who received maxillary impaction surgery and autorotation of the mandible (no mandibular surgery) showed more superiorly directed condylar growth than matched untreated controls,[42] showing the same remodeling changes associated with forward rotators during growth.

If the mandible adapts similarly to true rotation in both untreated and treated individuals, then, theoretically, treatment modalities should be focusing on methods to alter mandibular position so that the skeletal problems that retrognathic hyperdivergent individuals present with could be addressed by true forward rotation of the mandible.

It has been well documented that significant amounts of true mandibular rotation occur during childhood and adolescence.[108, 176, 177] The greatest rate of true rotation occurs between the primary and early mixed dentition stages. Ueno and collaborators[185] recently showed why so much true mandibular rotation occurs during the transition of the late primary to early mixed dentition. This study demonstrated that the vertical positions of the anterior teeth were fundamentally important for rotation to occur. They showed that true forward rotation was significantly more closely related to anterior dentoalveolar changes than to any other growth parameter. The most important anterior dentoalveolar change that occurred during this stage was the loss of the primary incisors and the emergence of the permanent incisors into the oral cavity. Due to the amount of space created and the duration of time it takes for the space to fill in with teeth, the mandible is able to rotate forward without any interference from the anterior dentition. As previously shown, the most predictable method to enhance chin projection is mandibular rotation. As such, treatment goals should be directed towards this concept, which theoretically makes it possible to address the patients' dental, skeletal and soft-tissue problems. A representation of the optimal treatment goals for these individuals is shown in Figure 1A-E. For example, if a case presents with a backward chin position and excessive vertical development (Figure 1-A), the ideal treatment should be directed to initially control the vertical development of the maxillary and mandibular dentition (Figure 1-B). With this, the teeth can be maintained apart (Figure 1-C), making it possible for the mandible to change its position relative to the cranial base. The mandible rotates forward enhancing chin projection and reducing the vertical dimension (Figure 1-D). As a result of this positional change, the mandible has the potential to adapt through growth and remodeling to the new functional environment, where the condyle and mandibular body should respond with favorable growth adaptations (Figure 1-E).

The purpose of this project was to determine if vertical control of maxillary and mandibular posterior teeth is sufficient for rotating the mandible and producing a more forward and prominent chin.

The primary objective of this project was to determine whether dental intrusion is effective in treating growing retrognathic hyperdivergent patients. To this end, a number of hypotheses were tested:

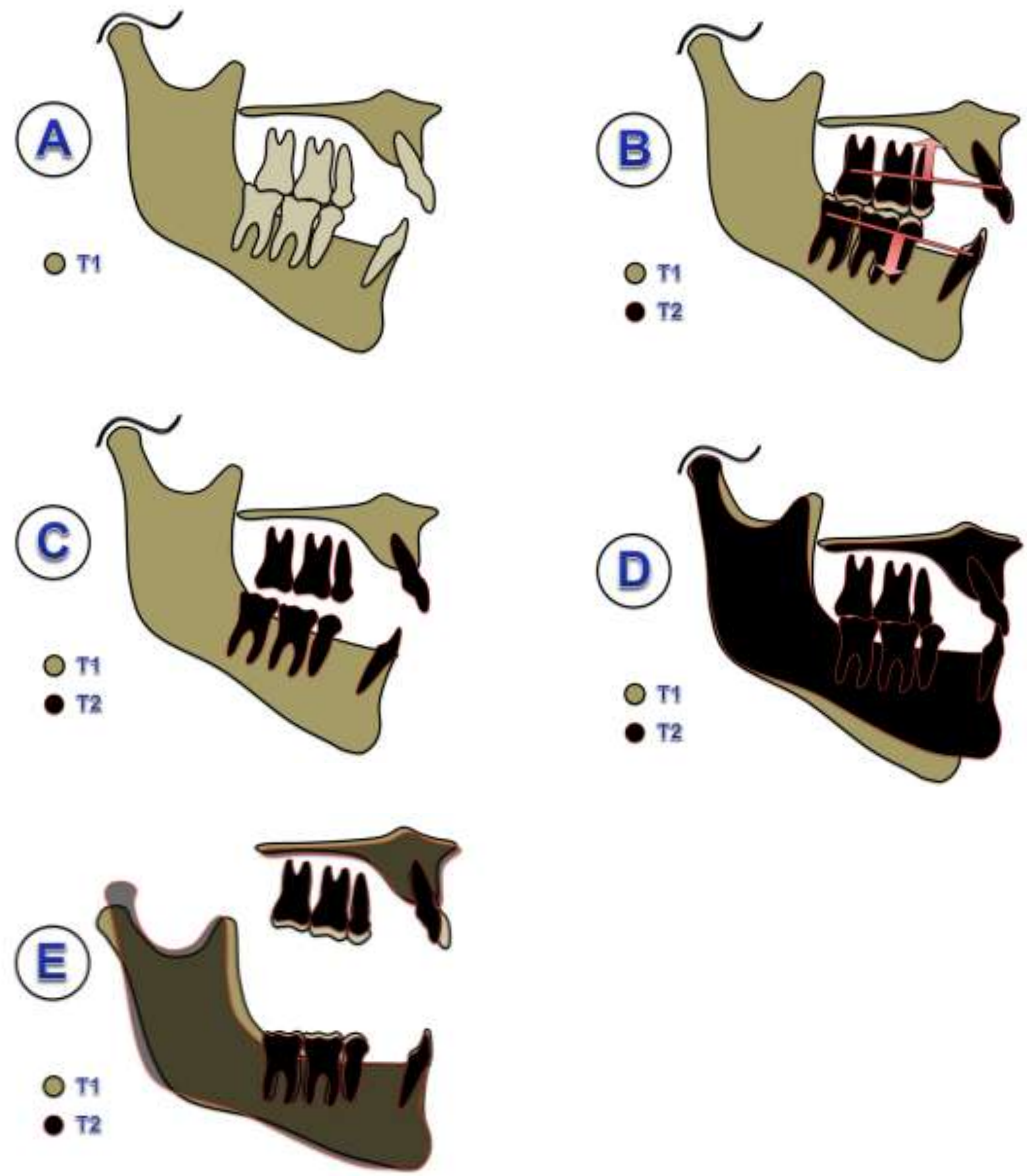
1) There is no significant difference in chin position between treated patients and untreated controls as a result of posterior intrusion.

2) There is no significant change in root length or alveolar crest height after the segmental intrusion of posterior teeth.

3) There is no significant difference in mandibular growth between treated and untreated controls after segmental intrusion of posterior teeth.

The secondary objectives of this project were to evaluate miniscrew implant stability and the patients' perceptions of the appliances used during treatment.

Figure 1. Diagram representing the optimal treatment changes for the growing retrognathic hyperdivergent patient, before (T1) and after (T2) intrusion mechanics; (A) representation of initial malocclusion; (B) intrusion and vertical control of the upper and lower dentition; (C) interdental space created between teeth to allow mandibular rotation; (D) mandibular rotation changes expected after intrusion of maxillary and mandibular dentition; and (E) expected maxillary and mandibular adaptations to mechanics.



CHAPTER II

ORTHOPEDIC CORRECTION OF GROWING RETROGNATHIC HYPERDIVERGENT PATIENTS USING MINISCREW IMPLANTS

Synopsis

The purpose of this study was to determine whether dental intrusion is effective in producing chin projection while controlling the vertical dimension of growing retrognathic hyperdivergent patients. Miniscrew implant (MSI) stability and the patients' perceptions of the appliances used during treatment were also evaluated.

The sample consisted of 17 (7 males and 10 females) consecutively treated patients who were 13.2 ±1.1 years old at the start of treatment (T1). The maxillary posterior teeth (premolars and molars) were treated using a segmental intrusion appliance. Two maxillary and two mandibular MSIs (immediately loaded with 150gr coil springs) were used for the intrusion mechanics. A matched control group was used to evaluate the skeletal changes that occurred during treatment. CBCT records were performed before (T1) and when the orthopedic phase (T2) had ended (25.3 ± 9.3 months). MSI stability was evaluated during treatment. Pain and discomfort related to the appliances used were evaluated with surveys completed before (T1) and after treatment (T2).

Significant intrusion of the maxillary posterior dentition was obtained for the treated group (2.5 ± 1.7 mm). The mandibular plane angle closed 2° ±1.7° and SNB angle increased 1.5° ±1.5°**.** Lower anterior facial height did not increase significantly

during treatment. The overall MSI failure rate was 4.6%. While the patients initially (T1) thought that the MSIs would be painful and uncomfortable, they actually were not perceived to be.

Segmental intrusion and vertical control of posterior teeth using MSIs in the maxilla and mandible is an effective mechanism for treating growing retrognathic hyperdivergent patients. Patient's growth potential is a determining factor for the differences in treatment response.

Introduction

Retrognathic hyperdivergent patients have excessive vertical dimensions and deficient chins, resulting in convex profiles.[43, 124, 186] Convex profiles are generally perceived as less favorable esthetically than profiles with a more pronounced chin projection.[8, 10, 187] In addition to the esthetic considerations, these patients also present with functional, masticatory and muscular deficiencies, as well as important respiratory impairments.[11-15]

These patients have complex three-dimensional skeletal, soft-tissue and dentoalveolar compensations that make them difficult to treat. Retrognathic hyperdivergent patients have excessive dentoalveolar heights (anterior and posterior), especially in the maxilla.[43] Skeletally, they have retrognathic mandibles and lack chin projection, due to excessive anterior vertical growth. Controlling the vertical dimension during treatment shows to be a determining factor for chin projection.[6, 188] Since orthodontic treatment can worsen the problem by rotating the mandible backwards,[107] vertical control may be the single most important factor when treating hyperdivergent patients.[6, 108-111] Importantly, the skeletal problems are primarily in the mandible;[2, 171] the ramus is short, the condyle grows in a more posterior direction, the mandibular plane is steep, the gonial angle is excessive and the symphysis is long and narrow.[43]

Common treatments for patients with vertical growth tendencies include high-pull headgear, acrylic splints with high-pull headgear, active vertical correctors, posterior bite-blocks with and without magnets and vertical pull chin-cups. Although most of these treatment alternatives are effective in correcting the dental malocclusion, in general they usually don’t have a positive impact on chin projection and soft-tissues.[112-119] Of these treatment approaches, the most effective for controlling dentoalveolar heights and increasing chin projection has been the vertical pull chin-cup.[124-131] Importantly, all of these approaches depend on patient compliance, which has been shown to be variable and difficult to measure during orthodontic treatment, but plays an important role in how these approaches affect the treatment results.[120-122]

In order to correct the skeletal dysmorphologies that characterize growing hyperdivergent patients, true forward mandibular rotation must be incorporated into their treatment. True mandibular rotation is the primary determinant of the AP position of the chin in both treated and untreated subjects.[184] Rotation could also address a number of the other problems that characterize hyperdivergent patients. In untreated subjects, true forward mandibular rotation has been associated with a greater chin projection, reductions in gonial angle, redirection of condylar growth and control of vertical eruption of the dentition.[173, 189, 190] Recently, it was suggested that in untreated individuals the vertical changes in dental position that occur during the transition from the primary to early mixed dentition are important determinants of true mandibular rotation during growth.[185]

Miniscrew implants provide an excellent means of controlling the vertical positions of the teeth. Multiple case reports and limited clinical studies of MSIs as well as other fixed anchorage devices have shown them to be successfully used for the intrusion of the dentition and mandibular rotation.[149, 150, 154, 155, 161-163, 165, 167-169, 191-198] Overall, MSIs are well accepted by orthodontists and have shown acceptable clinical stability during orthodontic treatment.[156-160] Importantly, intrusion and mandibular rotation in adults are not the same as in growing children. Non-growing individuals require active dental intrusion to produce mandibular autorotation, with the rotation axis being close to the condyle. In contrast, growing patients require only relative intrusion (holding the vertical development of the dentition) to produce true mandibular rotation (orthopedic change of the mandible), with the axis of rotation located more anteriorly, which is more effective for chin projection.

A new treatment approach has been proposed focusing on controlling the vertical dimension of both maxillary and mandibular dentition with MSIs in growing individuals.[17] By using MSIs to control the vertical dimension, patient compliance can be minimized during treatment, adding more predictability to the results. The primary objective of this project was to determine whether dental intrusion is effective in producing chin projection and controlling vertical growth in growing hyperdivergent patients. The null hypothesis was that there would be no difference in the vertical and

AP chin position between treated individuals and untreated controls. The secondary objectives were to evaluate MSI stability and the patients' perceptions of the mechanics used during treatment.

Materials and Methods

The sample consisted of 17 (7 males and 10 females) consecutively treated patients, who were 13.2 ±1.1 years old at the start of treatment. They were recruited during screenings held at the Graduate Orthodontic Clinic of Texas A&M University Baylor College of Dentistry (TAMBCD). The research protocol was approved by the TAMBCD IRB. Informed consents were obtained from all patients and parents prior to starting treatment.

Only patients who met the following criteria were included in the study:

- Premolars fully erupted
- Lower anterior facial height (ANS-ME) greater than age and sex specific mean values (based on Riolo et al.,1974[199]),
- The S-N-B angle 1 standard deviation or more below age and sex specific values (based on Riolo et al., 1974[199])
- End-on or greater bilateral Class II molar or canine relationships.

Subjects were excluded if they presented with poor oral hygiene prior to treatment or if their second molars were fully erupted into occlusion (the mesial marginal ridges of all second molars were required to be at least 2 mm apical to the distal marginal ridges of the first molars).

Maxillary arch treatment

All individuals followed the same treatment timeline and protocol (Figure 2). The treatment was started with a rapid palatal expander or RPE (Variety SP, Dentaurum, Germany), which was initially used to expand the maxillary posterior teeth and later as a rigid segmental unit to hold the premolars and molars vertically during intrusion.. The RPE was initially used to expand the maxillary posterior teeth and later as a rigid segmental unit to hold the premolars and molars vertically during intrusion. The RPE was fabricated so that the screw and arms were initially at least 3 mm away from the palatal tissues and with occlusal stops to the second maxillary molars (Figure 3A). The RPE was activated twice per day until the palatal cusps of the maxillary molars were in contact with the buccal cusps of the mandibular molars, which was usually achieved during the initial 2 months of treatment. This procedure was performed in all patients, regardless of whether or not they had posterior crossbites.

Figure 2. Timeline of treatment times for the maxillary and mandibular arches.

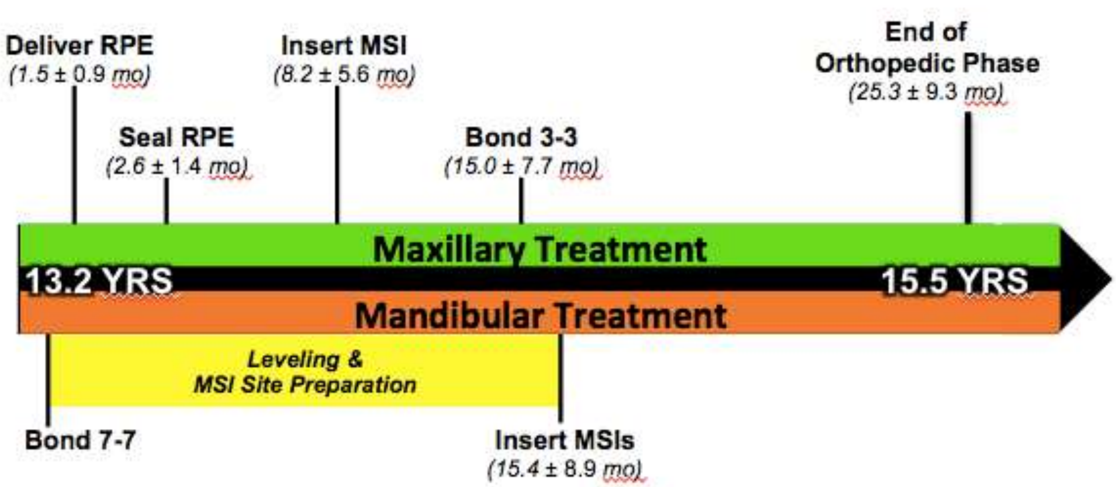
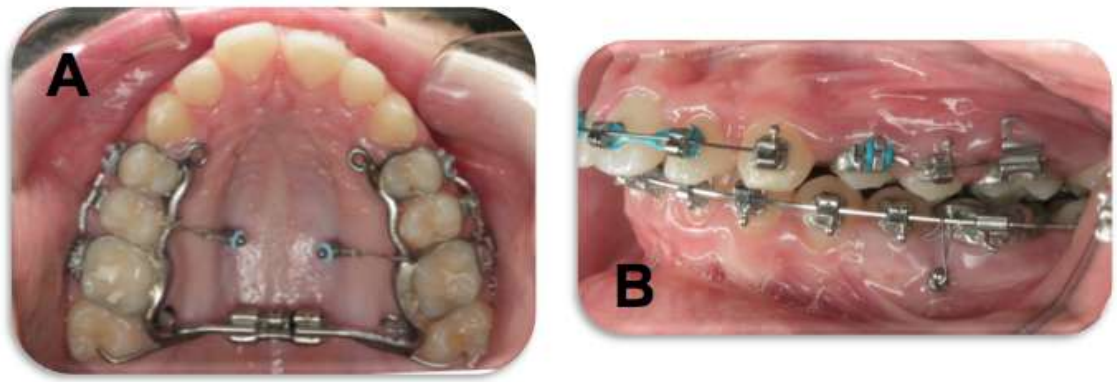
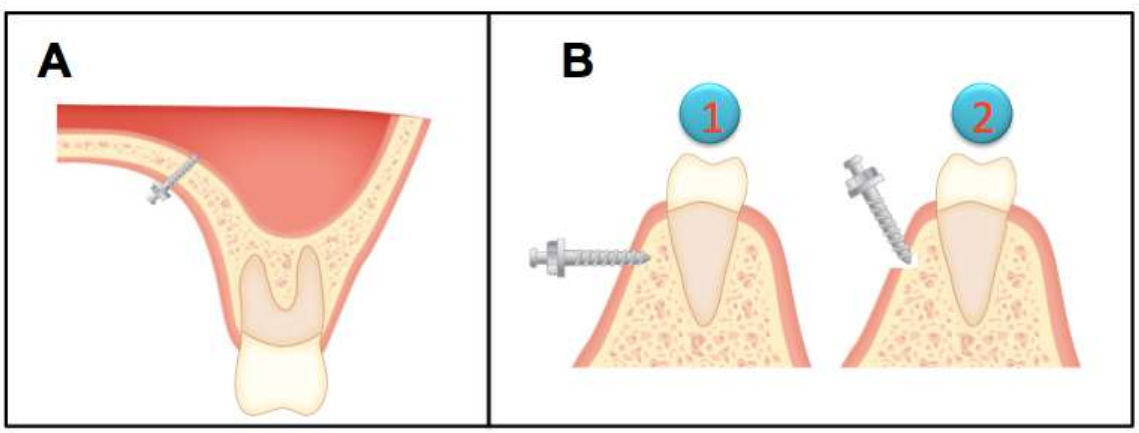


Figure 3. (A) RPE used for intrusion, including occlusal stops for the second maxillary molars and fixed appliances on the buccal surface of the maxillary posterior teeth. (B) mandibular arch with MSIs in place holding the archwire with 0.010 in stainless ligature



Approximately 8 weeks after the RPE was sealed (i.e. when the activation was stopped), two maxillary MSI's, 1.8 mm in diameter and 8 mm long (IMTEC 3M UNITEK), were placed in the parasagittal region of the palate, mesial to the first molars. Prior to MSI placement, the patients rinsed with chlorhexidine (Peridex, Zila Pharmaceuticals, Inc, Fort Collins, CO) for 30 seconds (rinsing was continued 2-3 times per day for the next 3–5 days). The technique used for MSI placement has been previously described.[200] The MSIs were placed where the palatal roof and lingual walls meet (Figure 4A). Each patient was anesthetized using topical anesthesia, followed by local infiltration of lidocaine with epinephrine (Xylocaine; Dentsply Pharmaceutical; USA) at the insertion site. A periodontal probe was used to puncture the palatal tissues; it was moved side-to-side to remove the tissue tension at the insertion sites. Using a manual contra-angle (LT-Driver; 3M UNITEK, USA), each MSI was inserted perpendicular to the cortical bone following the palate's anatomy. They were all inserted without pilot hole or tissue punch. The intrusion force was applied immediately after MSI placement using Sentalloy® coil springs (GAC international, Bohemia, NY). Each spring was calibrated using a gram force gage (Correx, Haag-Streit, Switzerland) to deliver a constant force of 150 g. The springs extended from the MSI to the RPE frame, and were ligated between the first molars and second premolars, following the protocol previously described.[201] After MSI insertion, all patients were given postoperative care instructions and had a dental hygiene check appointment one week after insertion.

Figure 4. Placement locations for (A) maxillary MSIs showing position and insertion angle used without pilot drill. . (B) Mandibular MSIs being placed following the Two-Step insertion technique, making one initial notch perpendicular to the buccal bone (B-1), then completely removing the MSI and repositioning it at the desired angulation (B-2) until fully inserted.



During the intrusion phase, all the cases were treated with segmental mechanics in the upper arch. The upper anterior teeth (canine to canine) were not bonded with fixed appliances to prevent their extrusion during the leveling phase. They served as a visual clinical assessment guide to observe the leveling of the maxillary anterior and posterior occlusal planes. The maxillary anterior teeth were bonded with fixed appliances (0.018 Slot, SPEED Industries, Canada) after they attained the same level as the posterior segments, or earlier if they were impeding the forward rotation of the mandible (i.e. if there was an anterior tooth contacting the lower dentition). After the upper arch was leveled and posterior intrusion was stopped, the RPE was removed and a transpalatal arch (TPA) was used to control torque, as well as the transverse and vertical dimensions of the maxillary first molars. Fixed orthodontic appliances were bonded on all of the maxillary posterior teeth. The MSIs were tied to the TPA using a 0.010" ligature wire for the duration of treatment, or until vertical control was not necessary.

Mandibular arch treatment

For the mandibular dentition, bands were placed on the lower first molars and fixed appliances (0.018 Slot, SPEED Industries, Canada) were placed on the remaining dentition (LR7 to LL7). The lower MSIs were not inserted until the patient had a lower 0.016×0.022 inch stainless steel wire in place (Figure 3B). To widen the site for MSI insertion in the mandible, brackets were bonded to diverge the roots between the first molars and second premolars. Periapical radiographs were taken to evaluate the interradicular spaces created. The MSIs were placed only after the interradicular space between the second premolar and first molar was ≥ 4 mm.

The mandibular MSIs were placed with the hand driver using a two-step insertion technique (Figure 4B) without pilot holes or tissue punches. The MSI were inserted at an angle with the head of the screw at the level of the mucogingival junction, as previously described.[200] The lower MSIs were loaded immediately using calibrated

150g coils, following the same protocol as in the maxilla. Lower lingual arches (LLA) were placed in 2 of the patients because their mandibular teeth were actively intruded and needed posterior torque control.

The orthopedic (i.e. intrusion) phase was terminated once the desired amount of posterior intrusion had been achieved (2.1 ± 0.8 years). This was determined by clinical assessment of the patients' profiles and dental relationships (i.e. AP and vertical relationships of the molars and anterior teeth). At the end of this phase, the RPE was removed and fixed appliances were placed on the remaining dentition. The maxillary and mandibular MSI's remained in place until full treatment was completed. The posterior teeth were held vertically using a 0.010 inch stainless steel ligature tied from the palatal MSIs to the palatal sheath in the maxillary first molar bands and from the mandibular MSIs to the archwire mesial to the first molar band in the mandible.

Except for one participant, all of the treated patients had MSIs in the upper and lower arches. This patient did not have lower MSIs because they would have impeded the mesial movement of the posterior teeth, which was necessary to close spaces.

Control sample

The treatment group was matched to 17 untreated individuals whose records were collected by the Human Growth and Research Center, University of Montreal, Montreal, Canada. The controls were matched on a case-by-case basis to the treated sample based on age, gender, Angle molar classification and pre-treatment mandibular plane angle.

Cephalometric tracing and analysis

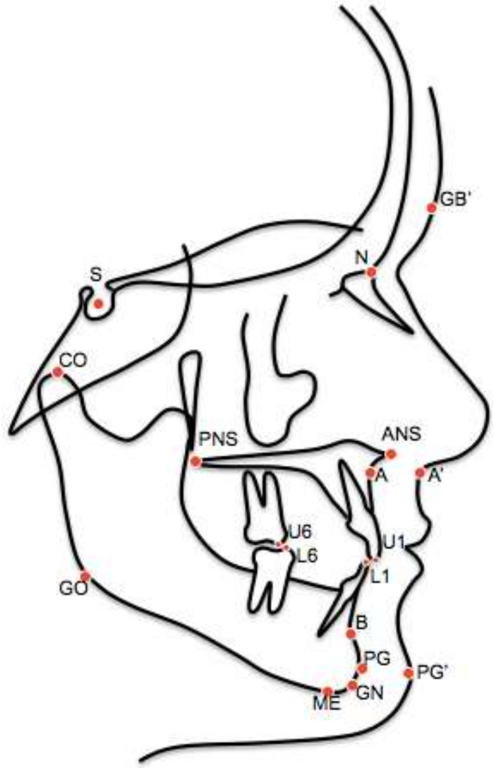
By using Dolphin Imaging (Patterson Technology, Chatsworth, CA) the treatment group's lateral cephalograms were constructed from the CBCTs taken before treatment started (T1) and after the orthopedic phase was finished (T2). The three-dimensional skulls were oriented using the right and left external auditory meatus. A lateral cephalometric radiograph was produced by segmenting the entire right half of the skull, along with a portion of the left extending to the medial border of the left orbit. Landmark identification for the treatment group was performed by the same individual.

For the control group, tracings of lateral cephalograms were obtained, scanned into the software, and adjusted for mangification. For both groups, the landmarks were digitized using Viewbox Software V4.0 (DHAL, Athens, Greece). Seventeen cephalometric landmarks, as defined according to Riolo et al.(1974)[199], were digitized (Figure 5). Nine dimensions were calculated from these landmarks, seven pertaining to AP skeletal relationships, eight pertaining to vertical dimension and four pertaining to the dentition. Replicate analysis of individuals showed no significant systematic differences or method errors. (Table 1)

Table 1. Variables and landmarks used, along with their reliabilities.

Variable	Landmarks Used
AP	
S-N-A	Sella, Nasion, A-Point
S-N-ANS	Sella, Nasion, ANS
S-N-B	Sella, Nasion, B-Point
S-N-PG	Sella, Nasion, Pogonion
N-A-PG	Nasion, A-point, Pogonion
GB’ – A’ – PG’	ST Glabella, ST A-Point, ST Pogonion
A-N-B	A-point, Nasion, B-Point
VERTICAL	
S-N/GO-ME	Sella, Nasion, Gonion, Menton
CO-GO-ME	Condillion, Gonion, Menton
S-N/GO-GN	Sella, Nasion, Gonion, Gnathion
S-N/OP	Sella, Nasion, Functional Occlusal Plane
S-N/PP	Sella, Nasion, ANS, PNS
PFH	Sella, Gonion
LFH	ANS, Menton
AFH	Nasion, Menton
DENTAL	
U1-PP	U1 tip, ANS, PNS
U6-PP	U6 mesial cusp, ANS, PNS
L1-MP	L1 tip, Gonion, Menton
L6-MP	L6 mesial cusp, Gonion, Menton

Figure 5. Landmarks used in this study.



Survey of pain and discomfort

All participants completed an initial survey to assess how much pain and discomfort they expected to be associated with the appliances and procedures. They completed the initial survey after having been shown a typodont with the appliances that were going to be used during treatment. The follow-up survey was completed by the patients the day the RPE was removed and the orthopedic phase was terminated. The surveys asked the following questions:

1. How uncomfortable do you expect the appliances (MSI, expander and braces) to be? Same question asked by the follow-up survey (both questions were answered using a Likert scale).
2. How painful do you expect the appliances (MSI, expander and braces) to be? Same question asked by the follow-up survey (answered using a Likert scale).
3. How much would you recommend this treatment to friends and family? Only asked by the follow-up survey (answered using a Likert scale).

Statistical analysis

The calculated measurements were transferred to SPSS Software (version 19.0; SPSS, Chicago, IL) for evaluation. Analysis of skewness and kurtosis showed that the variables were normally distributed. Paired and independent sample t-tests were used to evaluate within group changes and between group differences, respectively. The questions were evaluated using descriptive statistics and compared using a Wilcoxon Signed Ranks Test. A probability level of 0.05 was used to determine statistical significance.

Results

Throughout treatment, periodontal health was closely monitored and the need to maintain proper hygiene was emphasized. The clinical crowns were temporarily shortened during intrusion. There also was palatal tissue bulging during the intrusion phase of treatment. The overgrowth disappeared in all cases after intrusion was completed and the teeth had been held in place for 2–3 months.

For this study, MSI failure was defined as removal of the MSI or any MSI that became mobile when applying an intrusion force with a coil spring or when attaching the stainless steel ligature. The MSIs had an overall failure rate of 4.6%. Of the 66 MSIs that were placed, only 3 failed (one patient had no MSIs placed on the lower arch due to interferences with the mesial movement of a lower molar). There were 34 MSIs placed in the maxilla (2 of which failed) and 32 placed in the mandible (1 of which failed). This resulted in a slightly higher failure rate in the maxilla (5.9%) than in the mandible (3.1%), but the difference was not statistically significant.

When asked how much they would recommend this treatment to friends and family, 58.8% answered “very” or “extremely”, almost 30% answered “moderately” and nobody answered “slightly" or "not at all” (Figure 6). Approximately 29% of the patients initially thought that the MSIs would be either “very” or “extremely” uncomfortable. (Figure 7) This was significantly different ($p<0.05$) than when they were asked the same question after the intrusion phase, at which time 53% said that the MSIs were “not at all” uncomfortable, 35.3% said they were “somewhat” uncomfortable, and 11.8% said they were “moderately” uncomfortable. No one indicated that the MSIs as being “very” or “extremely” uncomfortable. Initially, only 11.8 % said that they did not expect any pain with the MSIs. (Figure 8) Almost 30% thought that they would be "very" or "extremely" painful. The post-intrusion survey showed significant ($p<0.001$) changes in patient perception, with 100% of the patients responding that the MSI were “not at all” painful.

Figure 6. Responses to the question "How much would they recommend this treatment to friends and family?"

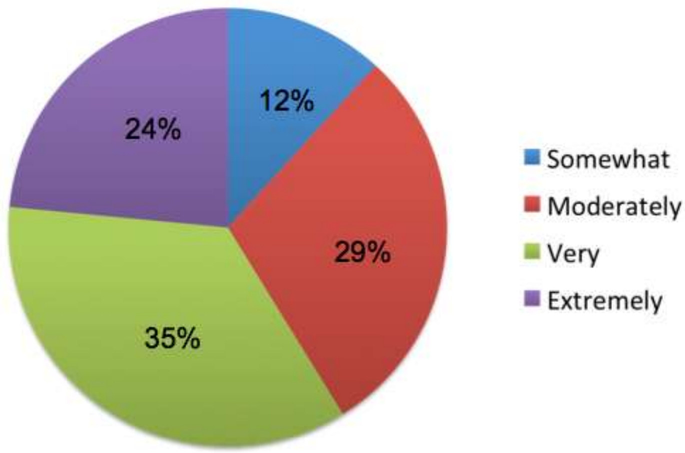


Figure 7. (A). How uncomfortable did the patients expect the appliances to be and (B) how uncomfortable they actually were

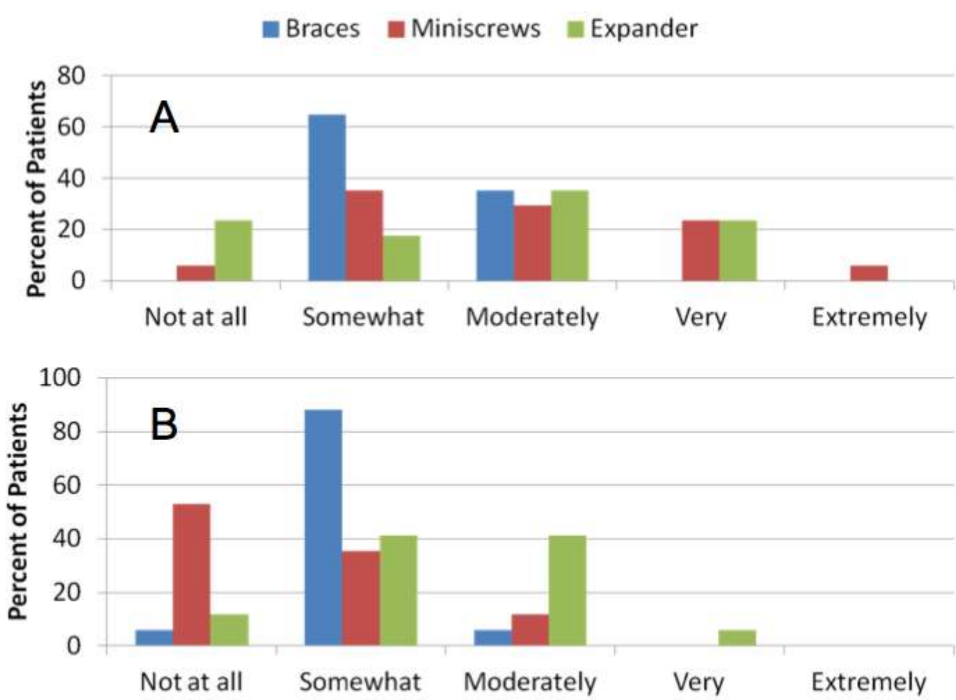
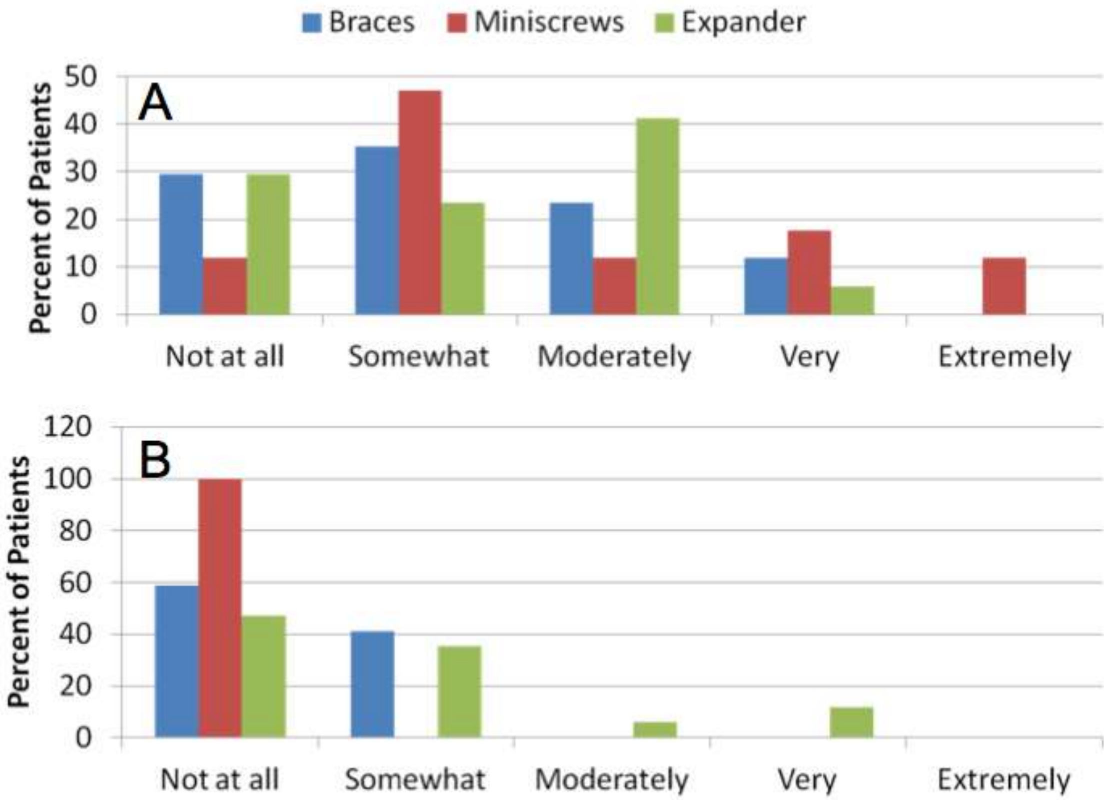


Figure 8. (A) How painful did the patients expect the appliances to be and (B) how painful they actually were.



Cephalometric comparisons

The only pre-treatment measurement that showed statistically significant ($p<0.05$) group differences were S-N/PP, PFH, LFH and L6-MP. The treatment group was consistently larger than the controls, while the controls had larger palatal plane angles (Table 2).

The S-N-A and S-N-ANS angles showed no statistically significant group differences during treatment (Table 3). In contrast, all measures of AP mandibular position showed significant group differences. The S-N-B and S-N-PG angles increased approximately 1.5 degrees more in the treated than the control group. Hard-tissue convexity (N-A-PG) decreased 3.4° more in the treated group (3.6°± 2.9). Soft-tissue convexity (GB'-A'-PG') decreased 2.0° more in the treated than the control group. The A-N-B angle decreased 1.5° in the treated group and did not change significantly in the controls.

Table 2. Pre-treatment cephalometric comparisons of the treatment group and matched controls.

Variable	Units	TX Group		Control		Group Differences	
		Mean	SD	Mean	SD	Mean	Prob
				AP			
S-N-A	Deg	79.2	4.4	78.9	2.4	0.25	0.841
S-N-ANS	Deg	85.5	4.2	85.5	2.8	-0.03	0.977
S-N-B	Deg	74.1	3.8	74.6	2.5	-0.50	0.653
S-N-PG	Deg	74.8	3.5	75.2	2.4	-0.46	0.653
N-A-PG	Deg	8.8	4.6	7.5	4.2	1.30	0.399
GB' – A' – PG'	Deg	16.9	4.4	17.3	4.4	-0.46	0.767
A-N-B	Deg	5.1	1.9	4.4	2.2	0.74	0.304
				VERTICAL			
S-N/GO-ME	Deg	43.8	3.1	43.3	2.7	0.53	0.602
CO-GO-ME	Deg	130.1	4.2	130.5	3.6	-0.38	0.777
S-N/GO-GN	Deg	41.2	3.2	41.2	2.5	0.06	0.952
S-N/OP	Deg	20.2	3.7	19.3	3.6	0.90	0.474
S-N/PP	Deg	7.2	2.9	10.1	3.9	-2.91	0.018
PFH	mm	69.4	4.7	65.5	6.2	-3.85	0.048
LFH	mm	69.7	4.0	65.0	5.8	-4.74	0.009
AFH	mm	116.1	4.6	111.9	7.7	-4.17	0.065
				DENTAL			
U1-PP	mm	29.3	2.4	28.0	3.0	-1.34	0.164
U6-PP	mm	22.9	2.6	22.1	2.4	-0.74	0.396
L1-MP	mm	39.7	2.3	39.1	3.2	0.57	0.549
L6-MP	mm	30.7	2.4	28.2	3.5	2.5	0.021

Statistically significant vertical skeletal changes associated with treatment were observed in the mandible. The mandibular plane angles (S-N/GO-ME and S-N/GO-GN) decreased 2.0°±1.7 and 2.0°±1.9, respectively, in the treated group, and did not change in the control group. The treatment showed no significant increases in lower face height (LFH), while the control group increased 3.0 ± 2.9 mm. No group differences were observed in posterior facial height changes.

Table 3. Treatment changes of cephalometric variables compares to untreated control changes.

Variable	Units	TX Group		Control		Group Differences	
		Mean	SD	Mean	SD	Mean	Prob
			AP				
S-N-A	Deg	-0.1	1.5	0.1	1.4	-0.19	0.703
S-N-ANS	Deg	0.8	1.6	0.6	1.6	0.12	0.823
S-N-B	Deg	1.5	1.5	0.04	1.0	1.42	0.002
S-N-PG	Deg	1.8	1.5	0.2	1.0	1.56	0.001
N-A-PG	Deg	-3.6	2.9	-0.2	2.4	-3.41	0.001
GB’ – A’ – PG’	Deg	-2.2	2.2	-0.2	2.2	-2.03	0.016
A-N-B	Deg	-1.5	1.3	0.03	1.0	-1.58	0.001
			VERTICAL				
S-N/GO-ME	Deg	-2.0	1.7	-0.1	1.2	-1.85	0.001
CO-GO-ME	Deg	-0.8	2.1	-0.7	1.7	-0.12	0.859
S-N/GO-GN	Deg	-2.0	1.9	-0.2	1.5	-1.80	0.005
S-N/OP	Deg	3.9	2.3	-0.9	1.5	4.76	0.000
S-N/PP	Deg	-0.6	1.4	0.1	1.2	-0.71	-0.127
PFH	mm	2.9	3.1	3.5	3.6	0.60	0.609
LFH	mm	0.3	3.0	2.9	2.8	2.60	0.013
AFH	mm	1.7	3.9	4.4	4.1	2.71	0.061
			DENTAL				
U1-PP	mm	0.8	1.2	0.7	1.0	-0.09	0.823
U6-PP	mm	-2.5	1.7	1.5	1.4	3.93	<.001
L1-MP	mm	-0.7	1.5	-1.4	1.3	-0.75	0.139
L6-MP	mm	-2.0	1.6	-1.6	1.7	0.44	0.444

The occlusal plane (S-N/OP) increased 3.9°±2.3 in the treatment group and decreased in the control group, resulting in a difference of almost 5°. The maxillary first molars (U6-PP) were intruded significantly (2.5 mm± 1.7) during treatment, while they erupted in the control group, producing a difference of approximately 4 mm. None of the other dental measurements showed statistically significant group differences.

Discussion

For this novel treatment alternative to be successful, it had to be well accepted by the patients. The results showed that the treatment was well accepted by the participants, with 58.8% indicating that they were very or extremely likely to recommend it to their friends and family. This high rate of acceptance was probably due to the lack of pain and discomfort that they experienced, as well as the favorable functional, facial and dental changes that occurred during treatment.

The patients' initial perceptions of how uncomfortable and painful the MSIs would be changed considerably during the course of treatment. Initially, many of them expected the MSIs to be "very or "extremely" uncomfortable, and even more thought they would be "very or "extremely" painful. At the end of treatment, most of the patients reported that the MSIs were 'not at all' uncomfortable, and all of them thought they were "not at all" painful. This indicates that the MSIs were well accepted by the patients, confirming previous reports.[202-205]

MSI stability at the chosen implant sites was excellent and better than expected. The overall success rate was 95.4%, which was higher than previously reported for other

MSIs, which report a range from 70%-93%.[156, 206-212] MSI stability obtained compares well with that reported in a recent systematic review for short dental implants, which ranges from 92.2% to 100%.[213]

The high stability found in the present study is particularly important because it has been suggested that patients with higher mandibular plane angles tend to have lower success rates.[202, 203, 207, 209] One possible factor that could explain the higher MSI success rates in the present study is the length of the MSIs (8 mm) used. Since trabecular bone adapts around MSIs and enhances their stability,[214] a longer screw allows more surface areas for the bone to make contact with the MSI. The fact that the MSIs were placed in younger patients, whose cortical bone is not as dense as adult cortical bone, may also have played a role, because the insertion stress to the cortical bone would not have been as high. Also, and perhaps most importantly, the careful preparation of the implant site prior to insertion, especially in the mandible, where they were placed into interradicular bone, could have contributed to the success rates observed.

Although the results of this study show that the mandibular MSIs were more stable (96.9%) than the palatal maxillary MSIs (94.1%), the difference was not statistically significant. Whether MSI success rates are greater in one jaw than the other remains controversial, with some studies showing no significant differences between jaws[159, 211, 215] and others showing differences.[156, 158, 160, 194, 207, 210] A lower success rate (90%) has been reported for MSIs placed in similar palatal sites.[202] Moon et al (2010)[209] who place similar sized mandibular MSIs (1.6 diameter and 8mm length) in the same site as the present study showed 73.3% success rate. However, they loaded the MSIs with 150-200 grams of force 2-3 weeks post implant placement, while those in the present study were immediately loaded with 150gr. Moreover, the technique used for the placement of mandibular MSIs in the present study makes it possible to angle the MSI heads. As such, the threads of the MSIs go deeper into trabecular bone rather than the alveolar crest.

The vertical dimension was significantly reduced during treatment. The mandibular plane angle decreased substantially more than in the controls. The reduction in the mandibular plane angle (2.0°±1.9) compares well with the available literature that has used MSIs as anchorage (Table 4). Xun et al (2007),[169] who used MSI anchorage in both upper and lower jaws of young adults, reported MPA decreases of 2.3°± 0.8° as a result of treatment. Buschang et al (2012),[168] reported a 0.9° reduction of the MPA in patients aged 12.3 ± 1.8 years, but less than 30% of their patients had MSIs holding the vertical dimension of the teeth in both jaws. Studies that have used titanium mini-plates for anchorage during intrusion have reported reductions in the MPA ranging from 1.3° with plates in only one arch,[149] to 3.3° with plates in the maxilla and the mandible.[152] The fact that anterior lower face height did not change in the treated group, whereas it increased almost 3 mm in the untreated controls, demonstrates good vertical control of anterior growth in the present study.

Table 4. Literature comparison of the most relevant literature on the treatment of hyperdivergent patients with different treatment approaches.

Reference	Age (years)	Sample size	SNB/ SN.Pog*	MPA	Treatment Approach
SKELETAL ANCHORAGE					
Sugawara et al (2002)[149]	13 to 29	9	0.4	-1.3	Plates (MD only)
Sherwood et al (2002)[196]	Adults	4	1.9	-2.6	Plates (MX only)
Erverdi et al (2004)[155]	17 to 23	10	1.8	-1.7	Plates (MX only)
Kuroda et al (2007)[152]	16 to 46	10	1.5	-3.3	Plates (MX & MD)
Akay et al (2009)[197]	15 to 25	10	1.6	-3.0	Plates (MX only)
Seres and Kocsis (2009)[198]	15 to 29	7	NA	-3.1	Plates (MX only)
Xun et al (2007)[169]	14 to 27	12	1.6	-2.3	MSIs (MX & MD)
Buschang et al (2012)[168]	12.3 ±1.8	18	1.3	-0.9	MSIs (72% MX only; 28% MX & MD)
Present Study	**13.2 ±1.1**	**17**	**1.5**	**-2.0**	**MSIs (MX & MD)**
ORTHOPEDIC					
Pearson (1978)[125]	9 to 13	20	NA	-3.9	Chin cup and premolar extractions
Sankey et al (2000)[127]	8.3 ± 1.8	38	0.3	-0.3	Chin cup and posterior bite-block
Basciftci et al (2002)[128]	12.6	17	-0.0	-0.3	RPE and chin cup
Işcan et al (2002)[129]	7-10	18	NA	-1.4	Chin cup
Torres et al (2006)[130]	7- 10	30	0.3	-0.6	Removable palatal crib and chin cup
Cassis et al (2012)[131]	8.1 ± 0.7	30	-0.0	0.0	Bonded spurs and chin cup
Haralabakis and Sifakakis (2004)[30]	10.4 ± 1.3	31	0.7*	0.2	CPHG
LaHaye et al (2006)[184]	9-14	23	0.2	0.3	NE HG
LaHaye et al (2006)[184]	9-14	25	0.2	-0.2	EXT HG
SURGERY					
Washburn et al (1982)[216]	10-16	12	NA	-3.3	Surgery (only MX)
Mojdehi et al (2001)[42]	11-15	15	2.0	-3.4	Surgery (only MX)
Kuroda et al (2007)[152]	16 to 46	13	0.0	-0.3	Surgery (MX & MD)

When compared to other treatment approaches used in growing individuals (Table 4), the mandibular plane changes observed in this study were greater than previously reported for vertical-pull chin-cup[127-131] and headgears.[30, 184] The exception is one study by Pearson (1978),[125] who reported a mean decrease of 3.9° when using vertical pull chin-cup and extraction treatment in patients 9-13 years of age. Surgery studies of maxillary impaction on growing individuals show greater improvements of the vertical dimension, with decreases in the mandibular plane from 3.3° to 3.4°.[42, 216]

Hyperdivergent patients have important dentoalveolar compensations, primarily due to the fact that the maxillary posterior teeth have over erupted. In order to enhance chin projection and control the vertical dimension in a growing hyperdivergent individual during treatment, it was necessary to control both the upper and lower dentition. The upper molars in this study were intruded 2.5±1.7 mm during treatment, whereas they erupted 1.4±3.93 mm in the untreated controls. The lower molar erupted only slightly, but not significantly, more than the controls, demonstrating that the lower molars did not completely compensate for the upper molar intrusion. This is a positive treatment effect that, at least partially, accounts for the improvements of the vertical dimensions observed.

The improved AP relationships of the treated group were due to mandibular changes because the maxilla was not affected by treatment. Vertical control during treatment allowed the mandible to rotate forward, which is an important determinant of chin position.[184] All AP changes of the mandible were significant in the treated group, whereas they were not in the controls. As B-point and pogonion advanced 1.5°±1.5 mm and 1.8°±1.5 mm, respectively, the chin moved forward. The changes in chin projection compare well to previous studies that used fixed anchorage devices for vertical control.[149, 152, 155, 169, 197] Studies that used skeletal anchorage to intrude both the upper and lower dentition have reported SNB changes ranging from 1.3° to 1.6°. [61, 62, 86] AP treatment changes in the present study are only slightly less than those produced with maxillary impaction surgery; Mojdehi et al.[42] reported a 2° change of SNB after maxillary impaction surgery in growing individuals.

Although all patients followed the same treatment protocol, there were differences in how they responded. The patients fell into one of three categories:

1. **Patients with growth and a good chin projection:** all of these patients had acceptable treatment results. They grew the most during treatment and the biomechanics were able to successfully intrude/control the upper and the lower dentition throughout the orthopedic phase of treatment. These patients required only limited amounts of intrusion, and good control of both upper and lower dentition (Figure 9). All patients with growth had good chin projection, which is why there is no category of patients with growth with poor or limited chin projection.
2. **Patients with limited growth and a good chin projection:** these patients also had acceptable treatment results. Importantly, since they only grew limited amounts during treatment, their results were highly dependent on the intrusion/control of the dentition (Figure 10).
3. **Patients with limited growth and a limited chin projection:** these patients exhibited little or no growth and the vertical control/intrusion was less than it could have been during treatment. Although the dental relationships were finished as acceptable, better skeletal changes could have been produced if the dentition had been better controlled during treatment (Figure 11).

Figure 9. Case representing patients with growth and a good chin projection. (A) Initial photos, (B) superimposition of start of treatment and the end of orthopedic (intrusion) phase tracings, and (C) photos at the end of the orthopedic (intrusion) phase.

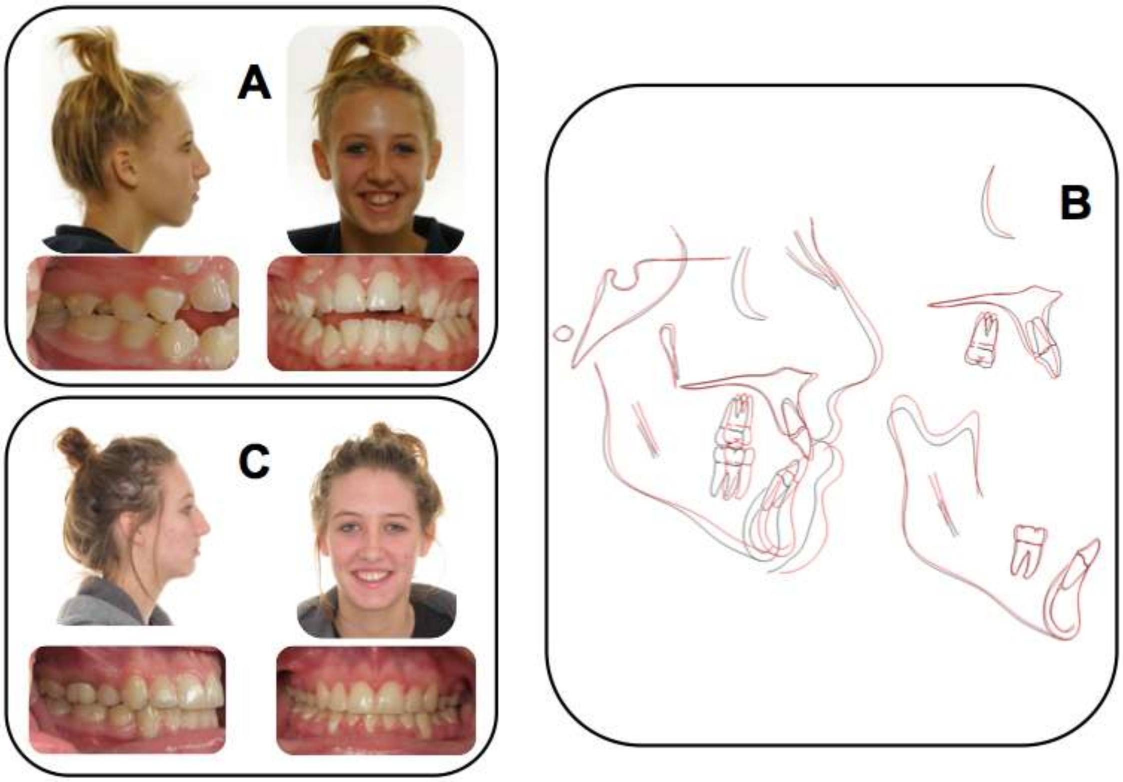


Figure 10. Case representing patients with limited growth and a good chin projection. (A) Initial photos, (B) superimposition of start of treatment and the end of orthopedic (intrusion) phase tracings, and (C) photos at the time of appliance removal at the end of treatment.

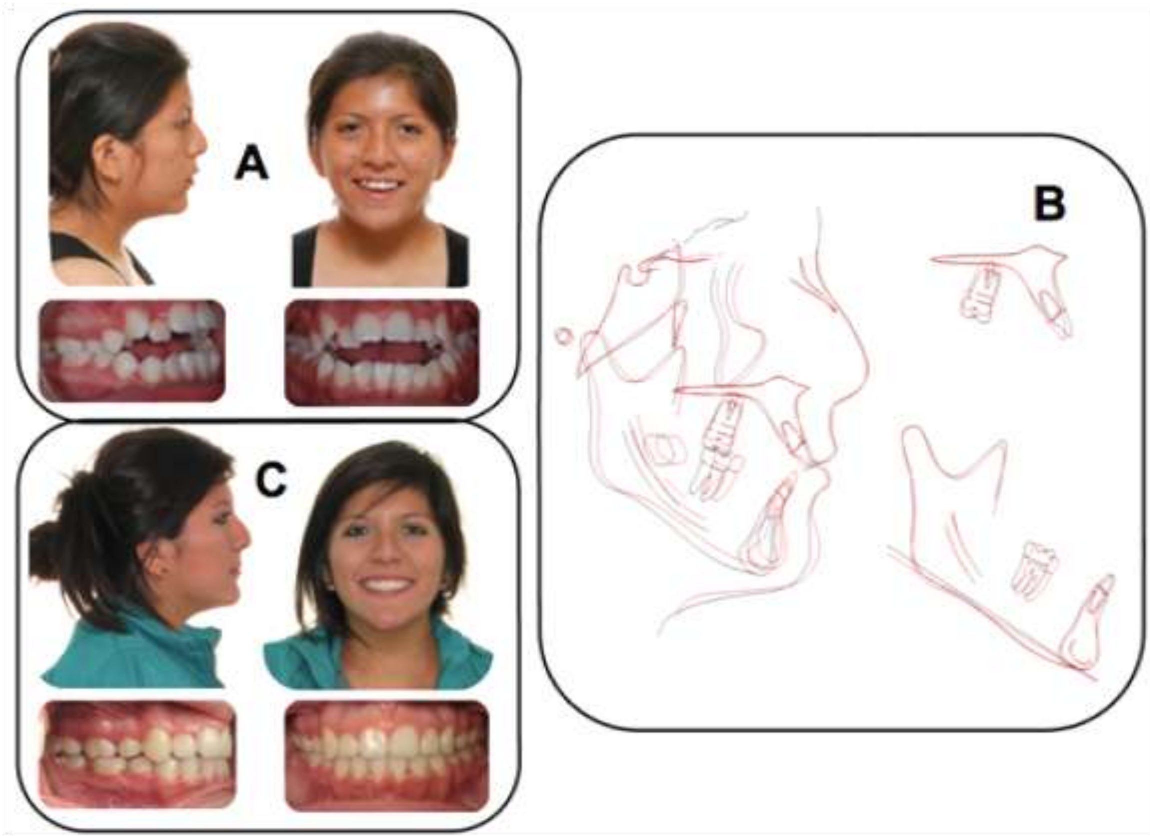
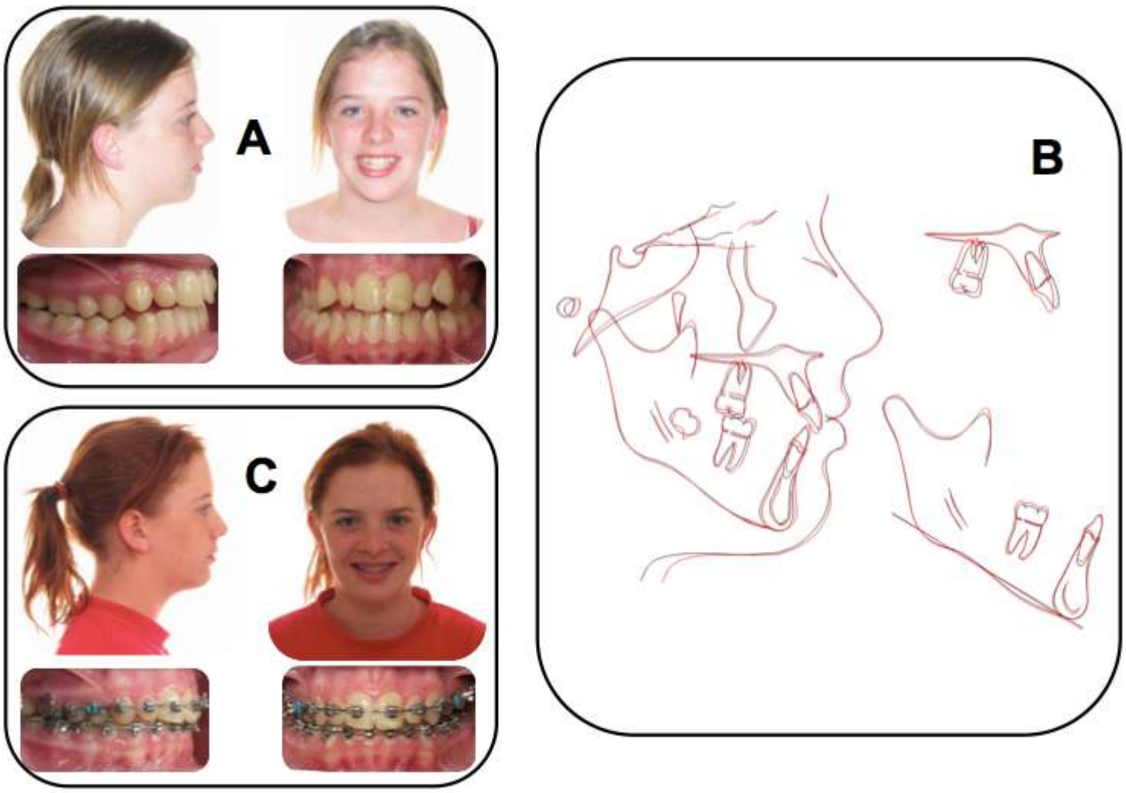


Figure 11. Case representing patients with limited growth and a limited chin projection. (A) Initial photos, (B) superimposition of start of treatment and the end of orthopedic (intrusion) phase tracings, and (C) photos at the end orthopedic (intrusion) phase.



The case in Figure 9 (patient with growth and a good chin projection) finished her orthopedic phase with a slight posterior open-bite. With growing patients such as this, who develop posterior open-bites during the initial phase of treatment, there is no need to intrude for extended periods of time. The mechanics are designed to hold the dentition, resulting in "relative intrusion" as the patient grows. Also, the upper anterior teeth (U3-3) were bonded and kept in a segmental wire until the posterior teeth reached their vertical level. The only thing limiting her mandibular rotation was contact of the anterior dentition. Once an anterior contact is noted, the orthodontist needs to decide if more rotation is needed. If so, the anterior teeth (maxillary or mandibular) will have to be intruded so that the mandible can continue to rotate forward. The decision on which anterior teeth to intrude (upper or lower) usually depends upon esthetic considerations (i.e., maxillary incisor display on smile). If no more rotation is needed, then the orthopedic (intrusion) phase is terminated and regular orthodontic mechanics can be used to finish the case, always maintaining the vertical control as long as possible during the finishing stages of treatment.

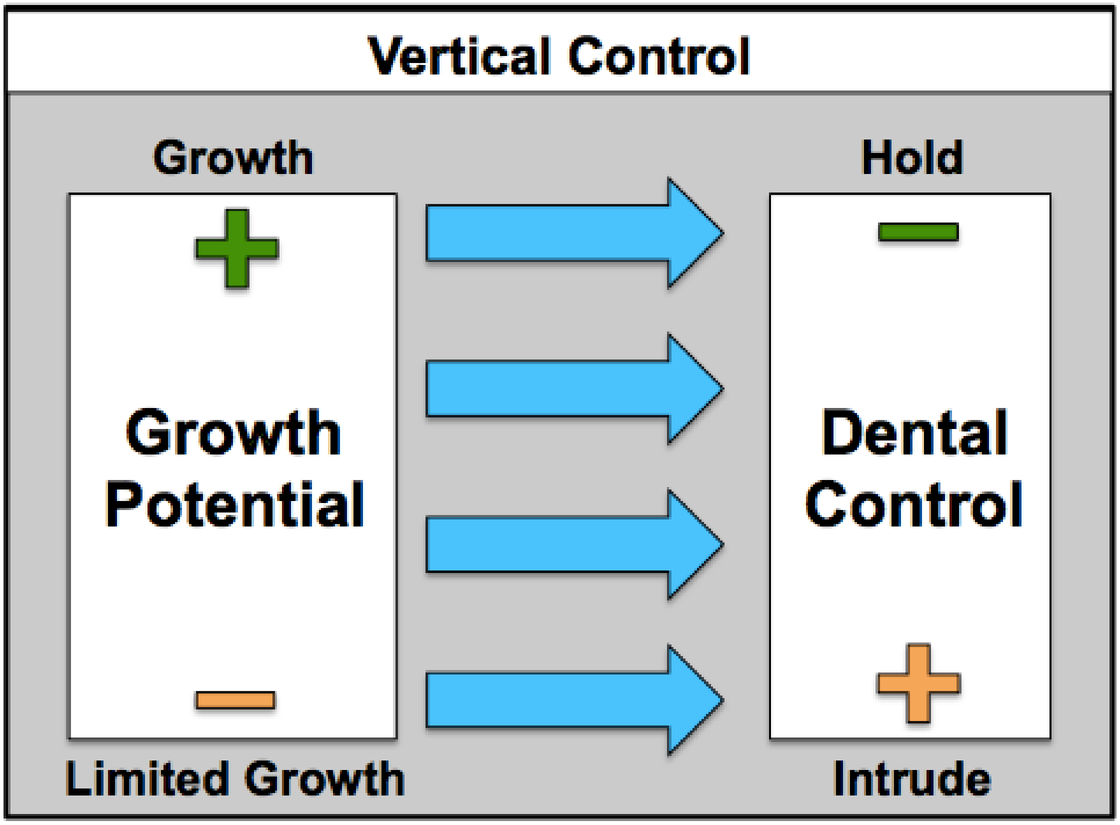
The patient in Figure 10 illustrates a patient with limited growth who had an acceptable amount of chin projection. This case shows significant maxillary intrusion, small amounts of intrusion of the lower posterior dentition and good vertical control of the anterior teeth of both arches. It is important to point out that this case was treated with extractions of upper and lower premolars, making it especially important to control the extrusion of the dentition as the space-closure mechanics took place. For patients with limited growth potential such as this, it is always necessary to plan for posterior intrusion of both upper and lower arches.

The patient in Figure 11 was also a patient with limited growth, whose vertical dimension was not well controlled. This was the only patient who did not have lower implants inserted. Even though the dental needs were met (upper arch was leveled and the open bite was resolved), the skeletal correction was somewhat less than desired. Chin projection was limited due to the fact that the lower molars compensated for the intrusion of the upper molars and prevented maximum mandibular rotation and chin projection. The patient finished with a clinically acceptable profile, but had the smallest orthopedic changes of the entire treatment group. A way to prevent other patients from having similar results is to have control of the lower dentition (as previously shown) and be able to maximize mandibular rotation.

Figure 12 illustrates the proposed treatment model. The differences in chin projection were dependent on how much the patients grew and how well the vertical dimension of the dentition was controlled during treatment. There was an inverse relationship between growth potential and vertical dental control during treatment. The need for dental intrusion was less for the patients with greater growth (i.e. those that exhibited more condylar growth) than for the patients with limited growth potential. For the patients with greater growth during active treatment, it was sometimes simply necessary to hold the dentition in place and allow growth rotation to occur.

Understanding the relationship and being able to apply it clinically can greatly assist the orthodontist when monitoring cases during treatment. For this sample, how the patients grew during treatment, and how well the dentition was controlled, were related to the amount of chin projection that the patients finished with.

Figure 12. Vertical control treatment model. Represents the inverse relationship between the patient's growth during treatment and the vertical control needed to have the best chances of improving chin projection.



CHAPTER III

MANDIBULAR GROWTH, MODELING AND ROTATION OF TREATED GROWING RETROGNATHIC HYPERDIVERGENT PATIENTS

Synopsis

The purpose of this study was to determine how intrusion of the posterior teeth of growing hyperdivergent patients affects mandibular growth and modeling.

The sample consisted of 17 consecutively treated patients who were 13.2 ±1.1 years old at the start of treatment. The maxillary posterior teeth (premolars and first molars) were intruded as a segment using a rigid RPE appliance. Four miniscrew implants (MSIs-two palatal and two mandibular) were used as anchorage for the intrusion mechanics. The changes that occurred during treatment were compared to untreated controls, matched based on age, sex, occlusion and mandibular plane angles. Analyses were based on cephalograms obtained from CBCT records taken at the beginning (T1) and end (T2) of the orthopedic (intrusion) phase, which lasted 25.3 ± 9.3 months. Cranial base superimpositions were used to evaluate true mandibular rotation; mandibular superimpositions were used to assess condylar growth and mandibular modeling changes. Non-parametric statistics were used to compare and describe group differences and relationships.

True forward rotation of the treated sample was significantly ($p<.05$) different (1.8° greater) than in the controls. All landmarks showed significant growth and modeling changes in both groups. In the treated group, condylion showed the greatest

overall change. The treated group tended to show greater superior and less posterior growth of the condyle than the controls, but the differences were not statistically significant. Only the lower incisor showed statistically significant group differences; its vertical position did not change in the treated group while it erupted 1.5 mm in the controls. While true rotation was correlated with the growth and modeling changes in the control group, there were no relationships in the treated group.

Intrusion of the posterior teeth in growing patients produced a significant true forward mandibular rotation. There were no group differences in condylar growth and mandibular remodeling.

Introduction

It has been well established that most of the mandible's surface changes during growth. The condyle grows and the cortical bone remodels. These are adaptions to changing functional relationships as the mandible alters its position and increases its size.[108, 172] The ramus grows and remodels primarily in a superior and posterior direction; it undergoes greater changes than the corpus of the mandible.[172-176] The condyle exhibits greater growth than most other aspects of the mandible.[172, 174] While bone is being resorbed along the lower border between gonion and the molars, it is typically being added below the symphyseal region. The superior aspect of the symphysis drifts superiorly and posteriorly.

These growth and modeling changes have been related to the type of true mandibular rotation that occurs. Individuals who undergo forward rotation show distinctly different growth patterns than do backward rotators. Compared to backward rotators, forward rotators exhibit greater and more superiorly directed condylar growth, greater decreases of the gonial angle, more and distinctive modeling of the lower border, more limited increases in lower face height, proclination of the lower incisors, and more chin projection. [6, 173, 189]

Mandibular growth and modeling also adapt to treatment imposed changes in mandibular position, following similar patterns exhibited by untreated individuals. Growing individuals who received maxillary impaction surgery and autorotation of the mandible showed more superiorly directed condylar growth than matched untreated controls.[42] Similarly, mixed dentition patients treated with vertical-pull chin cups showed more superiorly directed condylar growth and greater chin projection than untreated controls.[127] In general, functional appliances show condylar adaptations to altered mandibular positions.[217] The bionator, which rotates the mandible posteriorly, has been shown to modify condylar growth in a more posterior direction.[218] Other functional appliances, such as the Herbst, generally produce a more posterior growth direction of the condyle, especially in hyperdivergent patients.[219, 220]

If the mandible adapts similarly to true rotation in both untreated and treated individuals, then, theoretically, the skeletal problems that retrognathic hyperdivergent individuals present with could be addressed by true forward rotation of the mandible. Hyperdivergent subject have excessive anterior facial height, supraeruption of the teeth, large gonial angles, reduced ramus height, and retrognathic chins.[18, 43] The majority of these individuals maintain or worsen their vertical growth patterns over time.[44, 45]

The primary purpose of this study was to determine whether the growth and modeling of the mandible adapts to the true rotation produced by intrusion of the posterior teeth using miniscrew implants (MSIs) in growing hyperdivergent patients.

Materials and Methods

The treated group consisted of 17 (7 males and 10 females) consecutively treated patients. The mean age at the start of treatment was 13.2 ±1.1 years. They were recruited during screenings held at the Graduate Orthodontic Clinic of Texas A&M University Baylor College of Dentistry (TAMBCD). The research protocol was approved by the TAMBCD IRB. Informed consent was obtained from all patients and parents prior to starting treatment.

Only patients who met the following criteria were included in the study: premolars had to be fully erupted, lower anterior facial height (ANS-ME) had to be greater than age and sex specific mean values (based on Riolo et al., 1974[199]), the S-N-B angle had to be at least one standard deviation below age and sex specific mean values (based on Riolo et al., 1974[199]), and the subjects had to have end-on or greater bilateral Class II molar or canine relationships. Subjects were excluded if they presented with poor oral hygiene prior to treatment or if their second molars were fully erupted into occlusion.

The treatment of the maxillary arch for all individuals started with a rapid palatal expander or RPE (Variety SP, Dentaurum, Germany). The RPE was used to expand the maxillary posterior teeth and later as a rigid segmental unit to hold the premolars and molars vertically during intrusion. The RPE was activated in all of the patients twice per day until the palatal cusps of the maxillary molars were in contact with the buccal cusps of the mandibular molars.

The RPE was sealed approximately 8 weeks after the end of activation and two maxillary MSI’s, 1.8 mm in diameter and 8 mm long (IMTEC 3M UNITEK), were placed in the parasagittal region of the palate, mesial to the first molars. Using a manual contraangle (LT-Driver; 3M UNITEK, USA), the MSIs were placed where the palatal roof and lingual walls met. Each MSI was inserted without the use of a pilot hole or tissue punch perpendicular to the palate’s cortical bone anatomy, as previously described.[200] The intrusive force was immediately applied after MSI placement using Sentalloy® coil springs (GAC international, Bohemia, NY). Each MSI had one spring attached extending to the RPE frame and calibrated to deliver a constant force of 150 g, as verified using a gram force gage (Correx, Haag-Streit, Switzerland).

During the posterior intrusion phase, the upper anterior teeth (canine to canine) were not bonded with fixed appliances. This was done to prevent their initial extrusion during the leveling phase. Additionally, the anterior teeth served as a visual clinical assessment guide to assess the height of the posterior maxillary occlusal plane during intrusion. The maxillary anterior teeth were bonded with fixed appliances (0.018 Slot, SPEED Industries, Canada) after they attained the same level as the posterior segments. In some cases, the upper anterior teeth had to be bonded earlier because they were impeded the forward rotation of the mandible (i.e. if there was an upper anterior tooth contacting the lower dentition). After the upper arch was leveled and posterior intrusion was stopped, the RPE was removed and a transpalatal arch (TPA) was inserted and used to control torque, as well as the transverse and vertical dimensions of the maxillary first molars. Fixed orthodontic appliances were bonded on all of the maxillary posterior teeth. The MSIs were tied to the TPA using a 0.010" ligature wire for the duration of treatment, or until vertical control was not needed.

For the mandibular arch, bands were placed on the lower first molars and fixed appliances (0.018 Slot, SPEED Industries, Canada) were placed on the remaining dentition (LR7 to LL7). The lower MSIs were not inserted until the patient had a lower 0.016×0.022 inch stainless steel wire in place and the interradicular space at the MSI site between the second premolar and first molar was approximately 4 mm. The mandibular MSIs were inserted using the hand driver as previously described.[200] The lower MSIs were loaded immediately using calibrated 150g coils, following the same protocol as in the maxilla. Lower lingual arches (LLA) were installed in two of the patients because their mandibular teeth were actively intruded and needed posterior torque control.

The orthopedic phase (i.e. posterior intrusion) was terminated once the desired amount of posterior intrusion had been achieved (2.1 ± 0.8 years). Clinical assessment of the patients' profiles and dental relationships were the key factors for terminating the orthopedic phase (i.e. AP and vertical relationships of the molars and anterior teeth). At the end of this phase, the RPE was removed and fixed appliances were placed on the remaining dentition.

Except for one participant, all of the treated patients had MSIs in the upper and lower arches. This patient did not have lower MSIs because they would have impeded the mesial movement of the posterior teeth, which was necessary to close spaces.

Control sample

The control group was composed of 17 untreated individuals matched on a case-by-case basis to the treated sample. They were matched based on age, gender, Angle molar classification and pre-treatment mandibular plane angle. Records were collected from the Human Growth and Research Center, University of Montreal, Montreal, Canada.

Cephalometric data collection

The treatment group's lateral cephalograms were constructed from the CBCTs taken before treatment started (T1) and after the orthopedic phase was finished (T2) using Dolphin Imaging (Patterson Technology, Chatsworth, CA) They were oriented using the right and left external auditory meatus. A lateral cephalometric radiograph was produced by segmenting the entire right half of the skull, along with a portion of the left extending to the medial border of the left orbit. The same individual performed all landmark identification for the treatment group.

For the control group, tracings of lateral cephalograms were obtained, scanned into the software, and adjusted for mangification. For both groups, the landmarks were digitized using Dolphin Imaging (Patterson Technology, Chatsworth, CA). Seventeen cephalometric landmarks, as defined according to Riolo et al.(1974)[199], were digitized

(Figure 13). Replicate analysis of individuals showed no significant systematic differences and method errors. (Table 5)

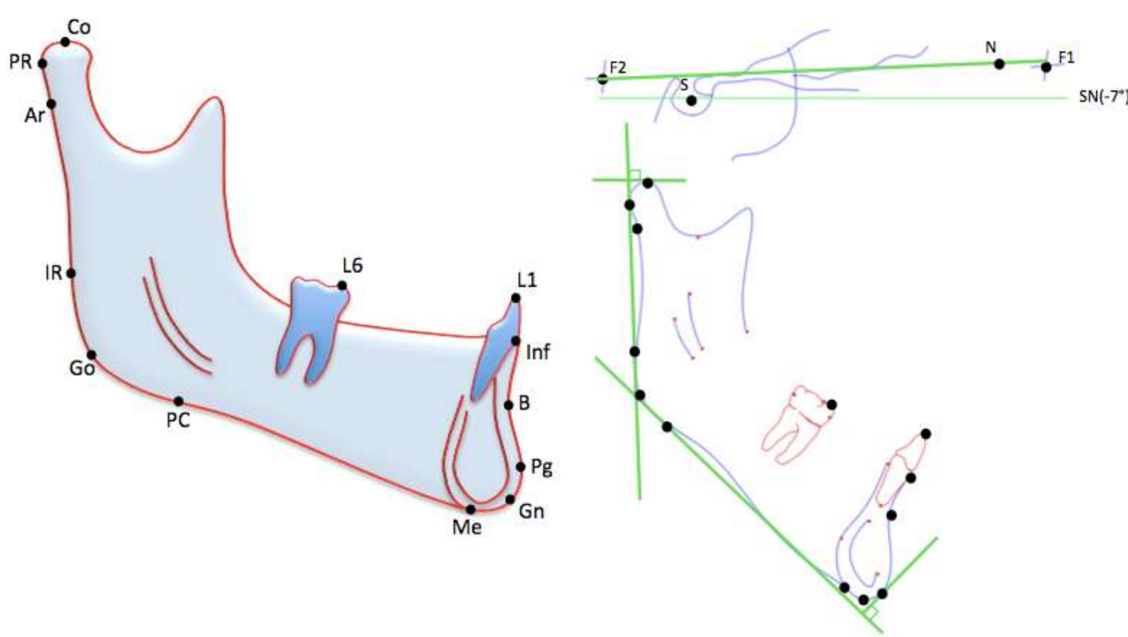
Table 5. Landmarks, abbreviations and definitions used for the tracing, along with their reliabilities.

Landmark	Abbrev.	Definition
Sella	S	The center of the hypophyseal fossa (sella tursica)
Nasion	N	The junction of the nasal and frontal bones at the most posterior point on the curvature of the bridge of the nose
Condylion	Co	Superior tangent on the mandibular condyle determined from a perpendicular from the ramal tangent
Posterior Ramus	PR	Point on the posterior contour of the condyle defined by the superior tangent of the ramal plane
Articulare	Ar	Intersection point of the inferior cranial base surface and the averaged posterior surfaces of the mandibular condyles
Inferior Ramus	IR	Intersection pint between the posterior contour of the mandibular ramus and its inferior tangent
Gonion	Go	Point on the contour of the mandible determined by bisecting the angle formed by the mandibular and ramal planes
Posterior Corpus	PC	Intersection point between the inferior contour of the mandible corpus and its posterior tangent
Menton	Me	Intersection point of the posterior symphysis contour and the inferior contour of the corpus
Gnathion	Gn	Point between menton and pogonion, determined by bisecting the angle formed by the mandibular pane and perpendicular tangent to pogonion
Pogonion	Pg	Most anterior point on the contour of the chin, determined by the perpendicular tangent to the mandibular plane
Point B	B	The most posterior point on the anterior surface of the symphyseal outline, as determined by a line from Infradentale to pogonion
Infradentale	Inf	The highest anterior point of the alveolar process of the mandible in the midline
Lower Incisor	L1	Incisal edge of the lower incisor
Lower Molar	L6	Mesiobucal cusp tip of the lower first molar
Fiduciary Landmark 1	F1	Anterior fiduciary landmark
Fiduciary Landmark 2	F2	Posterior fiduciary landmark

After each lateral cephalogram was traced, two fiduciary landmarks (F1 and F2) were marked on T1 tracing. The T2 tracing was superimposed on the T1 tracing using stable cranial base reference structures,[189] and F1 and F2 were transferred onto the T2 tracing. True rotation[190] was calculated as the angular changes to the lines connecting the F1 and F2 fiduciary landmarks. The mandibles were superimposed using stable reference structures[189]. With the mandibular superimpositions oriented horizontally along the SN-7° plane, the horizontal (X-axis) and vertical (Y-axis) distances between the T1 and T2 landmarks were computed. The total change that occurred was computed as

$$\text{Total Change} = \sqrt{[(X_{T2}-X_{T1})^2 + (Y_{T2}-Y_{T1})^2)]}.$$

Figure 13. Landmarks and reference planes used for digitizing all lateral cephalograms.



Statistical analysis

The data was collected and evaluated using SPSS Software (version 19.0; SPSS, Chicago, IL). The skewness and kurtosis statistics showed that the variables were not normally distributed. The samples were described using median and interquartile ranges. Each group's changes over time (T1 to T2) were compared using a One-Sample Wilcoxon Signed Rank Test and the Mann-Whitney test was used to compare groups. Spearman correlations were calculated to determine whether the variables were significantly correlated with true mandibular rotation. The significance level was set to $p<0.05$ for all of the analyses.

Results

True mandibular rotation was significantly different between the two groups (Figure 14). In the treated group, the mandible rotated forward 1.24 deg, whereas it rotated backward 0.53 deg in the untreated controls.

All of the 14 landmarks showed significant growth and modeling changes (Table 6). In the treated group condylion (Co) showed the greatest overall or total change, whereas articulare (Ar) showed the greatest changes in the control group. The six ramal landmarks showed greater changes that the other landmarks. Gnathion (Gn) and pogonion (Pg) showed the smallest changes over time in both groups. None of the landmarks showed statistically significant differences between the control and treated group (Figure 15).

Figure 14. Medians ■ and interquartiles (25th and 75th) of true mandibular rotation of treatment and control groups, along with the probability of a group difference

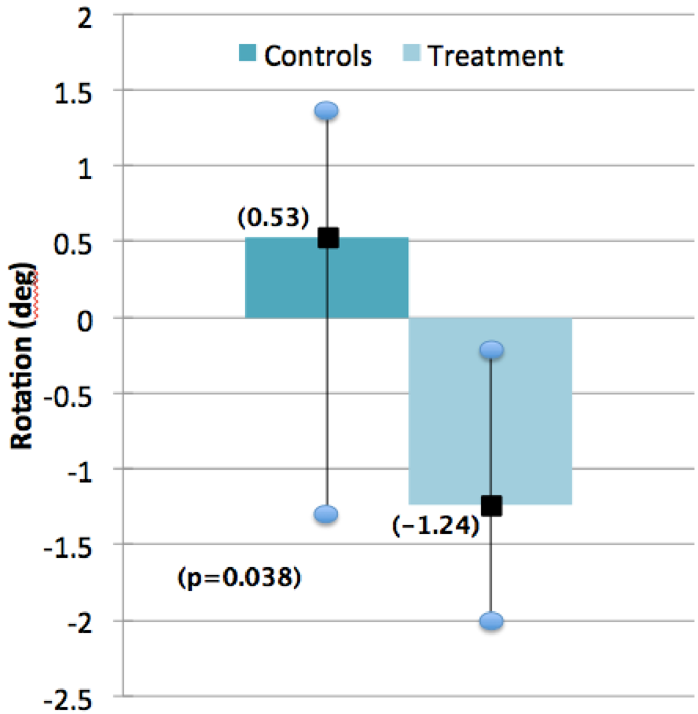


Table 6. Medians and interquartile ranges of total changes of the treatment and control groups, along with probabilities of group differences.

Variable	Treatment Group			Control Group			Diff
	25	50	75	25	50	75	
Co	**2.06**	**5.23**	**7.26**	**2.34**	**3.47**	**9.51**	0.958
PR	**1.68**	**3.57**	**6.68**	**2.2**	**3.11**	**9.47**	0.683
Ar	**1.39**	**3.43**	**6.11**	**1.15**	**3.72**	**8.54**	0.708
IR	**2.47**	**3.04**	**5.55**	**1.86**	**2.97**	**7.21**	0.892
Go	**1.08**	**2.35**	**4.10**	**1.45**	**2.12**	**4.17**	0.786
PC	**0.97**	**2.14**	**4.06**	**1.53**	**2.68**	**4.35**	0.357
Me	**0.71**	**1.10**	**1.75**	**0.43**	**1.01**	**1.12**	0.306
Gn	**0.37**	**0.76**	**1.07**	**0.38**	**0.72**	**1.06**	0.973
Pg	**0.25**	**0.71**	**1.42**	**0.48**	**0.78**	**1.15**	0.658
B	**1.04**	**1.52**	**2.46**	**0.81**	**1.30**	**2.07**	0.433
Inf	**1.18**	**1.91**	**3.29**	**0.84**	**1.41**	**2.65**	0.357
L1	**1.17**	**1.94**	**3.01**	**0.91**	**1.92**	**2.77**	0.708
L6	**1.19**	**2.19**	**3.50**	**1.17**	**2.02**	**2.09**	0.711

* Bolded landmarks changed significantly ($p<0.05$).

With the exception of condylion in the treated group, the landmarks located on the ramus showed significant ($p<.05$) posterior growth and modeling changes (Table 7).The lower molars of both groups migrated anteriorly. None of the horizontal changes showed statistically significant group differences, although condylion approached the significance level.

Table 7. Medians and interquartile ranges of horizontal changes of the treatment and control groups, along with probabilities of group differences.

Variable	Treatment Group			Control Group			Diff
	25	50	75	25	50	75	
Co	-0.90	-0.20	1.25	**-1.40**	**-0.80**	**-0.07**	0.118
PR	**-1.40**	**-0.90**	**0.35**	**-1.78**	**-0.67**	**0.45**	1.000
Ar	**-1.30**	**-0.50**	**0.25**	**-2.09**	**-0.98**	**-0.27**	0.357
IR	**-2.60**	**-1.30**	**0.20**	**-2.35**	**0.35**	**2.98**	0.563
Go	**-3.15**	**-0.80**	**-0.05**	**-2.53**	**-1.70**	**-0.53**	0.586
PC	**-2.60**	**-1.40**	**0.60**	**-2.93**	**-1.60**	**-0.49**	0.540
Me	-0.76	-0.40	0.65	-0.80	-0.18	0.13	0.760
Gn	-0.70	-0.20	0.25	-0.53	-0.27	0.18	0.973
Pg	-0.50	-0.10	0.00	-0.44	-0.18	0.31	0.708
B	-0.70	-0.30	0.30	-0.80	-0.18	0.22	1.000
Inf	-0.40	0.60	1.35	-0.50	-0.09	0.50	0.218
L1	-0.95	0.80	1.70	-0.50	0.09	0.89	0.540
L6	**0.15**	**1.10**	**1.60**	**0.18**	**1.16**	**2.00**	0.833

* Bolded landmarks changed significantly ($p<0.05$).

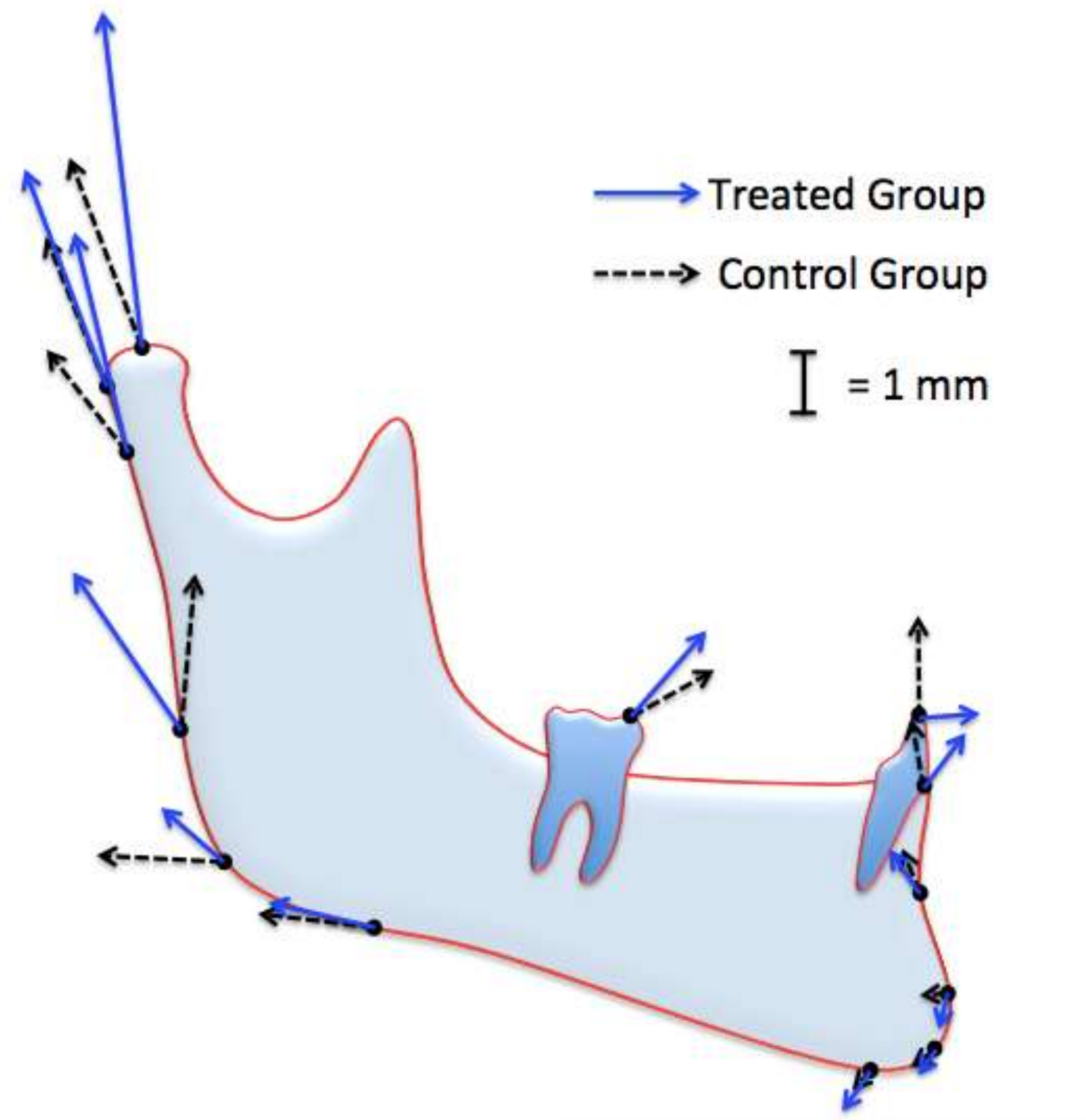
The three superiormost landmarks on the ramus (Co, PR, Ar) showed significant superior growth and modeling changes (Table 8). The inferior ramus (IR) landmark showed significant superior changes in the control group, but not in the treated group, whereas gonion (Go) showed significant superior changes only for the treated group. Gnathion (Gn) showed significant inferior drift in both groups. Infradentale (Inf) moved superiorly along with the lower incisor (L1). The lower molar of the treated group, but not the control group, showed statistically significant eruption. Despite the significant group and treatment changes that occurred, only the lower incisor (L1) showed a statistically significant group difference. It did not move in the treated group, whereas it erupted approximately 1.5 mm in the control group.

Table 8. Medians and interquartile ranges of vertical changes of the treatment and control groups, along with probabilities of group differences.

Variable	Treatment Group			Control Group			Diff
	25	50	75	25	50	75	
Co	**1.05**	**5.20**	**7.05**	**1.06**	**2.93**	**8.40**	0.817
PR	**0.90**	**3.40**	**6.60**	**1.8**	**2.31**	**8.40**	0.709
Ar	**0.75**	**3.40**	**5.80**	**0.71**	**1.60**	**7.56**	0.865
IR	-1.85	2.50	3.70	**0.36**	**2.31**	**5.82**	0.433
Go	**-0.30**	**0.90**	**2.80**	-0.58	0.27	2.40	0.786
PC	-0.50	0.50	2.80	-0.76	0.36	2.98	0.760
Me	-0.50	-0.50	-0.95	-0.71	-0.18	0.40	0.786
Gn	**-0.50**	**-0.30**	**-0.10**	**-0.40**	**-0.18**	**0.00**	0.394
Pg	-0.95	-0.40	0.15	-0.58	0.00	0.58	0.245
B	-0.60	0.60	2.35	-0.44	0.62	1.51	0.865
Inf	-0.45	0.70	2.90	**0.49**	**0.98**	**2.05**	0.540
L1	-1.10	0.00	0.85	**0.44**	**1.51**	**2.00**	**0.005**
L6	**0.55**	**1.20**	**2.75**	0.04	0.62	1.86	0.312

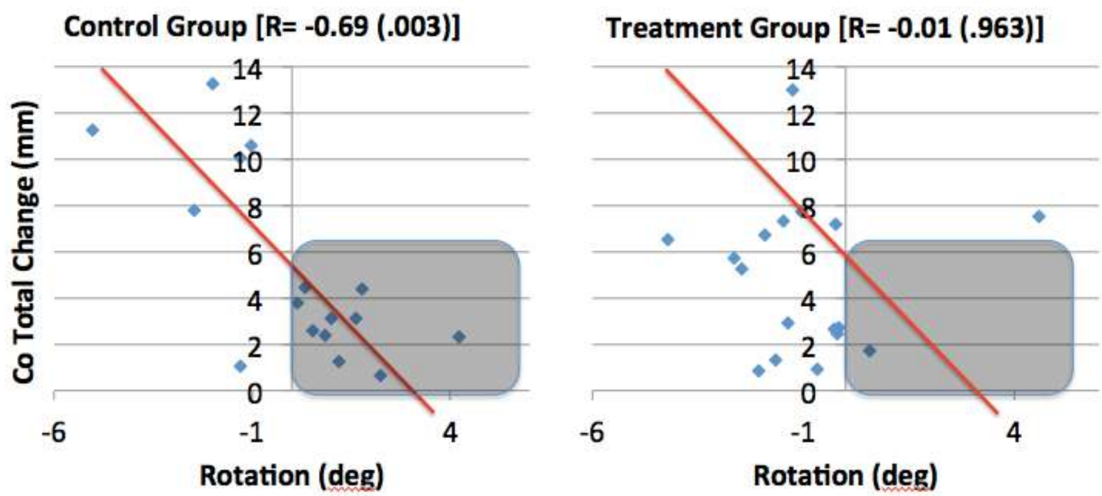
* Bolded landmarks changed significantly (p<0.05).

Figure 15. Total growth and remodeling changes of the mandibular landmarks. Control and treated group are indicated with arrows. Mandible not to scale.



True mandibular rotation was significantly related to the growth and modeling changes of the landmarks in the control group, particularly for the landmarks located on the ramus (Table 9). For example, the control group showed a significant negative correlation ($R=-0.65$; $p<0.006$) between vertical condylar growth and true rotation, whereas the treated group showed no correlation (Figure 16). There were no statistically significant correlations in the treated group.

Figure 16. Spearman correlation coefficients and probabilities of relationship between true mandibular rotation (degrees) and Condylion (Co) vertical growth for the treated and the control groups. Shaded areas indicate backward rotators with limited condylar growth (Red line indicates the regression line for the control group, also superimposed on the treatment group diagram)



Discussion

Unexpectedly, the untreated hyperdivergent subjects exhibited backward true rotation. While backward rotation has been previously reported for individuals, it has not been reported for groups of untreated subjects.[173, 179, 180] Karlsen [178], who specifically designed the study to compare individuals with high and low mandibular plane angles, showed that subjects with high angles underwent less forward rotation than those with low angles, but they did not rotate backwards as a group. This reflects the severe nature of the hyperdivergent phenotypes who participated in the present study.

Table 9. Spearman correlations between true mandibular rotation and the total horizontal and vertical changes of the treatment and control groups.

Variable	Treatment Group						Control Group					
	Total		Horizontal		Vertical		Total		Horizontal		Vertical	
	R	Prob	R	Prob	R	Prob	R	Prob	R	Prob	R	Prob
Co	-0.01	0.963	0.25	0.326	0.06	0.815	**-0.69**	**0.003**	-0.42	0.106	**-0.65**	**0.006**
PR	-0.21	0.422	0.11	0.666	-0.03	0.918	**-0.64**	**0.008**	-0.12	0.672	**-0.66**	**0.005**
Ar	-0.13	0.626	0.16	0.531	-0.06	0.811	-0.47	0.057	-0.02	0.948	**-0.56**	**0.019**
IR	-0.48	0.051	0.01	0.974	-0.05	0.837	-0.46	0.063	**0.48**	**0.049**	**-0.55**	**0.021**
Go	-0.08	0.772	0.01	0.963	0.09	0.743	**-0.56**	**0.019**	**0.60**	**0.011**	**-0.72**	**0.001**
PC	-0.12	0.653	0.21	0.416	-0.09	0.747	-0.40	0.112	**0.53**	**0.030**	**-0.79**	**<0.001**
Me	0.38	0.135	-0.30	0.249	0.37	0.143	0.10	0.701	-0.20	0.441	-0.02	0.933
Gn	0.42	0.098	-0.20	0.435	-0.15	0.569	-0.15	0.554	0.11	0.673	0.15	0.562
Pg	0.15	0.580	0.01	0.962	0.15	0.567	-0.21	0.419	-0.10	0.690	-0.10	0.718
B	0.17	0.510	0.15	0.573	0.13	0.615	0.02	0.948	**-0.59**	**0.013**	-0.22	0.399
Inf	0.40	0.112	0.22	0.405	0.16	0.547	**-0.50**	**0.040**	0.36	0.161	**-0.55**	**0.022**
L1	0.56	0.830	0.12	0.660	-0.09	0.732	-0.28	0.273	0.02	0.944	-0.39	0.117
L6	0.07	0.786	0.05	0.863	0.06	0.808	-0.55	0.125	-0.30	0.433	-0.60	0.088

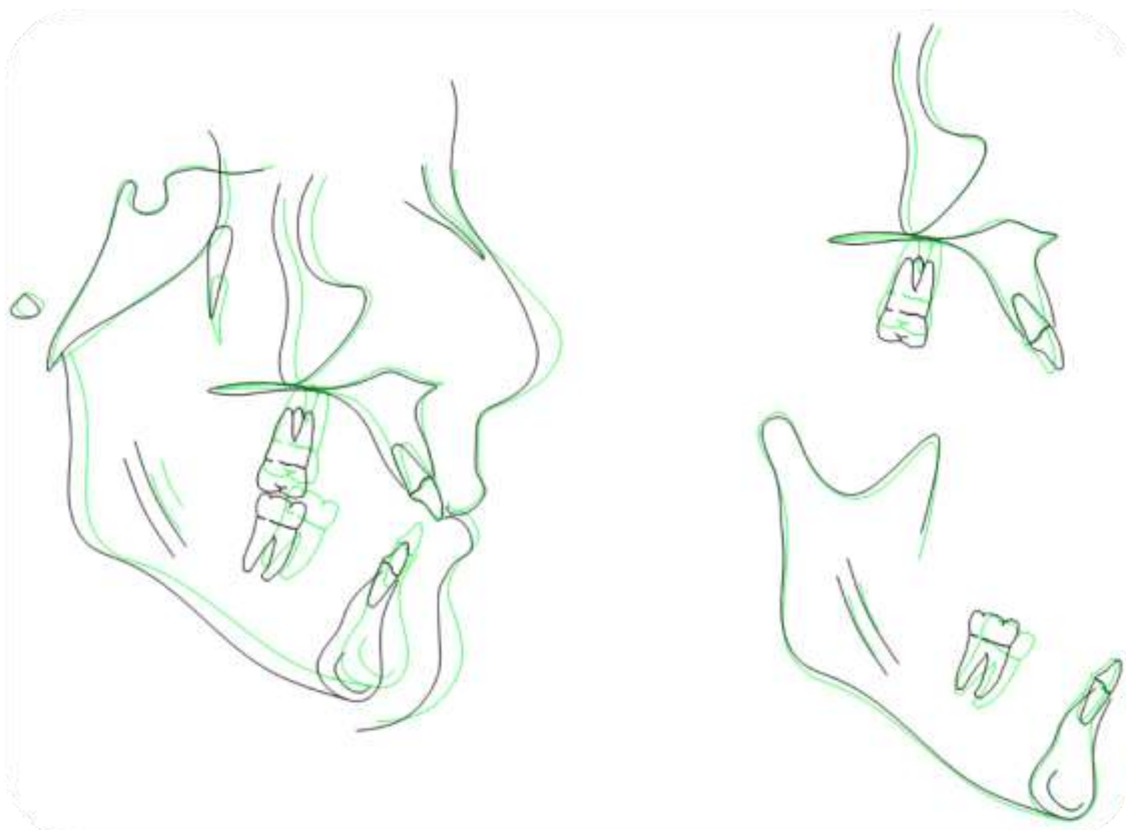
* Bolded numbers indicate significance level of $p<0.05$.

Intrusion and vertical control of the posterior dentition in growing retrognathic hyperdivergent patients produced significant true forward mandibular rotation. Treatment rotated the mandible forward approximately 1.8 degrees. This was greater than the amount of true mandibular rotation (1.0 degree) obtained in younger (8.2 ± 1.2 years) growing individuals treated with vertical-pull chin cups.[127] In contrast, hyperdivergent Class II Division 1 cases treated with high-pull headgears (both non extraction and extraction) and Herbst appliances showed no significant chin projection due to the lack of true mandibular rotation.[184] Bionator therapy produced 2.4° less true forward mandibular rotation than no treatment.[218]

The lower incisors extruded significantly less in the treated patients than in the controls. As part of the intended treatment mechanics, the anterior teeth were controlled vertically to allow the mandible to rotate forward. The vertical position of the teeth had to be controlled in order to achieve the rotation needed by these extreme hyperdivergent patients. If there had been any anterior contact during the orthopedic phase of treatment, the mandible could not have rotated forward. This is why the lower incisor extrusion was controlled indirectly with the MSIs placed in the posterior mandible.

Despite the fact that treatment rotated the mandible forward, the forward rotation did not show the expected growth and modeling changes. Unexpectedly, true rotation was not correlated with either the condylar growth changes or the mandibular modeling that occurred in the treated group. There are at least two reasons for the lack of associations. First, a number of the patients exhibited minimal growth. While the study sought to focus on growing children, several of girls had limited growth potential. If there is no growth, the center of true rotation is located in the region of the condyle,[108] and the amount of rotation will depend on dental movements produced during treatment.(Figure 17) Individuals with limited growth potential will necessarily have less potential to adapt to the rotational changes that occur. Future studies should evaluate the patients' pretreatment skeletal ages to ensure adequate growth potential.

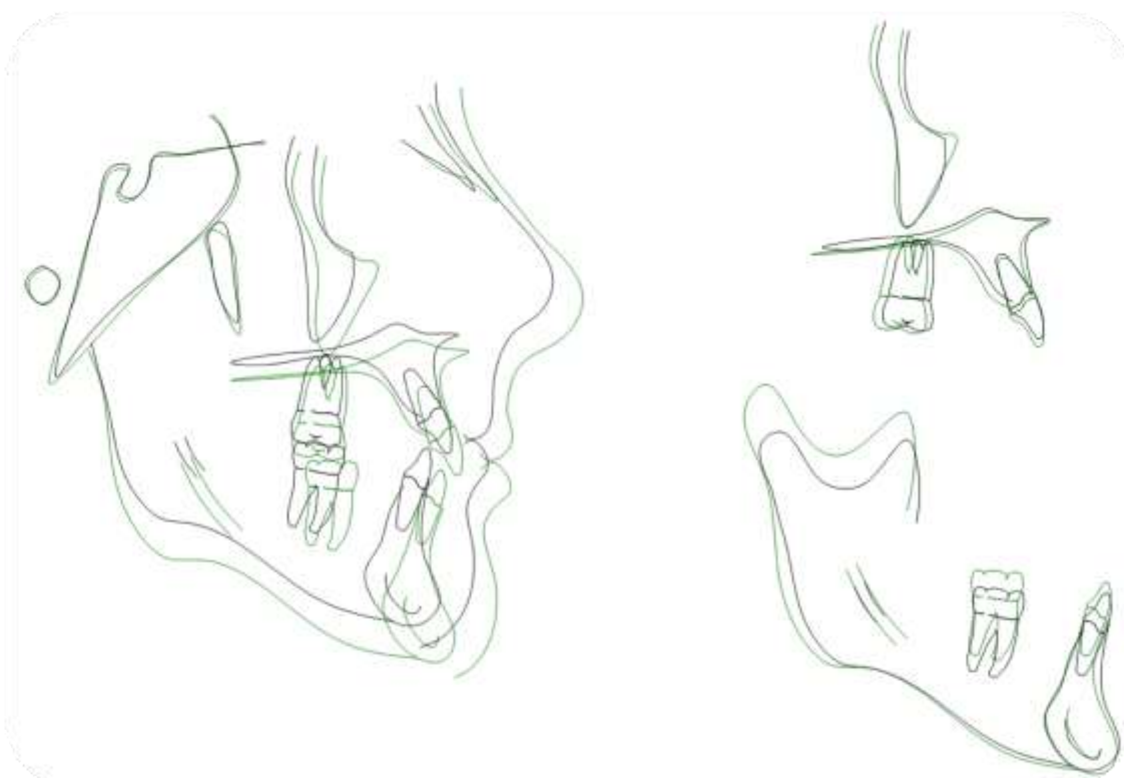
Figure 17. Patient with limited growth potential, showing good chin projection as a result of dental intrusion and rotation around the condyle.



Secondly, treatment rotated the mandibles of patients with limited growth potential, which substantially reduced the overall number of backward rotators (Figure

16), but the individuals with greater growth potential did not rotate forward as much as they could have. Their anteroposterior growth of the mandible helped them achieve the treatment effect. (Figure 18) It is important to remember that the effects of treatment were monitored clinically based on profile changes and the anteroposterior changes in dental relationships. As long as the patients were improving clinically, the amount of intrusion was limited (i.e. more relative rather than absolute intrusion was performed) to prevent the development of Class III malocclusions. This also limited the amount of true rotation that occurred. If the patients were rotating less, then there were less adaptive changes possible.

Figure 18. Patient with growth potential showing forward displacement of the mandible with less control of the lower dentition.



While the differences were not statistically significant, the treated group did show less posterior and more superior condylar growth than the control group. This is what was expected and was probably not statistically significant due to the lack of power. Larger untreated samples of growing individuals have been shown to exhibit approximately 1 mm of posterior condylar growth for every 8-9 mm of superior condylar growth.[174, 175] In the present study, the condyles grew 0.2 mm posteriorly and 5.2 mm superiorly, resulting in a ratio indicating even greater relative superior condylar growth than in normal populations. This suggests that the treatment probably had an effect on condylar growth in a direction that would be expected for forward rotators.[173, 179, 180]

Most functional appliances and treatment approaches for growing hyperdivergent Class II patients show condylar growth adaptations.[221] The mandibular condyle is an active growth site of the mandible and it has the potential to adapt to different positions.[222] The Herbst appliance, which has been extensively studied, has repeatedly been shown to produce more posteriorly directed condylar growth.[219, 220, 223-225] For example, Pancherz and Michailidou (2004)[220] showed that when the Herbst appliance produced more posterior condylar growth during treatment and 5 years post-treatment in hyperdivergent than in average or hypodivergent patients. Surgical treatments that reposition the maxilla and rotate the mandible forward also produce adaptive changes in the mandible after autorotation. The mandible clearly has the ability to adjust its growth to new positions in growing individuals.[42]

While rotation was not related to the growth and modeling changes in the treated group, there were numerous relationships in the control group. The lack of associations in the treated group were probably due to the fact, as previously discussed with respect to Figure 16, that treatment rotated the potential backward rotators forward (i.e. shift them to the left). The ramus of the control group consistently showed greater superior growth and modeling of all the landmarks, and greater posterior modeling of the inferior landmarks in the subjects who exhibited greater forward rotation. Similar patterns of relationship have been previously reported for large samples of untreated individuals.[176]

The results of this study hold several clinical implications. First, when treating Class II retrognathic hyperdivergent patients, it is important to understand that the more growth potential an individual has, the more potential there is for true rotation, and the more potential there is to control the modeling that occurs. Skeletal anchorage such as the MSIs can effectively be used for preventing vertical alveolar growth in patients, as well to actively intrude the dentition when desired. If treatment can be directed toward patients with growth potential, the mechanics should be directed to controlling vertical alveolar growth rather than intruding the dentition. Here patients that are growing during treatment can benefit from preventing the natural eruption of the dentition, thus having a relative intrusion of the teeth rather than an active intrusion. Patients with limited growth will require more active intrusion and do not have the mandibular modeling potential of subjects with better growth. Since the vertical positions of the anterior teeth play an important role in determining the amount of rotation that occurs,[185] it may be necessary to control both the anterior and posterior dentition during treatment in order to maximize rotation. Finally, treatments that produce more rotation make it more likely to increase the modeling of the mandible and change the direction of condylar growth.

CHAPTER IV

APICAL ROOT RESORPTION AND CRESTAL BONE ADAPTATION AFTER POSTERIOR INTRUSION IN GROWING PATIENTS – A 3D EVALUATION

Synopsis

The objective was to evaluate root resorption and alveolar crestal bone adaptation to segmental intrusive forces applied to the maxillary posterior teeth of growing individuals using CBCT radiographs.

The sample consisted of 22 patients (9 males and 13 females) with an average age of 13.2 ± 1.1 years at the start of treatment (T1), who were treated for 25.3 ± 9.3 months (T2). The maxillary posterior teeth (premolars and first molar) were intruded as a segment using 150g coils (one per side) anchored to two palatal miniscrew implants (MSIs). The intrusive forces were applied for an average of 7 months (range 3-10 months), after which the segments were held using a 0.010 in stainless steel ligature tied to the MSIs. External apical root resorption (EARR) and alveolar crest heights were evaluated three dimensionally using CBCT radiographs taken at T1 and T2. Within group changes and between group differences were evaluated using paired and independent sample t-test, respectively.

All roots showed statistically significant ($p<.05$) EARR between T1 and T2, ranging from 0.67 mm to 1.21 mm. There were no significant differences in EARR between teeth. Pointed roots showed the greatest amounts of resorption, followed by bent roots, normal shaped roots, and roots with open apices, which showed the least

EARR. Alveolar crest heights between first molar and second premolar decreased significantly (0.38 ± 0.6 mm) over time, and the distance between the bone and the CEJ increased significantly (0.52 ± 0.9 mm) on the distal aspect of the maxillary second premolar.

EARR was statistically significant, but clinically acceptable, for all posterior teeth that were intruded, with no differences between teeth. Crestal bone loss was minimally affected by segmental intrusion mechanics.

Introduction

Changes of the vertical facial dimensions during growth have major effects on the profile and chin projection.[6] Excess vertical development of the dentoalveolar complex, especially in growing hyperdivergent patients, is a primary contributing factor to their malocclusion.[18, 22, 23, 27, 143, 226, 227] Any lack of vertical control during orthodontic treatment exacerbates the negative effects of hyperdivergence.[170] For such patients, posterior dental intrusion provides a treatment alternative because it controls vertical development of the posterior dentoalveolar processes, and makes it possible to orthopedically improve skeletal dysmorphology by rotating the mandible.[154, 155]

Miniscrew implants (MSIs) provide skeletal anchorage and make it possible to control forces while intruding teeth.[149, 151, 169, 197, 228-231] The ability to control forces is important because the use of light forces during intrusion has been recommended to minimize unwanted external apical root resorption (EARR).[232] Clinicians consider intrusion to be a problematic form of treatment because it concentrates the forces at the root apices, which is thought to increase the potential for root resorption. Interestingly, Baumrind and coworkers,[233] who retrospectively evaluated pre- and post-treatment periapical radiographs of adults, showed that there was no difference in the resorption between teeth that had been intruded or extruded. The amounts of resorption reported for patients whose teeth have been intruded are highly variable (Table 10). Reported EARR of the incisors that have been intruded varies from 0.3 to 2.7 mm; resorption of the posterior teeth ranges from 0.2 to 1.0 mm. Several studies have not been able to correlate the amounts of intrusion to the amounts of EARR.[234, 235] While the effects of intrusion on EARR remain unclear, well designed SEM (scanning electron microscope) evaluations of the entire premolar root surfaces indicate 2-4 times greater resorption of intruded than control teeth, with differences depending on the amount of force applied.[229, 236]

The amount of EARR that occurs depends partially on root shape and open bite malocclusion, with abnormally shaped roots and open bite patients being at higher risk for root resorption. Harris and Butler [237] found pre-treatment root lengths of open-bite patients to be significantly shorter than the roots of non open-bite patients. Motokawa et al,[238] also found a higher prevalence of abnormal root shapes among open-bite than non open-bite cases; they also showed that the prevalence of root resorption was higher for abnormally shaped than normally shaped roots. Other studies have also shown that abnormally shaped roots have greater potential for EARR.[234, 239, 240]

Table 10. Clinical trials evaluating EARR during orthodontic intrusion sumarized by type of anchorage.

Reference	Sample	Teeth	Type of movement	Movement (mm)	Treatment time	Amount of resorption	Amount of force (g)	Assessment	Type of device
				Dental Anchorage					
Dermaut and Munck (1986)[235]	20 pts 11-37 yrs	Incisors	Intrusion	3.6±1.6	Ranged from 24 to 32 (weeks)	18% of the original root length (2.5 mm)	100	PA	Intrusion arch
McFadden et al (1989)[234]	38 pts 13.1±1.4 yrs	Incisors	Intrusion	0.84±2.1	28.8±7.4 (months)	13.2% (1.84 mm)	25	PA	Utility arch
Goerigk et al (1992)[264]	31 pts 14-50 yrs	Incisors	Intrusion	2.3±1.1	4.3 (months)	6.2±2.8%	0.5-0.7 Newtons	PA	Intrusion arch
Costopoulos and Nanda (1996)[265]	17 pts 11.9-18.3 yrs	Incisors	Intrusion	1.9±0.8	4.6 (mo)	0.6±0.6	15 gm /tooth	PA	TMA intrusion arch
Ramanathan and Hofman (2009)[266]	G1 - 15 pts G2 - 17 pts 9-30.1 yrs	Incisors	Intrusion	NA	6 (mo)	0.26±0.24 0.46±0.32	10	PA	TMA intrusion arch
				Skeletal Anchorage					
Sugawara et al (2002)[149]	9 pts 19.3 yrs	Molars	Intrusion	1.7 and 2.8	27.1 months	5.7%	NA	LAT/PAN	Elastic modules
Ari-Demirkaya et al (2005)[151]	16 pts 19.25 yrs	Molars	Intrusion	NA	20 months	MB=1.0±0.6 (R) DB=0.7±0.7 (R) MB=0.8±0.7 (L) DB=0.8±0.5 (L)	NA	PAN	NiTi coil springs
Liou and Chang (2010)[230]	50 pts 25.4±5.6 yrs	Incisors	Intrusion and retraction	2.7±1.8 (intrusion) 3.0±2.7 (retraction)	28.3 ± 7.3 (months)	2.7 ± 1.0 (right lateral) 2.8 ± 1.0 (left lateral) 2.5 ± 1.4 (right central) 2.5 ± 1.5 (left central)	250 (retraction) 100 (intrusion) en-masse	PA	Intrusion arch TMA and NiTi coil spring
Xun et al (2013)[267]	30 pts 35.5±9	Molars	Intrusion	3.1-3.4	NA	0.2-0.4 mm	100-150	LAT/PAN	Elastic Chain
Heravi et al (2011)[231]	10 pts 25-57 yrs	Molars	Intrusion	2.1±0.9	7.7 (months)	P=0.2±0.2 MB=0.4±0.3 DB=0.2±0.3	100	PA	TMA springs

* (PA) Periapical radiographs; (PAN) Panoramic radiograph; (LAT) Lateral cephalogram.

In order to fully understand the effects of intrusion on EARR, several limitations of previous studies need to be addressed. Clinically, the relationship between intrusion and root resorption has been typically evaluated using lateral, panoramic or periapical radiographs. (Table 10) While periapicals are better than other two-dimensional radiographs for evaluating EARR, they can distort the lengths of both the roots and the teeth. Under controlled conditions, CBCT measures reflected the actual lengths, whereas periapicals have underestimated root lengths and overestimated tooth lengths.[241] In addition, most studies have evaluated the effects of intrusion on isolated teeth (e.g. incisors, premolars or molars), which limits the ability to make comparisons. For example, in order to determine whether all of the posterior teeth respond similarly to intrusive forces, the molars and premolars must be assessed simultaneously.

In addition, periodontal and bone adaptations to intrusive mechanics need to be better understood. There is a concern that intrusion of teeth might cause crestal bone loss. Orthodontic treatment has been shown to produce some loss of crestal bone.[242, 243] The only study that evaluated the effects of intrusion on crestal bone height around molars reported no significant effects, but the sample size was small and the measurement technique could have been biased.[149] Animal research that evaluated the effects of intrusion in dogs showed that premolars that were experimentally intruded 1.7-2.3 mm exhibited 1.1-1.5 mm of crestal bone resorption, with greater amounts of intrusion and less bony resorption associated with teeth that had received supracrestal fiberotomies.[244] Clinical conclusions are simply not clear and a better understanding of how the crestal bone adapts to intrusion is needed.

Using CBCT radiographs, the primary aim of this study was to three dimensionally evaluate root resorption of posterior maxillary teeth that were intruded using light forces. The secondary aim was to evaluate crestal bone adaptation to intrusive tooth movements.

Materials and Methods

The sample consisted of 22 patients (9 males and 13 females) who where 13.2 ± 1.1 years at the start of treatment (T1). All patients were recruited during screenings held at the Graduate Orthodontic Clinic of Texas A&M University Baylor College of Dentistry (TAMBCD). The research protocol was approved by the TAMBCD IRB. Informed consent was obtained from all patients and parents prior to starting treatment.

Only patients who met the following criteria were included in the study:

- Premolars fully erupted
- Lower anterior facial height (ANS-ME) greater than age and sex specific mean values (based on Riolo et al.,1974)[199]
- The S-N-B angle one standard deviation or more below age and sex specific mean values (based on Riolo et al., 1974)[199]

For all patients, treatment of the maxillary arch was started with an expansion phase using a rapid palatal expander or RPE (Variety SP, Dentaurum, Germany). It was designed to function as a rigid segmental intrusion appliance for the posterior teeth, including the first molars and premolars (Figure 19). Occlusal rests extended over the second molars. The expander was activated twice per day (1/2 mm/day) until the palatal cusps of the maxillary teeth were in contact with the buccal cusps of the mandibular dentition, which was usually achieved during the first month of treatment.

The appliance served as a retainer for approximately 2 months after the expansion was completed, after which two miniscrew implants (MSIs; 8 mm long and 1.8 mm diameter; IMTEC 3M UNITEK) were placed in the parasagittal region (mesial to the first molars) of the palate. The miniscrews were placed using techniques previously described.[200] The MSIs served as skeletal anchors for the intrusion mechanics. They were all inserted without pilot holes or tissue punches.

The intrusion force was applied immediately after placement using two Sentalloy® coil springs (GAC international, Bohemia, NY), which extended from the MSIs to the RPE frame, between the interproximal contacts of the second premolar and first molar. Each spring was calibrated using a gram force gage (Correx, Haag-Streit, Switzerland) to deliver a constant force of 150 g, following a protocol previously described.[201] The anterior maxillary dentition (canine to canine) was not intruded. Intrusion forces were only used when required, as determined on a case-by-case basis. The average active intrusion time during this phase was 7 months (range 3-10 months). If intrusive forces were not required, the vertical position of the RPE was held using a 0.010-inch stainless steel ligature tied from the MSIs to the RPE frame.

Figure 19. Expansion/Intrusion appliance design. Rigid framework (A) connecting posterior teeth; occlusal stops (B) on upper second molars; and buccal stainless steel 0.016x0.022 in wire connecting buccal surfaces of premolars and first molar (C).

For the treatment of the mandibular dentition, bands were placed on the lower first molars and fixed appliances (0.018 Slot, SPEED Industries, Canada) were placed on the remaining dentition (LR7 to LL7). The lower MSIs were not inserted until the patient had a lower 0.016×0.022 inch stainless steel wire in place. The mandibular MSIs were inserted at an angle using the hand driver, as previously described.[200] The lower MSIs were loaded immediately with 150g coils, and calibrated following the same protocol as in the maxilla.

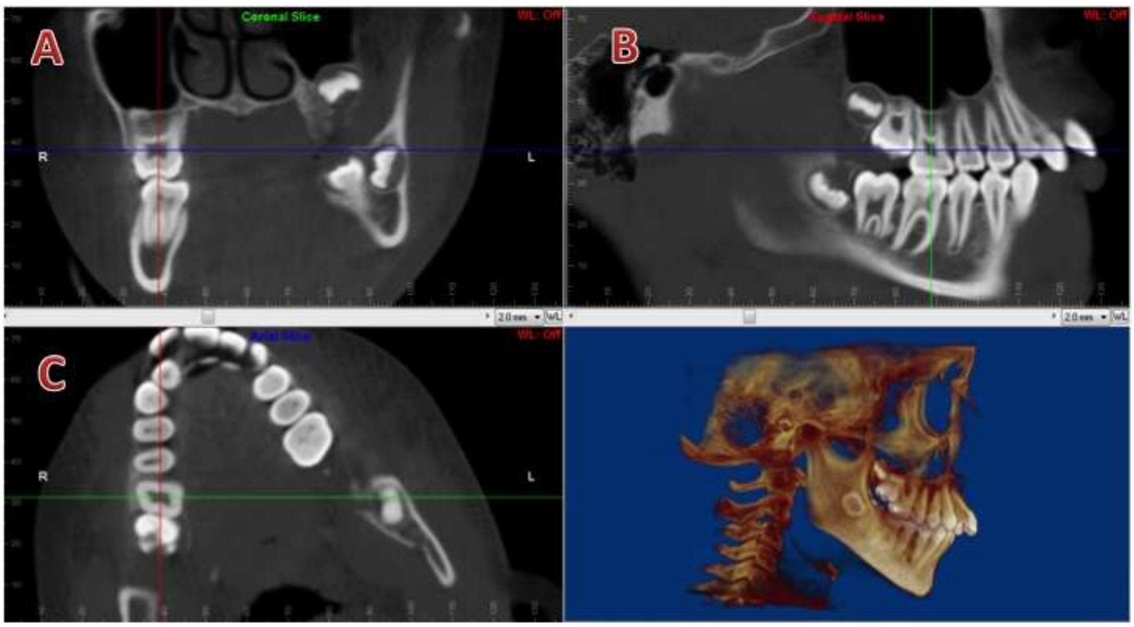
The orthopedic phase of treatment was terminated (T2) once the posterior dentition had been intruded to the level of the anterior dentition. The duration of the orthopedic phase (T1-T2) was 25.3 ± 9.3 months. The RPE and intrusion forces were removed immediately after the orthopedic phase (posterior intrusion phase) was terminated. The segment's vertical dimension was held in place with a 0.010-inch stainless steel ligature wire extending from the MSIs to the posterior dentition.

Root resorption assessment

Root resorption was assessed using the patients' T1 and T2 CBCT images. All of the CBCT images were analyzed using Dolphin Imaging version 11.5 (Patterson Technology, Chatsworth, CA). A separate CBCT orientation was performed for each tooth. The CBCTs were oriented using the cemento-enamel junctions, as viewed on the coronal slice (Figure 20A). The orientation of each maxillary tooth (first molar, second premolar, and first premolar) involved a 4-step process: 1) the coronal, sagittal, and axial planes were adjusted to intersect in the pulp chamber of the tooth (Figure 20B); 2) using the axial view (Figure 20C), the sagittal and coronal planes were moved to intersect in the center of the tooth. After establishing this axis of rotation (intersection point), the axial view was rotated so that the sagittal plane passed through the most mesial and distal aspects of the tooth; 3) the coronal view was then rotated until the labial and lingual cemento-enamel junctions (CEJ)) also contacted the axial plane; 4) the sagittal plane was rotated until the mesial and distal CEJ contacted the axial plane.

After each tooth was oriented, 8, 4 and 6 landmarks were digitalized on the first molars, second premolars, and first premolars, respectively (Figure 21, Table 11). The mesial and distal CEJ points were digitized using the sagittal view and the cusp tips were digitized using the coronal view. The positions of all the points were verified on all three views and adjustments were made as needed. To better visualize the cusps, the sagittal view was used to move the coronal slice from mesial to distal, as needed. If the location of a cusp tip was in doubt, the axial view was checked. The root apex was identified by moving the axial plane apically, and was digitized on the slice just before the root disappeared on the axial view.

Figure 20. CBCT showing the three-dimensional orientation for each individual tooth on coronal (A), sagittal (B) and axial (C) planes of space.

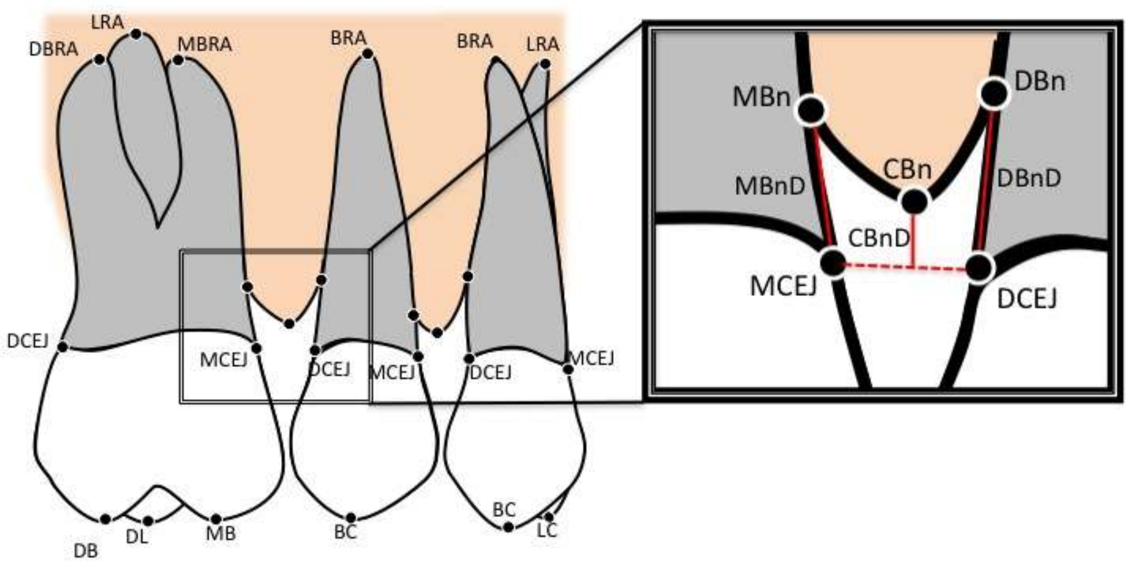


The X, Y, and Z coordinates of the digitized landmarks were used to calculate the 3-dimensional distances between two landmarks using the formula:

$$d= \sqrt{((x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2)}$$

The calculated reference points were used to obtain the total tooth lengths (cusp tip to root apex), root lengths (CEJ to root apex) and crown lengths (cusp tip to CEJ).

Figure 21. Bone height evaluation. (MBnD and DBnD) Linear measurement from most apical bone level to the CEJ on the mesial and distal aspect of each tooth. Alveolar crest height (CBnD) obtained from a perpendicular line to the midpoint between the CEJs of the mesial and distal tooth.



Bone and crestal bone height assessments

Bone height was calculated as the linear distance from the highest bone level at the mesial and distal contact point of the roots (MBn and DBn) and their respective MCEJs (Figure 21). The crestal bone height was measured from the midpoint of the line connecting the two CEJs to the most coronal point of the crest (CBn).

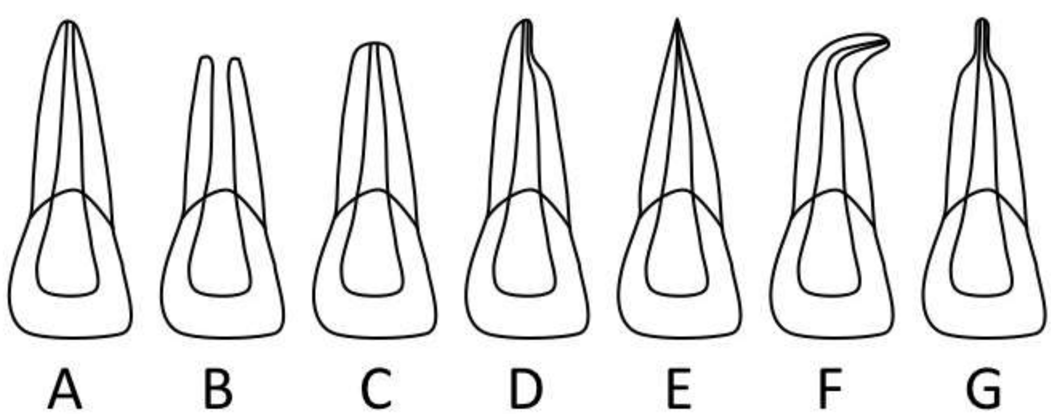
Table 11. Landmarks used to compute measurements of root resorption and crestal bone adaptation.

	Abbreviation	Description
		Landmarks
	MCEJ	Mesial cemento-enamel junction
	DCEJ	Distal cemento-enamel junction
	MBRA	Mesiobuccal root apex
	DBRA	Distobuccal root apex
	LRA	Lingual root apex of premolar
	BRA	Buccal root apex of premolar
	MB	Mesiobuccal cusp tip
	DB	Distobuccal cusp tip
	DL	Distolingual cusp tip
	BC	Buccal cusp tip of premolar
	LC	Lingual cusp tip of premolar
	MBn	Most apical crestal bone contact with root on mesial surface
	DBn	Most apical crestal bone contact with root on mesial surface
	CBn	Most coronal point of the alveolar crest
		Measurements
Bone Level	MBnD	Distance from the MCEJ to the MBn
	DBnD	Distance from the DCEJ to the DBn
	CBnD	Perpendicular distance from CBn to the midpoint between the CEJs of the mesial and distal tooth of that crest
Molar	MB Root	Distance from midpoint between MCEJ and DCEJ to MBRA
	DB Root	Distance from midpoint between MCEJ and DCEJ to DBRA
	L Root	Distance from midpoint between MCEJ and DCEJ to LRA
	MB tooth	Distance from MB to most apical point on MBRA
	DB Tooth	Distance from DB to most apical point on DBRA
	L Tooth	Distance from LC to most apical point on LRA
Premolar	B Root	Distance from midpoint between MCEJ and DCEJ to BRA
	L Root	Distance from midpoint between MCEJ and DCEJ to LRA
	B Tooth	Distance from BC to the BRA
	L Tooth	Distance from LC to the LRA

Root shape classification

Root shape was categorized based using the patient's initial (T1) CBCT image. The CBCT was oriented individually using the long axis of each tooth to evaluate the 3-dimensional root shape on the sagittal, axial and coronal plane. Each root was categorized as being normal, open (i.e. immature) apex, blunt, eroded, pointed, dilacerated (bent) or bottle (pipette) shaped (Figure 22). Roots of multiradicular teeth were categorized individually. (Modified from Mirabella and Årtun 1995[239])

Figure 22. Root shape classification diagram.(A)normal, (B)open apex, (C)blunt, (D)eroded, (E)pointed, (F)bent and (G)bottle. Modified from Mirabella and Årtun (1995)[239]



Statistical analysis

The calculated measurements were transferred to SPSS Software (version 19.0; SPSS, Chicago, IL) for evaluation. The skewness and kurtosis statistics showed that the variables were normally distributed. Paired and independent sample t-tests were used to evaluate within group changes and between group differences, respectively. A probability level of 0.05 was used to determine statistical significance.

Results

The tooth and root lengths of the molars and premolars showed no statistically significant ($p>.05$) left-right side differences. On that basis, the statistical comparisons were limited to the right side. With the exception of U4PR, none of the crown lengths showed significant changes during treatment.

Statistically significant EARR was noted for the maxillary first premolars, second premolars and first molars (Table 12). Resorption of the maxillary first molars ranged between 0.82 mm and 1.09 mm. There were no statistically significant differences in the amounts of EARR between the molar roots. The second premolar root resorbed between 0.67 mm and 0.93 mm. The first premolar roots showed the greatest resorption, with lengths decreasing more than 1 mm in most instances. However, the differences in the amounts of EARR between the roots of the three teeth were not statistically significant ($p\geq.05$).

Table 12. Root resorption measured for all the maxillary teeth that were intruded as a segment (first premolar, second premolar and first molar).

Tooth	Total Length			Root Length			Crown Length		
	Mean	SD	Prob	Mean	SD	Prob	Mean	SD	Prob
U6DR	-0.95	0.87	<.001	-0.85	1.01	.002	-0.12	0.52	.323
U6MR	-0.82	1.14	.006	-0.82	1.26	.011	0.12	0.75	.487
U6PR	-1.09	0.83	<.001	-0.84	0.92	.001	-0.10	0.56	.429
U5R	-0.93	1.24	.004	-0.67	1.25	.031	-0.23	0.55	.094
U4BR	-1.16	1.19	.001	-0.93	1.08	.004	-0.12	0.32	.165
U4PR	-1.11	1.14	.001	-1.21	1.05	<.001	-0.23	0.34	.016

Due to the lack of differences in resorption between roots, the effects of root shape were evaluated with all the teeth combined. Based on the initial assessments of root shape, less than 5% of the roots were either blunt, eroded, or bottle shaped. The normal, open apex, pointed, and bent roots showed statistically significant ($p<.05$) amounts of EARR. Approximately 64% of the roots were normally shaped; their total length decreased approximately 1.02 mm (Table 13). Open apex roots (12.5%) showed the least EARR, decreasing 0.45 mm in length. The pointed roots (10%) showed the greatest amount of resorption, with 1.46 mm of root shortening. The bent roots (9%) showed 1.11 ± 0.96 mm the root shortening. The normal shaped root exhibited significantly less EARR than the pointed roots, but significantly more resorption than the open apex roots. Open apex roots showed significantly less EARR than the pointed and bent shaped roots.

Table 13. Frequencies (%) of different root shapes of intruded maxillary teeth(first premolar, second premolar and first molar) at the beginning of treatment (T1) on both sides.

Group	Shape	Number of Roots	Frequency (%)	Mean	SD	Sig	Sig p<.05 between Groups
1	Normal	159	60.2	-1.02	1.13	<.001	5, 2
2	Open Apex	31	11.7	-0.45	0.96	.003	1, 5, 6
3	Blunt	05	1.9	-0.61	0.68	N/A	
4	Eroded	05	1.9	-0.82	0.80	N/A	
5	Pointed	25	9.5	-1.46	0.80	<.001	1, 2
6	Bent	23	8.7	-1.11	0.96	<.001	2
7	Bottle	01	0.4	-1.18	0.05	N/A	
Missing		15	5.7				
Total		264	100				

The only statistically significant amount of crestal bone loss near the CEJs occurred at the distal aspect of the maxillary second premolar root (U5 DBnD), where the distance between the bone and the CEJ increased 0.52 ± 0.9mm. None of the other distances between the CEJs and bone showed statistically significant changes. (Table 14) The alveolar crest between the maxillary first molar and second premolar (U6/U5) lost 0.38 ± 0.6 mm, a change that was statistically significant. Crestal bone height between the premolars did not change significantly.

Table 14. Changes (mm) in (A) bone level to CEJ and (B) to the alveolar crest from T1 and T2.

	Variable	Mean	SD	Sig
A	U6 MBnD	0.26	0.9	0.164
	U5 DBnD	0.52	0.9	**0.012**
	U5 MBnD	0.21	0.6	0.127
	U4 DBnD	0.24	0.6	0.061
	U4 MBnD	-0.04	0.8	0.867
B	U6/U5 CBnD	0.38	0.6	**0.010**
	U5/U4 CBnD	0.19	0.5	0.168

Discussion

The roots of the premolars and molars resorbed during intrusion, but the amounts of EARR that occurred was less than generally associated with other types of orthodontic tooth movements**.** Literature reviews[232, 245] suggest that root resorption is usually less than 2-2.4 mm during orthodontic treatment, which is more than the 0.67-1.21 mm of resorption observed in the present study. A meta-analysis evaluating EARR associated with various treatment modalities reported that the overall mean root resorption from eight studies was 1.42 ±0.5 mm.[246] However, it is important to distinguish between the posterior and anterior teeth, where the latter have been shown to be at greater risk of EARR.[232, 245] Based on pre- and post-treatment full-mouth x-rays from 6 different orthodontic offices of 868 patients treated with various treatment approaches, Sameshima and Sinclair reported that molars and premolars experienced less resorption than the anterior dentition, averaging 0.6 mm of root resorption during full orthodontic treatment.[247] The amount of EARR associated with intrusion is also greater for the anterior than posterior dentition (Table 10).

The posterior EARR observed in the present study compares well with the amounts previously reported for posterior intrusion. The few clinical studies evaluating posterior EARR after intrusion are difficult to compare due to variability in methods used to evaluate resorption, differences in force application, and age differences (Table 10). The study that most closely matches the present study in design, performed by Ari-Demirkaya et al[151], sixteen treated cases with posterior segmental intrusion and skeletal anchorage were compared to 16 matched cases that had been treated orthodontically without intrusion mechanics. They reported 0.7-1.0 mm of EARR of the intruded first molars, which compares well the 0.8-1.1 mm of molar resorption identified in the present study. Importantly, they measured root length on panoramic radiographs, which might be expected to be less accurate than measurements from CBCT.[241]

The EARR observed in the present study was greater than previously reported for adult supraerupted molars that had been intruded. Approximately 0.2-0.4 mm of EARR has been reported after intruding supraerupted molars with 100-150 g of force.[231] Interestingly, Heravi et al. were intruding supraerupted molars of adults and applying higher forces than those used in the present study, and still observed less EARR. This could be a result of the methods used to apply the forces (i.e., power chain and TMA wire loops) or to the methods used to evaluate the EARR, which are less reliable than CBCT. Importantly, our findings show no significant differences in EARR between posterior teeth (premolars and first molar) after being intruded as a segment with 150 g of force. It is important to understand how the different teeth respond to the same force applied, since orthodontist are most commonly dealing with segments of teeth during intrusion mechanics, rather than single teeth needing intrusion.

Roots with abnormal shapes showed the greatest amount of resorption**.** The pointed roots showed approximately 43% more resorption than the normally shaped roots, while the bent or dilacerated roots showed approximately 9% more resorption. Abnormal root shapes have been previously linked to an increased risk of root resorption.[234, 238, 239, 247-250] Kamble et al, who evaluated different root shapes using finite element analyses, confirmed that pipette shaped roots exhibited higher stress levels during intrusion.[251] Of the various root forms tested, clinical reports have shown that pointed and pipette shaped roots are at greatest risk for root resorption, which supports the findings of the present study. [240, 247]

It has been suggested that open roots exhibit less EARR than fully formed roots, and that apical root resorption does not prevent future root growth**.**[252] In the present study, the open roots showed less resorption than all of the other roots. This confirms previously reports showing that growing children with incomplete root formation exhibit less root resorption.[253-255] The fact that open roots showed less EARR than normally shaped roots indicates that the roots were still growing. However, it is possible that this is an oversimplification, because it has been suggested the open roots will not achieve their normal length when forces are applied to them.[255] Further studies are needed to resolve these issues.

Crestal bone loss was minimal during posterior intrusion. Crestal bone loss of 0.2 to 0.5 mm has been previously reported during orthodontic tooth movement[242, 243] It has been suggested that there is approximately 1 mm of crestal bone loss for every 3 mm of root lost,[256] which corresponds to the ratios obtained in the present study. It has been suggested that crestal bone remodels as a result of intrusion to maintain adequate sulcus depth, and that the supra alveolar fibers are responsible for the remodeling that occurs.[244] Importantly, it is thought that crestal bone loss plays a role in EARR, due to a greater concentration of the forces at the apex associated with the loss of bony support.[257] As such, controlling periodontal health and crestal bone loss during intrusion is of utmost importance.

It is also possible that the RPE phase of treatment could have contributed to the EARR observed**.** A systematic review showed that CBCT evaluation of root volume was significantly less after maxillary expansion therapy.[258] The posterior teeth of experimental monkeys that underwent RPE therapy alone also exhibited significant amounts of EARR.[259, 260] While the resorption that occurs during expansion is restricted primarily to the middle and cervical regions on the buccal surfaces, where the roots are in contact with the buccal cortical bone, the apical region is also affected.[261]

Whether or not the lighter forces used to intrude teeth limit the amounts of EARR observed remains controversial. Since 150 g of force was delivered to the segments, each root in the present study would have been loaded with approximately 12-13 g of force. As previously discussed, 100-150 g of force applied to individual teeth resulted in less EARR than observed in the present study.[231] Reitan,[252] who compared teeth intruded with 80-90 gm to those intruded with 30 gm, showed that apical root resorption increased with greater intrusive forces. Dellinger suggested that root resorption was directly related to the magnitude of force, with less EARR associated with lighter forces.[262] Faltin et al. showed that teeth intruded with less force had fewer resorptive lacunae than those with higher forces.[228] Interestingly, Carrillo and co-workers showed no effect of force on the amount of EARR in premolars of the beagle dog.[263] While there may be a relationship between the amount of force applied and the amount of EARR observed, the exact nature of this relationship remains unclear.

The present study helps to clarify some previous concepts concerning root and bony adaptations to intrusive movements. Certainly, the mechanics used produced clinically acceptable results. The roots showed limited amounts of EARR after 7 months of intrusion with light forces. Importantly, the forces were applied to the whole segment by coil springs attached to palatal MSIs, so that a constant and light force could be maintained throughout the intrusion phase. Root shape should be taken into consideration before applying these mechanics. It should be reassuring for the orthodontist to know that the crestal bone of growing patients adapts to the segmental intrusion mechanics without any relevant bone loss or periodontal implications. The clinical application of these concepts should be planned based on each individual's characteristics.

CHAPTER V

CONCLUSION

Using skeletal anchorage and light forces, the posterior teeth of 17 consecutive patients, who were 13.2 ±1.1 years old at the start of treatment and treated for 25.3 ± 9.3 months, were absolutely or relatively intruded. The intrusive mechanics used produced true mandibular rotation and were highly effective in treating growing retrognathic hyperdivergent patients with minimal detrimental effects. Within the limits of this study, the following specific conclusions can be drawn:

1. Posterior intrusion is an effective way to produce chin projection while controlling vertical dimension of growing hyperdivergent patients.
2. MSI stability was excellent, with over 95% of the miniscrew implants remaining stable throughout treatment.
3. The treatment approach was well accepted by the patients, producing limited discomfort and pain.
4. Intrusion of the posterior teeth in growing individuals produced significant true forward rotation.
5. Forward rotation and treatment limited lower incisor eruption.
6. Untreated hyperdivergent subjects who rotated backward had less vertical condylar growth than those who rotated forward.

7. Treatment did not significantly alter the modeling pattern of the mandible, due primarily to the limited growth potential of some of the patients and limited amount of rotation of other patients.
8. Statistically significant, but clinically acceptable, amounts of external apical root resorption occurred to the intruded posterior maxillary teeth with light forces.
9. Crestal bone was only minimally affected by the intrusion of posterior teeth.
10. Pointed roots, followed by bent or dilacerated roots were more prone to external apical root resorption during intrusion than normally shaped roots.
11. Open roots are less susceptible to root resorption during intrusion than normally shaped roots.

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APPENDIX A*

The Morphological Characteristics, Growth, and Etiology of the Hyperdivergent Phenotype

Peter H. Buschang, PhD, Helder Jacob, DDS, PhD, and Roberto Carrillo, DDS, MS

Due to the skeletal complexity of the problem, hyperdivergent retrognathic patients are among the most difficult for orthodontists to treat. It is imperative to treat these patients for both esthetic and functional reasons. Hyperdivergent growth patterns are generally established early and most do not improve over time. The etiology appears to be environmental, due to postural adjustments related with compromised airways and weak masticatory musculature. If a lowered mandible posture is maintained in growing subjects, the dentition, dentoalveolar complex, and the mandible should be expected to compensate. Dentoalveolar heights should be expected to be excessive (i.e., supraeruption of the teeth), the ramus is shorter, the gonial angle is larger, the mandibular symphysis is taller and thinner, the mandibular plane is steeper, the mandible is retrognathic, and anterior lower face height is increased. Moreover, the jaws, especially the upper, are narrow. The most important factor underlying these developmental adaptations is true mandibular rotation. Rotation is important because it is the major determinant of the anteroposterior (AP) chin position. The detrimental skeletal changes that characterize hyperdivergent patients are ultimately due to backward or less than average true forward rotation. Theoretically, a therapeutic treatment that mimics normal growth (i.e., one that builds in true forward rotation) is desirable because it might be expected to correct not only the anteroposterior (AP) and vertical position of the chin, but also many of the other morphological maladaptations associated with the hyperdivergent retrognathic phenotype. (Semin Orthod 2013; 19:212–226.) © 2013 Published by Elsevier Inc.

Introduction

Hyperdivergent retrognathic patients are among the most difficult for orthodontists to treat because their malocclusion is multifaceted and complex. Hyperdivergent retrognathic patients were initially categorized as having vertical dysplasia[1] and have since been called by a variety of names (Table 1). Most investigators have referred them as skeletal open bites.[2,3] Schudy[4] was the first to characterize them as hyperdivergent, which more accurately reflects their skeletal phenotype.

While the prevalence of the problem has not been precisely quantified, many of the subjects with open-bite malocclusions, who have been estimated to comprise approximately 3.5% of the population,[3] might be expected to be hyperdivergent and retrognathic. More importantly, at least half of Class IIs, who comprise approximately 15% of the population,[5] are retrognathic and hyperdivergent. Children with Class II molar relationships show a slightly—but not statistically significant—greater tendency toward hyperdivergence than Class Is (Fig. 1). Average pretreatment mandibular plane angles of Class II patients reported in the literature fall both above and below age- and sex-specific reference data (Fig. 2). Based on the prevalence of open-bite and Class II malocclusions, it can be

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Table 1. Terms Adopted to Describe the Various Types of Rotation

Author	Terms
Wylie and Johnson[3]	High vertical dysplasia
Schudy	Hyperdivergent/hypodivergent
Richardson[123]	Open-bite/deep-bite
Bjork[40]	Forward/backward rotation
Linder-Aronson[43]	Adenoid face
Schendel et al.[124]	Long face syndrome
Opdebeeck and Bell[125]	Short face syndrome
Karlsen[126]	Low-/high-angle face
Betzenberger et al.[127]	High-angle malocclusion

conservatively estimated that approximately 10% of the population is both retrognathic and hyperdivergent.

Hyperdivergent subjects exhibit both esthetic and functional problems. Orthodontists and lay people perceive excessive mandibular height (measured from lower lip to menton) as being unattractive.[6] Excessively convex profiles are considered to be less esthetically pleasing than straight profiles.[7–9] It has also been well established that hyperdivergent subjects have smaller masticatory muscles and weaker bite forces than normal and hypodivergent subjects.[10–12] The muscle strength of hyperdivergent subjects is clinically important because it is positively related to occlusal contacts, occlusal support, and masticatory performance.[13–16] Vertical skeletal relationships appear to be more closely associated with maximum voluntary bite force than AP relationships.[17]

Morphologic Characteristics

Understanding the morphology of hyperdivergent retrognathic subjects is necessary in order to appreciate the full magnitude of the problem. Hyperdivergent retrognathic subjects show consistent differences when compared to normal Class Is (Fig. 3). The specific maxillary characteristics of untreated hyperdivergent retrognathic subjects depend in part on whether the samples were classified based on dental or skeletal criteria (Table 2). Most studies that evaluated anterior maxillary height have reported no statistically significant differences between hyperdivergent subjects and normal controls, although a few have found deficits. Posterior maxillary height also does not appear to be affected. Maxillary length and the sella–nasion–A-point (SNA) angle tend to be smaller—indicating a more posterior position—in hyperdivergent subjects classified based on open-bite, but not when the classification is skeletally based. Hyperdivergence does not appear to affect the palatal plane angle. Studies consistently show increased anterior and posterior dentoalveolar heights among hyperdivergent subjects. Thus, the primary maxillary problems of hyperdivergent subjects are dentoalveolar rather than skeletal.

The mandible shows substantially more pronounced and a greater number of differences between untreated hyperdivergent and control subjects than the maxilla (Table 3). Hyperdivergent subjects have greater anterior face height. While posterior facial height shows no consistent group differences, ramus height has most commonly been reported as being smaller among hyperdivergent subjects. The gonial angle is consistently larger than normal among hyperdivergent subjects. Most studies have also reported retrognathic mandibles and steeper mandibular plane angles among hyperdivergent subjects. While anterior dentoalveolar heights do not appear to be affected, posterior dentoalveolar height of subjects classified on skeletal criteria tend to be excessive.

The transverse dimensions of hyperdivergent retrognathic subjects are also affected, which should be expected if vertical growth patterns are closely

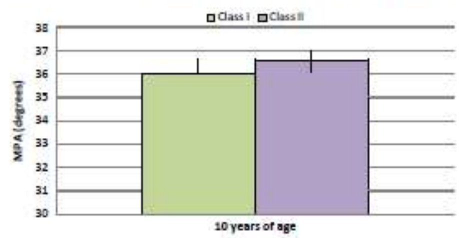

Figure 1. Mandibular plane angles (±1.96 S.E.) of untreated Class I and Class II children at 10 years of age.

Table 2. Summary of the Studies Comparing the Maxillas of Hyperdivergent and Normal Subjects. Statistically Significant Group Differences Indicated as Being Larger (↑) or Smaller (↓) Than Control Values.

	Heights		Dentoalveolar Heights				
Author	Anterior	Posterior	Anterior	Posterior	PPA	SNA	Length
Skeletal							
Isaacson et al.[24]	¼	X	↑	↑	X	¼	X
Fields et al.[128]	¼	¼	¼	¼	X	¼	X
Janson et al.[129]	X	X	↑	↑	X	X	X
Joseph et al.[130]	¼	X	X	↑	X	↓	X
Erdinc et al.[131]	X	X	X	X	X	X	X
Enoki et al.[132]	↓	X	↑	¼	X	X	X
Cha et al.[133]	X	X	X	X	X	X	X
Average	¼	¼	↑	↑	X	¼	¼
Open-bite							
Subtelny and Sakuda[134]	¼	X	↑	↑	¼	↓	¼ Lopez-
Gavito et al.[135]	↓	X	↑	↑	↓	↓	X Haralabakis and
Sifakakis[136]	X	X	↑	↑	X	X	↓ Kao et al., male[137]
↓	X	X	X	X	X	↓ Kao et al., female[137]	¼
X	X	X	X	X	↓ Ceylan and Eröz[138]		X
X	↑	↑	X	X	¼		
Taibah and Feteih, female[139]	¼	¼	¼	¼	¼	↓	↓
Taibah and Feteih, male[139]	¼	¼	¼	¼	¼	↓	↓
Sonnensen and Kjaer[140]	X	X	X	X	¼	↓	X
Average	¼	¼	↑	↑	¼	↓	↓

X, not evaluated; ¼, no significant difference; ↑, significantly larger; ↓, significantly smaller.

is the rotation that appears (i.e., apparent) to be occurring. What appears to be occurring is actually not occurring because the lower border of the mandible remodels. The remodeling camouflages or covers up the true rotation that actually occurs. For example, Spady et al.[30] showed that almost 51 of true forward rotation occurred between 6 and 15 years of age, but there was less than 11 change of the mandibular plane angle.

Table 3. Summary of the Studies Comparing the Mandibles of the Hyperdivergent and Normal Subjects. Statistically Significant Group Differences Indicated as Being Larger (↑) or Smaller (↓) Than Control Values.

		Dentoalveolar Heights		Ramus Height				
Author	Heights	Anterior	Posterior	Anterior	Posterior	MPA	SNB	Gonial Angle
Skeletal								
Isaacson et al.[24]	↑	X	X	↑	↓	↑	↓	X
Fields et al.[128]	↑	¼	¼	↑	¼	↑	¼	↑
Janson et al.[129]	X	X	↑	↑	X	X	X	X
Joseph et al.[130]	X	X	X	X	X	↑	↓	X
Erdinc et al.[131]	¼	↓	X	X	X	↑	X	↑
Enoki et al.[132]	X	X	¼	¼	X	X	X	X
Cha et al.[133]	X	X	X	X	X	↑	X	X
Average	↑	¼	¼	↑	↓	↑	↓	↑
Open-bite								
Subtelny and Sakuda[134]	↑	X	¼	¼	¼	↑	↓	↑ Lopez-
Gavito et al.[135]	¼	¼	¼	¼	↑	↑	↓	X Haralabakis and
Sifakakis[136]	↑	X	↑	¼	↓	X	X	X Kao et al., male[137]
X	¼	X	X	X	X	X	X Kao et al., female[137]	X
¼	X	X	X	X	X	X Ceylan and Eröz[138]		X
X	↑	¼	↓	X	X	↑		
Taibah and Feteih, female[139]	↑	↓	¼	¼	↓	↑	↓	↑
Taibah and Feteih, male[139]	¼	¼	¼	¼	¼	↑	↓	↑
Sonnensen and Kjaer[140]	X	X	X	X	X	↑	↓	X
Average	↑	¼	¼	¼	↓	↑	↓	↑

X, not evaluated; ¼, no significant difference; ↑, significantly larger; ↓, significantly smaller.

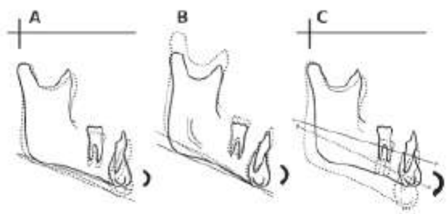

Figure 4. Mandibular (A) apparent rotation of the mandibular plane relative to cranial base, (B) angular remodeling based on mandibular superimposition, and (C) true rotation of the fiduciary reference line related to cranial base.

Untreated patients normally undergo forward or counterclockwise (as viewed by the observer when the patient is facing to the right) rotation. Average true rotation ranges between approximately 0.41 and 1.31 per year,[30–36] with greater rates reported during childhood than adolescence (Fig. 5).[30,34,36] Hyperdivergent patients undergo significantly less (23–43%) true forward rotation than hypodivergent patients.[35] Substantially greater amounts of true rotation occur during the transition between the primary and early mixed dentition than between the early mixed and early adulthood,[36] implying that the dentition plays a fundamental role.

True mandibular rotation has been repeatedly shown to be the most important determinant of the anteroposterior position of the chin in untreated[37] and treated subjects.[38,39] There are only three possible ways to explain the forward or backward movements of the chin in untreated growing subjects. The tip of the chin undergoes little or no remodeling.[30,32,37,40,41] This only leaves condylar growth changes, glenoid fossa changes, and true mandibular rotation.

Carefully consider the two patients in Fig. 6. The backward rotator (A) underwent approximately 3–4 mm of posterior condylar growth, which—all other things being equal—should move the chin forward 3–4 mm; there were no changes in glenoid fossa position and no remodeling changes at the tip of the chin. However, the AP position of the patient's chin did not change, which can only be explained by the backward true rotation that occurred. In contrast, the forward rotator (B) shows 1–2 mm of forward condylar growth and 2 mm of posterior movement of the glenoid fossa, which together should be associated with 3–4 mm of posterior chin movements. However, the chin moved 4–5 mm forward, which again can only be explained by true forward rotation.

True mandibular rotation is important because it is directly related to chin position and

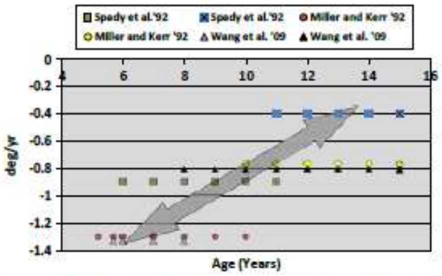

Figure 5. Annualized true mandibular rotation (total true rotation/duration of the study) of untreated subjects showing greater annual rates among children than adolescents.

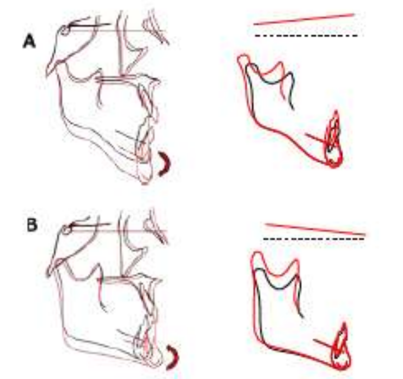

Figure 6. Changes in chin position, condylar growth, and glenoid fossa position of backward (A) and forward (B) rotators.

indirectly related to various other growth and remodeling changes that occur. Strong associations have been reported between true mandibular rotation, the amount of condylar growth, and the condylar growth direction.[31,32,37,41,42] Forward rotators show more condylar growth, oriented in a more anterior direction, than backward rotators. The lower mandibular border of forward rotators tends to show bony apposition anteriorly and resorption posteriorly, which is not the remodeling pattern exhibited by backward rotators.[32,33] True mandibular rotation also produces compensatory changes in the eruptive paths of teeth, with the molars erupting more than the incisors in forward rotators and the incisors erupting more among backward rotators.[32] The mandibular incisors and molars tend to retrocline and tip distally, respectively, in backward rotators; they procline and tip mesially in forward rotators.[32,40]

Importantly, the same remodeling changes associated with forward rotation during growth can be produced with treatment. For example, 11–15-year-old patients show changes in their patterns of condylar growth and mandibular remodeling after maxillary impactions (no mandibular surgery).[43] The changes that occurred during the years after the impactions had been performed and the mandible had been rotated forward were similar to the changes normally observed for forward rotators.

Timing and Stability of the Development Changes

It is important for orthodontists to understand that the growth patterns of most hyperdivergent patients are established early. Differences in lower facial height between deep and open-bite subjects are well established at 4 years of age.[44] Most individuals who have higher mandibular plane angles at 15 years of age also had higher mandibular plane angles between 6 and 15 years of age.[45] Bishara and Jakobsen[46] showed that 82% of 5 year olds classified as having long faces had long faces at 25 years of age. Most (64%) hyperdivergent 6 year olds are still hyperdivergent at 15 years, with 25% worsening over time.[45] Approximately 75% of 10 year olds classified as hyperdivergent, within normal limits, or hypodivergent maintain their classifications through 15 years of age.[47]

Differences in the vertical dimensions of hyper- and hypodivergent subjects are well established by 6 years of age, making them easier to distinguish early than subjects who eventually become retrognathic. Adolescents classified as retrognathic at 14–16 years of age show only limited morphological differences at 6–7 years, whereas those classified as hyperdivergent shows numerous differences, especially in the mandible.[48] Hyperdivergent subjects also demonstrate less improvements of their skeletal relationships over time; their mandibular plane angles decrease only 0.31 between 6 and 15 years of age, compared with 2.51 and 4.01 decreases for average and hypodivergent subjects, respectively (Fig. 7). The sella–nasion–basion (SNB) angle of hyperdivergent subjects increases only 0.21 compared with 1.21 and 1.41 for average and hypodivergent subjects, respectively.

Etiology of the Hyperdivergent Retrognathic Phenotype

Most craniofacial, dentoalveolar, and occlusal traits show a quantitative, often normal, distributions of phenotypes. Traits showing such distributions are polygenetic, due to the actions and interactions of multiple genes. It follows that variation in such traits must be due to genetic, epigenetic, and environmental influences. For example, a trait associated with five genes is necessarily affected by the interactions of those

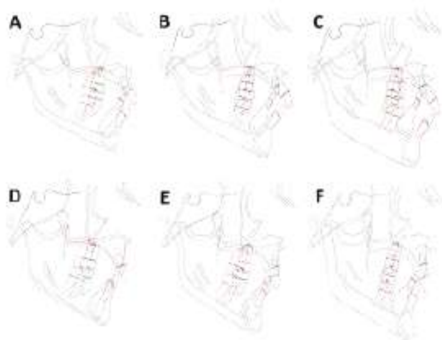

Figure 7. Growth of hyperdivergent (top row) and normal (bottom row) children, with cranial base superimpositions showing the growth changes between 6 and 9 years of age (A and D), 6 and 12 years of age (B and E), and 6 and 15 years of age (C and F).

genes, as well as environmental effects on the interactions. Genes provide the instructions to make proteins, and the interaction of proteins determines the phenotype; the interaction is via proteins that regulate transcription factors, proteins that make up enzymes, and proteins that build structure.

The relative contribution of genes to phenotypic expression varies greatly, depending on the environments in which they are expressed. The way in which environmental variation is translated into phenotypic variation is based on the norm of reaction, which states that the same genotype can produce a variety of phenotypes across a range of environmental circumstances. Traits showing greater phenotypic variation are either under less direct genetic control and/or mature (i.e., grow relatively) less rapidly than traits showing less phenotypic variation. For example, modern day Finns exhibit substantially larger gonial and mandibular plane angles than Finnish samples from the 15th and 16th centuries.[49] Since the time span was insufficient for genetic changes to have occurred, the same genotypes must have been adapting to different environmental factors. As expected, the vertical aspects of mandibular growth, which are the least mature in the craniofacial complex,[50] showed the most pronounced effects.

Three broad environmental factors have been proposed to explain changes in malocclusion over time, including habits, interferences with normal breathing, and decreases in masticatory muscle strength.[51] Only two of the factors appear to explain the development of the hyperdivergent retrognathic phenotype.

Effects of Habits

The literature does not support habits as a direct —certainly not a major—explanatory factor for the hyperdivergent phenotype. Thumb sucking, finger sucking, nail biting, tongue sucking, and tongue thrusting have been shown to be the most prevalent habits of young children.[52] While the prevalence of digit sucking is population specific, it decreases as the prevalence of dummy (pacifier) sucking increases.[53]

It has been long been known that there is a high prevalence of cross-bites among children in the primary dentition who suck their fingers[54–56] or pacifiers.[57,58] However, most cross-bites self-correct if the habit is stopped before the transition to the early mixed dentition, and most children with finger habits after the transitional dentition do not exhibit cross-bites after 9 years of age.[59,60]

There may be a link between finger habits and the development of a Class II, maxillary protrusive phenotype. An early study performed on 7–16-year-old children with persistent thumb sucking habits showed greater tendencies for open-bite malocclusions, a propensity toward Class II molar and canine relationships, proclined upper incisors, and a longer maxilla, but no effects on the mandibular or palatal plane angles.[61]

This suggests that finger habits help to explain the Class II maxillary problems, but not the retrognathic hyperdivergent phenotypes, whose malocclusions are primarily due to mandibular dysmorphology.

Effects of Interferences With Normal Breathing

Interferences in the upper, middle, and lower airway have been more closely linked than habits with developmental changes leading to a hyperdivergent retrognathic phenotype. Given the abundance of literature showing relationships—albeit few causal—with hyperdivergence, interferences with normal breathing must be considered as primary environmental factors explaining the development of retrognathic hyperdivergent dysmorphology. The morphological similarities that have been reported for subjects with enlarged tonsils, allergic rhinitis, and enlarged adenoids lead to the conclusion that chronic airway interferences produce similar phenotypes.

The classic experiments by Harvold and colleagues[62] established a causal relationship between mode of breathing and changes in craniofacial morphology. Compared to control monkeys, those with blocked nasal airways developed steeper mandibular planes and larger gonial angles. The changes were most pronounced in the animals that maintained a low postural position of the mandible. When the blockages were removed, growth reverted back toward their normal, more horizontal, pattern.

Clinically, the relationship between airway and growth disturbances has been perhaps best established for patients with enlarged adenoids. Linder-Aronson[63] was among the first to report systematic differences between children with enlarged adenoids and nose breathing controls. Children with enlarged adenoids have increased lower anterior facial heights, larger gonial angles, narrow maxillary arches, retroclined incisors, and larger mandibular plane angles.[63] Subsequent studies have confirmed that subjects with enlarged adenoids have more vertical mandibular growth tendencies than their nose breathing counterparts, along with retroclined mandibular incisors, smaller SNB angles, larger mandibular plane angle, and larger lower face heights.[64-66]

Following adenoidectomies, most (E75%) children change to nasal breathing within 1 year.[67] Spontaneous improvements in the mandibular plane angles, arch widths, and incisor inclinations have been reported 5 years after adenoidectomy.[68] The mandible also changes it growth direction after adenoidectomy, assuming an even more horizontal direction than in controls.[69,70] Kerr et al.,[65] who followed 26 children 5 years after adenoidectomies, showed changes in their mode of breathing and a normalization of growth, with a more anterior direction of mandibular growth and forward true rotation of the mandible. Interestingly, it appears that the timing of the adenoidectomies is an important factor in determining the growth response that occurs.[66]

Although less well studied, chronically enlarged tonsils produce the same phenotype as enlarged adenoids. Behlfelt and colleagues,[71] who evaluated 73 ten-year-old children with enlarged tonsils, showed that they were more retrognathic, had longer anterior facial height, and larger mandibular plane angles than children who do not have enlarged tonsils. Furthermore, the skeletal features were directly related to the childrens' open mouth and lowered tongue postures.

Sleep apnea produces similar morphological characteristics. Lowe et al.[72] showed that adult males with severe obstructive sleep apnea exhibited steep occlusal and mandibular plane angles, overerupted maxillary and mandibular teeth, larger gonial angles, and anterior open bites. Andersson and Brattström[73] reported similar morphological patterns among 51 heavily snoring patients with and without apnea. More recently, it was shown that children with obstructive sleep apnea also have steeper mandibular plane angles, greater lower anterior face heights, and more retroclined incisors; 5 years after adeno-/tonsillectomies none of the differences between apnea patients and controls were statistically significant.[74]

There are similar associations between allergic rhinitis and craniofacial development. This is important because the prevalence of allergic rhinitis ranges between 10% and 20%; most patients with allergic rhinitis also have asthma.[75] Bresolin et al.[76] showed that mouth breathers have significantly longer anterior facial heights, larger mandibular plane angles, relatively greater mandibular than maxillary retrusion, larger gonial angles, higher palates, greater overjet, and narrower maxillas than nose breathers. Mouth breathers

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with perennial allergic rhinitis display deeper palates, retroclined lower incisors, smaller SNB and SNPg angles, increased overjet, increased lower face heights, larger gonial angles, and larger mandibular plane angles than their siblings.[77] Children 6–16 years of age with chronic perennial allergic rhinitis display more vertical and divergent facial growth patterns than controls, with the degree of hyperdivergence being directly related to the severity of the allergic rhinitis.[78] Harari et al.,[79] who compared 55 children with signs and symptoms of nasal obstruction to 61 normal nasal breathers, showed that the mouth breathers had larger mandibular plane angles, greater overjet, retrognathic mandible, larger Y-axis, and narrower intermolar widths.

Effects of Muscle Weakening

Historically, reduced masticatory muscle forces have provided the best explanation for the prevalence of hyperdivergence retrognathic phenotypes. Anthropological studies have consistently shown that the prevalence of malocclusion is much lower for subjects living under primitive conditions than for their counterpart eating processed foods.[80,81] Since individuals living under more primitive conditions eat harder foods that require greater muscular effect for communition,[82] they might be expected to have larger masticatory muscles and greater force output. The treatment priority index (a composite index of open/overbite, overjet, posterior cross-bite, tooth displacements, and buccal segment relations) has been shown to be consistently higher among groups eating traditional diets than their counterparts eating modern diets (Fig. 8), with those eating modern diets often exhibiting clinically significant malocclusions. Importantly, this association is not limited to dental malocclusion; maladaptive changes to technological advances have also been associated with larger inter-maxillary (i.e., mandibular plane) angles, larger gonial angles, and narrower jaws. Comparisons of the present day Finns to Finnish samples from the 16th and 17th centuries showed that posterior, but not anterior, facial heights were significantly smaller in present day Finns; hyperdivergence was attributed to the softer foods in the present day diet, supporting the notion that craniofacial growth is regulated with masticatory stress.[83]

There are also numerous experimental studies showing differences in muscle strength, muscle morphology, and craniofacial growth between animals fed soft and hard diets. Various species of growing animals fed on soft diets show structural differences in their masticatory muscles, lower bite forces, differences in condylar growth, narrower maxillas, and differences in bony remodeling.[84–89] Remodeling of the gonial process has been directly related with the sizes of the masseter and medial pterygoid muscles[90,91]; resection of the masseter and pterygoid muscles results in alterations in condylar growth, mandibular length, and ramus height.[92–94]

Most importantly, weak jaw muscles among humans have been directly linked with

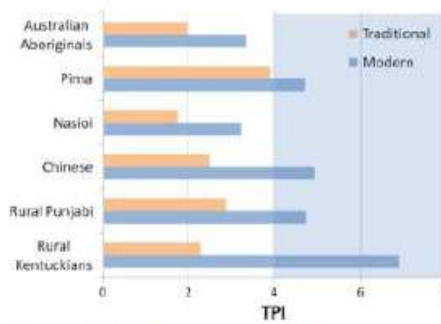

Figure 8. Treatment priority index (TPI) of the sample populations subsisting on either modern or traditional diets, with values greater than 4 indicating malocclusions that need to be treated.

hyperdivergent growth tendencies. Skeletal hyperdivergence has been directly related to reduced muscle size, low EMG activity, and reduced muscle efficiency.[95–97] Increased dentoalveolar heights have also been associated with decreased masticatory muscle function.[98,99] Adults with larger mandibular plane angles have substantially weaker bite forces.[10–12] Facial divergence has also been related to lower bite force in younger children.[100]

Patients with muscular dystrophy and spinal muscular atrophy most dramatically demonstrate the relationship between muscle function and hyperdivergence. Over 30 years ago, Kreiborg and colleagues[101] showed the profound effects that muscular dystrophy had on the craniofacial growth of a 12.5-year-old girl. The same single recessive gene defect that directly weakened muscles indirectly produced a severe hyperdivergent retrognathic skeletal phenotype.[101] Subsequent research has shown that subjects with Duchenne and myotonic muscular atrophy,[102,103] as well as spinal muscular atrophy,[96,104] have significantly weaker masticatory muscles and show the same constellation of features presented by hyperdivergent retrognathic subjects, including narrow and deep palates, increased anterior facial heights, larger gonial angles, and steeper mandibular planes. The sizes of the masticatory muscles have also been related to the breadth of the ramus,[92,105,106] bizygomatic width[107,108] and, especially, maxillary width.[98,109–111]

Importantly, strengthening of the masticatory muscles produces morphological changes opposite of those produced by weakened muscles. Hyperdivergent patients who underwent chewing exercises show greater true forward mandibular rotation than untreated hyperdivergent subjects do and even greater rotation than subjects treated with vertical-pull chin-cups.[112] Ingervall and Bitsanis[113] also showed that masticatory muscle training produces significant increases in bite forces and greater than expected forward rotation of the mandible.

Mandibular Posture is the Key

Mandibular posture provides the only logical explanation for why airway blockages and weakened muscles produce the same hyperdivergent retrognathic phenotype. Navarro et al.,[99] who showed that posterior mandibular rotation occurs in association with reduced muscle function, provide the only direct experimental support of the relationship between masticatory muscle strength and mandibular posture. There is, however, substantial indirect evidence supporting the relationship between muscle strength and posture. For example, muscle strength has been implicated as a limiting factor in standing posture[114]; it is one of the main causes for postural instability in Parkinson's disease patients,[115] and it has been related to posture in patients with chronic lumbar pain.[116] Most importantly, muscle exercises are also commonly used to correct postural deviations.[117–120]

It is much easier to understand why the mandible is typically lowered in individuals with airway obstruction. By definition, mouth breathers must move their mandibles in order to breathe, and it is more efficient to lower than protrude or laterotrude the mandible.

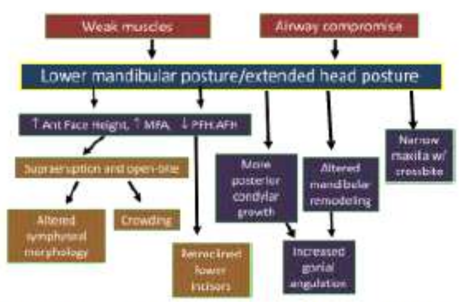

Figure 9. The development of the hyperdivergent retrognathic phenotype from lowered mandibular posture produced by weak muscles or airway compromise.

Experimental obstruction of the upper airway results in lowered resting posture of the mandible, and a 51 increase in the cranio-cervical extension.[121]

If the lower mandibular posture is maintained (i.e., if it is habitual), and especially if the subject has growth potential, then the dentition, dentoalveolar complex, and mandible might be expected to adapt to the changed position (Fig. 9). Lower mandibular posture immediately increases the mandibular plane angle, as well as decreases the posterior to anterior face height ratio. Over time, lowered posture causes increases in anterior face height and supra-eruption of the dentition. Whether or not the anterior teeth overerupt depends, at least in part, on whether the tongue is postured between the teeth, in which case an open-bite would be produced. The incisors, especially the mandibular incisors, adapt to lower mandibular position by retroclination. Retroclination and overeruption cause changes in symphyseal morphology and increased crowding. Lowered mandibular and tongue posture leads to a narrow maxillary arch with possible cross-bites. A lower posture leads to changes in the mandible's remodeling pattern and a more posteriorly directed condylar growth, which in turn lead to increases in the gonial angle.

Theoretically, therapeutic forward rotation of the mandible will reverse and perhaps correct the hyperdivergent retrognathic dysmorphology. Buschang and colleagues[122] recently showed that it is possible to produce meaningful orthopedic corrections of growing retrognathic hyperdivergent patients. They produced an average of 3.91 mandibular plane rotation by intruding the posterior teeth with miniscrew implants. The mandibular rotation advanced the chin by 2.4 mm, increased the SNB angle by 2.11, improved facial convexity by 3.21, and decreased the gonial angle by 2.41. Their best outcomes produced substantial orthopedic effects, similar to those seen with surgery (Fig. 10). The outcomes were growth related; patients with greater growth required less intrusion to produce the desired effects.

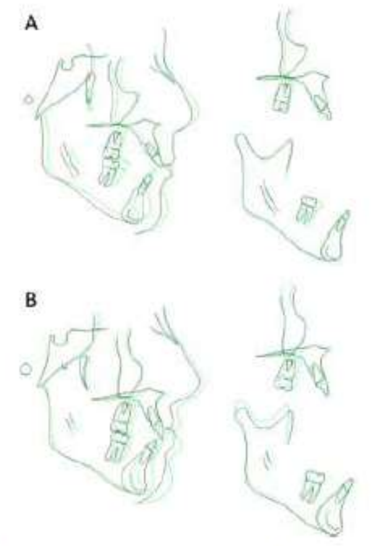

Figure 10. Orthopedic correction of (A) minimally growing and (B) growing patients by molar intrusion miniscrew implants and mandibular rotation.

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APPENDIX B*

OVERVIEW

Palatal and Mandibular Miniscrew Implant Placement Techniques

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PETER H. BUSCHANG, PHD

(Editor's Note: In this regular column, JCO provides an overview of a clinical topic of interest to orthodontists. Contributions and suggestions for future subjects are welcome.)

Miniscrew implants (MSIs) have revolutionized orthodontics by broadening the spectrum of potential dental movements and opening new possibilities for dentofacial orthopedics. Although treatment with MSI anchorage is now routine in orthodontic offices, reported implant success rates still range from only 70% to 100%—generally less than 90%.[1-4] Because success with MSIs is so technique dependent, we need reliable and tested methods for placing these implants to ensure trouble-free use in clinical practice.

This article describes two standardized MSI placement procedures: the "Thumb-Index" technique for palatal insertion and the "Two-Step" technique for buccal insertion. Using these methods, we have reduced our failure rate to 4% for both maxillary and mandibular MSIs.[5]


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Choosing the Insertion Site

Assuming the patient is a good candidate for MSI treatment, several factors must be considered in determining the best MSI insertion site.

Bone Condition

To provide optimal MSI stability, it is important to choose the best available bone that fits the biomechanical needs of the case, following these steps:

1. *Develop a good implant site.* Planning for multibracketed treatment should include enhancement of interradicular implant sites through intentional root divergence. It is important to wait for adequate interradicular space (ideally, at least 1mm between the MSI and the periodontal ligament) to be opened prior to MSI placement, since clinical reports have shown that root proximity has a negative effect on implant stability.[6-8]

2. *Check bone thickness.* With the introduction of cone-beam computed tomography in dentistry, it is now possible to measure cortical thickness prior to MSI insertion. Because primary stability

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depends largely on cortical bone, studies recommend placing MSIs in cortical bone at least 1mm thick while carefully controlling insertion torque.[9-16]

3. *Consider alveolar crest height.* In an attempt to avoid potential hygiene problems and peri-implant inflammation, the clinician may compromise the bone site for an MSI by placing it too high in the alveolar crest and perpendicular to the cortical bone. When the mucogingival junction (MGJ) is at approximately the same height as the alveolar crest, the MSI should be inserted at an angle.[17] The implant can be inserted at the level of the crest (so that the screw head ends up in attached gingiva), but the insertion path of the MSI should be oriented towards the apices of the teeth and the trabecular bone. Trabecular bone has been shown to play an important role in secondary MSI stability.[18-20]

4. *Note the clinical implications of insertion site choices.* In some cases, MSIs will need to be used as indirect anchorage to avoid compromised placement sites.

Good bone and adequate space for MSI placement are of paramount importance. Suitable insertion sites can usually be found between the second premolars and first molars in both arches. The palate is another excellent location for MSI insertion, since it is covered by keratinized gingival tissue and offers considerable flexibility in the selection of safe placement zones.[11,21-25]

Tissue Type

Peri-implant tissue inflammation can make appliance adjustments uncomfortable and limit the utility of MSIs. Together with good bone, the right type of tissue plays an important role in MSI stability. Primary considerations are as follows:

1. *Place the MSI in the attached gingiva.* To avoid inflammation, try to place an interradicular MSI in the attached gingiva, or as close to the MGJ as possible.[26,27] Keratinized gingival tissue has been shown to adapt nicely and form a biological seal around titanium surfaces.[28] The palate is recommended as an implant area because of its tissue characteristics and its ability to heal rapidly. Frena should be avoided due to commonly reported problems of patient discomfort and tissue mobility.[29]

2. *Insert the MSI at an angle.* Again, by angulating the MSI, it is possible to keep the head in the attached gingiva while directing the body of the implant into interradicular bone, away from dental roots and the alveolar crest. Note that the insertion path and angle will affect the height of the screw head, which can interfere with planned mechanics.[30]

3. *Reduce inflammation.* Because plaque accumulation around the MSI head is a risk factor for peri-implant inflammation, therefore increasing the likelihood of failure,[29] proper oral hygiene is imperative.[31] Any attachment to the MSI head should be easy for the patient to clean and avoid contact with the surrounding soft tissues. A chlorhexidine gel (.2%) can be prescribed to help reduce inflammation. Tissue hyperplasia can easily be removed with a soft-tissue laser at check-up visits.

Anatomy

We strongly recommend the use of radiographic analysis and palpation to determine the anatomy of the implant area and the structure, shape, and position of adjacent roots, thus reducing the risk of injury. The most important anatomical structures include the following:

Maxilla (Fig. 1)

- Greater palatine foramen, usually located about 15mm lateral to the midpalatal suture at the level of the maxillary second or third molars.[32]
- Greater palatine neurovascular bundle, extending anteriorly from the greater palatine foramen to the canine area[33]; depending on the height of the palatal vault, it may be 7-17mm above the cementoenamel junctions of the premolars and molars.[34]
- Incisive canal and foramen, including the nasopalatine bundle.
- Midpalatal suture (in growing patients).
- Nasal floor and maxillary sinuses.

Mandible

- Mental foramen, located between the lower

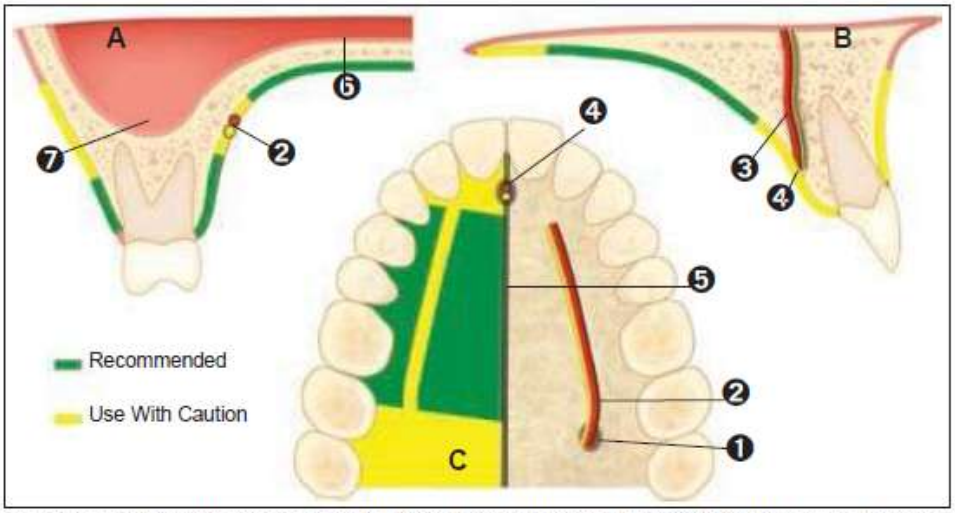

Fig. 1 Coronal (A), sagittal (B), and axial (C) views showing important anatomical structures related to maxillary miniscrew implant (MSI) placement: (1) greater palatine foramen, (2) neurovascular bundle, (3) incisive canal and nasopalatine bundle, (4) incisive foramen, (5) midpalatal suture, (6) nasal floor, (7) maxillary sinuses.

premolars 12.4mm ± 3.3mm from the alveolar crest.

• Mandibular canal, which can be viewed on a panoramic radiograph.[35]

Biomechanics

Biomechanics associated with MSI placement should be kept as simple as possible, so that chairside adjustments can be made quickly and patient discomfort minimized. MSIs should be loaded with constant forces,[26,36] either immediately after placement or after a five-to-six-week healing period,[37,38] depending on primary stability as described below.

MSI Placement Techniques

By first choosing a good implant site and then planning the biomechanics from that site, considering both direct- and indirect-anchorage options, the clinician increases the chances of reliable and trouble-free treatment. The next link in the chain of MSI success is the placement procedure.

We have developed two basic techniques for MSI insertion, which we use for virtually all of our palatal and buccal (mainly mandibular) placements.

Palatal Anchorage: "Thumb-Index" Insertion Technique

The "Thumb-Index" technique, used for most palatal MSIs, allows the desired insertion path to be visualized throughout the procedure. By using only the thumb and index finger, the operator can more easily maintain tactile sensation while avoiding any wobbling of the MSI. Torque levels applied with two fingers are generally lower than the torque needed to fracture an MSI.[39,40]

After a 30-second chlorhexidine rinse, the procedure is as follows:

1. Locate the insertion site. Especially with the first few cases, this technique may require more planning time than when placing MSIs in the buccal region. Highlight the site with a tissue marker so it can be viewed from different angles, then reassess the markings using an occlusal mirror. If placing MSIs bilaterally, evaluate the symmetry of the locations as necessary.

2. Anesthetize the patient. A discomfort- and pain-free palatal insertion can usually be achieved by local infiltration with a syringe and a short needle. When appropriate, the addition of a vasoconstrictor to the anesthetic will help slow the blood flow to the area. A tissue punch is not usually needed, but if one is used, it should be slightly smaller in diameter than the outer diameter of the MSI.

3. Measure tissue depth. After the patient has been anesthetized, test the depth of the tissue with a periodontal probe under firm pressure: it is important that the probe contact the bone. If the patient feels more than pressure, infiltrate more anesthetic into the site. Ensure that the MSI has the appropriate thread and neck lengths to keep the screw head out of the tissue without compromising insertion depth.

Fig. 2 A. "Thumb-Index" technique for MSI placement in posterior lateral alveolar bone (left) and anterior palate (right). B. MSI insertion path assessed in three planes of space using intraoral mirror. C. Firm and consistent pressure applied with one hand while driver is rotated with other hand to insert MSI.

4. Place the MSI tip in the insertion site. Load the MSI in the hand driver. Using just the thumb and index finger of one hand—one placed on the head of the driver and the other on the far side of the bone—apply firm and continuous pressure to the MSI until it contacts bone (Fig. 2A).
5. Assess the insertion path. While maintaining firm pressure on the MSI with one hand, use an intraoral mirror to assess the insertion path in the mesiodistal, anteroposterior, and apical/occlusal directions (Fig. 2B). Holding the driver with only two digits makes it possible to keep the MSI in constant view and thus to maintain a proper direction and angulation throughout insertion. Some situations—for example, insertion of an implant perpendicular to the posterior palate—will require more pressure from the thumb and index finger.
6. Insert the MSI. In most cases, especially with self-drilling screws, there is no need to drill a pilot hole. Insert the MSI into the palate by slowly rotating the driver end clockwise with the thumb and index finger of the hand that is not holding the driver in place (Fig. 2C). It is critical to keep a firm and consistent pressure on the driver head, while orienting it perpendicular to the bone surface, to prevent wobbling during insertion. Since tactile sensation plays an important role in ensuring that the appropriate amount of torque is maintained and that roots and other structures are not contacted, a manual contra-angle driver (such as the LT Driver* shown here) is recommended. Motorized drivers are not recommended due to this loss of sensation, which is critical for assessing insertion torque and primary stability.
7. Check for primary stability. There should be no mobility of the MSI head when pressure is applied with a hemostat. If moderate or severe mobility occurs, remove the MSI and reinsert it in a different location. If there is less than .5mm of mobility, apply only a light, constant force for the first five to six weeks.

Every patient should receive instructions on post-insertion care and oral hygiene. We recommend a quick check-up visit one week after insertion for assessment of hygiene and tissue health. If the hygiene is inadequate, twice-daily chlorhexidine rinses should be prescribed for five days.

Buccal Anchorage: "Two-Step" Insertion Technique

The "Two-Step" technique, used for placement in buccal bone, allows insertion of the MSI at any desired angulation without the need for a pilot drill. After a 30-second chlorhexidine rinse, the procedure begins with steps 1-3 listed above and continues as follows:
4. Place the MSI tip in the insertion site. Load the MSI in the hand driver. Place the MSI as close to the MGJ as possible, applying firm pressure with the palm of the hand to maintain stable contact with the bone (Fig. 3A).
5. Make a notch in the cortical bone. With the MSI perpendicular to the bone, rotate the driver until two threads of the MSI have been inserted into the bone (Fig. 3B), then turn the driver in the opposite direction and remove the MSI completely. This notch will prevent the implant from slipping on the bone during insertion.
6. Insert the MSI at the desired angle. Reinsert the MSI tip in the base of the notch at the correct angle of insertion (Fig. 3C). Keep a light but firm pressure on the driver with the palm of the hand to maintain a consistent angulation during the insertion process (Fig. 3D). Do not twist the wrist to rotate the drive; use only the thumb and one finger (index or middle) to turn the driver clockwise while holding the wrist firm and in alignment with the forearm.
7. Check for primary stability, following the same criteria outlined above.

We highly recommend a trial positioning of the driver in the patient's mouth before starting the actual placement procedure. This not only allows the operator to adjust the patient properly in the chair, but also lets the patient know what to expect. MSI placement can be made as easy as possible for the patient by clearly explaining the procedure, establishing a simple hand signal for communication (such as thumb up or down), and administering appropriate anesthesia. Some buccal insertions can be accomplished using only a topical compound anesthetic, eliminating the need for infiltration.[41,42]

*IMTEC, Ardmore, OK; www.imtec.com.

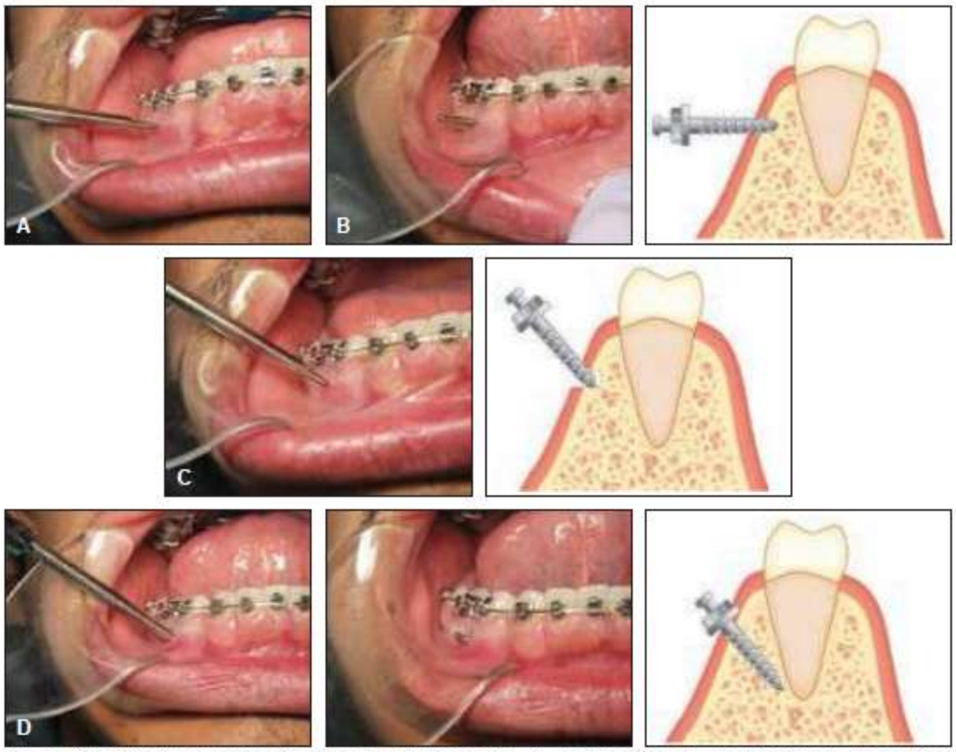

Fig. 3 "Two-Step" technique for buccal MSI placement. A. MSI positioned perpendicular to cortical bone. B. Notch made in cortical bone with first few threads of MSI. C. MSI reinserted at desired angle, using notch to avoid slipping on bone. D. MSI fully inserted.

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APPENDIX C*

TECHNIQUE CLINIC

Closed-Coil Springs for Intrusion Mechanics with Miniscrew Anchorage

A closed-coil spring can be anchored to a miniscrew to apply light force for molar intrusion. Because of the short distance between the two points of force application, it can be difficult to activate the spring sufficiently, especially as the distance spanned by the spring gradually decreases during intrusion.

Most miniscrew manufacturers are now producing closed-coil springs with eyelets sized to fit over the heads of the screws.* Fitting an eyelet over the head of the miniscrew at the anchorage site makes placement and removal of the spring easier and faster, but it is still challenging to attach the opposite end of the spring to a bracket, an archwire, or an appliance during intrusion mechanics. The following simple procedure can be used to apply forces over short distances using these closed-coil springs.

Procedure

1. Place the miniscrew at the desired site and height. If the distance from the miniscrew to the point of force application is too short to activate the coil spring, shorten the spring by cutting it with a ligature cutter, and thread an .010" stainless steel ligature through the first two coils (A).

(continued on next page)

*Pictured are Sentalloy nickel titanium springs and OrthoImplant miniscrews. Sentalloy is a registered trademark of GAC International, Inc., 355 Knickerbocker Ave., Bohemia, NY 11716; www.gacintl.com. OrthoImplant is a trademark of Imtec Corporation, Ardmore, OK; www.imtec.com; distributed by 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

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2. Make a loop in the ligature wire, and use it to attach the coil spring to the bracket, archwire, or appliance (B).
3. Adjust the spring length to the desired level of force using a force gauge (C). This is important to do for each spring, because the force level of manufactured springs can vary slightly, and the length of the spring has been altered to attach it to the miniscrew.
4. Complete the attachment of the activated spring (D).

To evaluate the force magnitude at subsequent appointments, simply remove the eyelet from the head of the miniscrew and measure the force with the gauge.

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APPENDIX D*

Orthopedic Correction of Growing Hyperdivergent, Retrognathic Patients With Miniscrew Implants

Peter H. Buschang, PhD, Roberto Carrillo, DDS, MS,† and P. Emile Rossouw, BChD, MChD‡*

Traditional orthodontic treatments do not adequately address the skeletal problems of retrognathic, hyperdivergent, Class II adolescents; the few approaches that do address them require long-term patient compliance. This article introduces a novel approach using miniscrew implants (MSIs) and growth to treat retrognathic, hyperdivergent adolescents. Nine consecutive patients were evaluated at the start of treatment (aged 13.2 ± 1.1 years) and again at the end of the orthopedic phase (after 1.9 ± 0.3 years). Each patient had 2 MSIs placed in either side of the palate. Coil springs (150 g) extended from the MSIs to a rapid palatal expander, which served as a rigid segment for intruding the maxillary premolar and molars. Two additional MSIs were placed between the first mandibular molars and second premolars; coil spring (150 g) extended from the MSIs to hold or intrude the mandibular molars. Before treatment, the patients exhibited substantial and significant mandibular retrusion (Z score = −1.0), facial convexity (Z score = 0.7), and hyperdivergence (Z score = 1.6). Treatment produced consistent and substantial orthopedic effects. The chin was advanced by a mean of 2.4 mm, the sella-nasion-basion (SNB) angle increased by 2.1°, the mandibular plane angle decreased by 3.9°, and facial convexity decreased by approximately 3.2°. Questionnaires showed that this treatment approach was not painful or uncomfortable; the majority of the patients indicated that they were very likely to recommend the treatment to others. Treatment was accomplished by titrating the amount of orthodontic intrusion performed based on the individual's growth potential.

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Growing individuals with Class II malocclusions comprise a large segment of the population requiring orthodontic treatment for both esthetic and functional reasons. Approximately 15% of untreated adolescents in the United States have Class II malocclusion.[1,2] Treatment is necessary to correct the malocclusion and to straighten the profile, which tends to be convex. Among white persons, convex profiles are among the least favored, whereas straighter profiles with prominent chins are the most favored.[3] Changing retrusive profiles to straighter, less retruded profiles significantly increases attractiveness.[4] Individuals with Class II malocclusion also have functional deficits and impaired masticatory function,[5,6] which have been directly related to their malocclusion.[7]

Class II patients often have retrognathic mandibles and hyperdivergent growth tendencies, which make them among the most difficult to treat orthodontically. The skeletal problems associated with Class II are primarily mandibular; the mandible becomes retrusive and hyperdivergent throughout childhood and adolescence.[8,9] Importantly, Class II patients with hyperdivergent tendencies have additional morphologic characteristics, the correction of which makes treatment more difficult, including excessive anterior and posterior dentoalveolar heights, open bites, increased lower face heights, steeper mandibular planes, and larger gonial angles.[10-19]

To address the myriad of problems associated with hyperdivergent Class II patients, forward mandibular

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Table 1. CHANGES IN SNA, SNB, AND MPA FOR TRADITIONAL HEADGEAR NON-EXTRACTION AND EXTRACTION TREATMENTS

Reference	Non-Extraction Treatments (°)			Extraction Treatments (°)		
	SNA	SNB	MPA	SNA	SNB	MPA
LaHaye et al[25]	−2.0	0.4	0.6	−3.7	0.6	0.6
Haralabakis et al[30]	−1.5	0.7	−0.4	—	—	—
Gandini et al[31]	−2.1	0.8	−0.3	—	—	—
Bishara[32]	−0.6	0.8	−1.4	—	—	—
Hubbard et al[33]	−2.1	−0.4	0.1	—	—	—
Luppanapornlarp and Johnston[34]	−1.4	−0.3	0.7	−1.8	−0.1	−0.2
Paquette et al[35]	−1.5	0.2	−2.0	−2.3	−1.8	0.3
Cangialosi et al[36]	−1.1	0.5	−0.3			
Brown[37] (HPHG)	−0.7	−0.2	0.9	−0.1	0.5	−0.3
Brown[37] (CPHG)	−0.9	0.1	0.8	−1.2	−0.1	0.7
Taner-Sarisoy and Darendeliler[27]	—	—	—	−1.2	−0.3	0.1
Bishara et al[38]	—	—	—	−2.3	−0.2	−1.4
Mean of all 12 studies	−1.4	0.3	−0.1	−1.8	−0.2	−0.1

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rotation must be incorporated into any treatment plan attempting to address the skeletal dysmorphology. Björk and Skieller's landmark studies were among the first to show that true forward rotation (as defined by Solow and Houston[20]) is associated with greater chin projection, reductions in the gonial angle, redirection of condylar growth, and control of vertical eruption.[21,22] True mandibular rotation has repeatedly been shown to be the most important determinant of the anteroposterior position of the chin in untreated[23] and treated subjects.[24,25]

Current orthodontic treatment approaches for growing hyperdivergent Class II patients do not control rotation and, therefore, cannot adequately address the skeletal dysmorphology. Because vertical control is especially difficult for hyperdivergent patients (ie, those with steep mandibular plane angles),[18] established treatment mechanics often impede improvements of the profile.[26-29] The most common orthodontic treatment approaches for hyperdivergent Class II patients produce mainly dental corrections. LaHaye et al[25] recently showed that the 3 most common treatment approaches for such patients (headgear with extractions, headgear without extractions, and Herbst appliance) corrected the Class II malocclusions but did not consistently improve the chin projection or hyperdivergent tendencies. The literature clearly shows that traditional treatment approaches to Class II hyperdivergent patients have little or no effect on the mandible (Table 1).

In contrast, vertical-pull chin cup appliances are effective at producing true anterior mandibular rotation and decreasing the anterior facial height.[39-41] For example, young patients treated with anterior-pull chin-cup therapy show twice as much forward movement of the chin as, and almost 3 times as much true mandibular forward rotation than, matched controls.[41] Such findings support the notion that rotation is the key mechanism in treating hyperdivergent Class II patients. However, vertical-pull chin cup appliances depend heavily on patient compliance, which makes treatment results unpredictable.

Currently, surgery is the most effective approach for treating moderately to severely hyperdivergent Class II patients. Although case studies have shown more spectacular results, the existing cohort studies evaluating maxillary impaction to advance the mandible have shown clinically significant increases in the SNB angle (0.4°-2.6°),[42-44] decreases in the mandibular plane angle (3.4°-3.5°),[42,44] and decreases in gonial angulation (0.2°-1.6°),[43,44] all of which address the underlying skeletal problems. However, Le Fort surgical procedures are substantially more expensive than orthodontics alone and can only be performed on non-growing individuals.

With the incorporation of fixed anchorage devices, the need for patient compliance has been mitigated and force magnitudes can be better controlled.[45] Of all the fixed anchorage devices, miniscrew implants (MSIs) are the least invasive, the most conservative in terms of placement and removal, the most flexible with respect to implantation site, and the least expensive. MSIs are also esthetically more acceptable than extraoral appliances, and they are especially well suited for noncompliant patients.

Although MSIs have been used for various orthodontic treatments, there is only limited information available on their use as anchorage for intrusive mechanics in growing patients. The existing studies, which pertain to adults (Table 2), have shown 1.7° to 3.3° decreases in the mandibular plane angle; 1.6- to 3.7-mm decreases in lower face height; 1.8 to 3.4 mm and 0.1 to 1.3 mm of upper and lower molar intru-

Table 2. SUMMARY STATISTICS FOR TREATMENT OF HYPERDIVERGENT ADULTS WITH INTRUSION OF TEETH WITH MSIs

	n	MPA (°)	SNB (°)	U6PP (mm)	L6MP (mm)	Gonial Angle (°)	ANS-Me (mm)
Erverdi et al[46]	10	−1.7	+1.8	−2.6	−0.1 (NS)	—	—
Kuroda et al[47]	10	−3.3	+1.5	−2.3	−1.3	−0.3 (NS)	—
Xun et al[48]	12	−2.3	+1.6	−1.8	−1.2	−1.0 (NS)	−1.6
Akay et al[49]	10	−3.0	+1.6	−3.4	—	—	−3.7

Abbreviation: NS, no statistically significant change.

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sion, respectively; and 1.5° to 1.8° decreases in the SNB angle.[46-49] However, these findings provide no guidelines for growing adolescents, who comprise most of the orthodontic cases being treated, and who might be expected to respond differently to treatment than adults.

The fact that MSIs make it possible for orthodontists to apply forces more effectively is important because it allows the application of light intrusive forces, thereby reducing the potential of root resorption. Our experimental and histologic studies have shown that light forces and miniscrews can be used to intrude multiple multiradicular teeth (segmental intrusion) without significant root resorption.[50-52]

The foregoing prospective feasibility study was designed to evaluate the skeletal and dental effects of intruding segments of teeth in a controlled fashion using MSIs. By intruding maxillary and mandibular teeth in a controlled fashion, we expected to produce mandibular forward rotation and remodeling changes that address both the skeletal and dental problems associated with growing Class II hyperdivergent patients.

Study Design

The sample consists of 9 consecutive patients (8 female patients and 1 male patient) recruited during screenings held at the Graduate Orthodontic Clinic of Baylor College of Dentistry, Dallas, Texas. The patients met the following selection criteria.

The inclusion criteria were as follows:

1. Early permanent dentition (premolars and permanent canines emerged)
2. Lower anterior facial height greater than age- and gender-specific mean values (based on reference data reported by Riolo et al[53])
3. Retrognathic mandible with the SNB angle being 1 SD or more below age- and gender-specific values (based on reference data reported by Riolo et al[53])
4. End-on or greater bilateral Class II canine and/or molar relationships

The exclusion criteria were as follows:

1. Inability to attain acceptable hygiene levels before starting orthodontic treatment

Institutional review board approval was obtained, and all of the subjects have been recruited into the study. The overall study included 20 patients; the present preliminary report pertains to the 9 patients for whom complete pretreatment and post-treatment records have been obtained.

The appliances used for skeletal anchorage were IMTEC MSIs (IMTEC Corporation, Ardmore, OK) (1.8 X 8 mm). Sentalloy coil springs (GAC International, Bohemia, NY) were used to intrude and hold the posterior teeth; each spring was calibrated by use of a gram-force gauge (Correx, Haag-Streit, Switzerland) to deliver a constant force of approximately 150g. A rapid palatal expander (RPE) (Variety SP; Dentaurum, Ispringen, Germany) was used to expand the maxilla and to hold the premolars and molars as a rigid segment during intrusion. Fixed orthodontic appliances (0.018 slot; SPEED Industries, Cambridge, Canada) were used to complete the orthodontic phase of treatment.

After approximately 2 months of treatment and retention, the RPE was sealed, and the 2 maxillary MSIs were placed in the parasagittal region of the palate mesial to the first molars. Vertically, the MSIs were placed where the palatal roof and lingual walls meet (Fig 1A). The patients rinsed with chlorhexidine (Peridex; Zila Pharmaceuticals, Fort Collins, CO) for 30 seconds immediately before MSI insertion and 2 or 3 times per day for the next 3 to 5 days. Each patient was previously anesthetized by use of topical anesthesia followed by local infiltration of a one-quarter cartridge of lidocaine with epinephrine. A periodontal probe was used to puncture the palatal tissues in the parasagittal region mesial to the maxillary first molar. Once firm contact with the cortical bone had been made, the tissue thickness at the implantation site was assessed. By use of a manual contra-angle, each miniscrew (1.8 mm X 8 mm) was inserted perpendicular to the cortical bone following the palate's anatomy. Miniscrews were inserted without a pilot hole or a

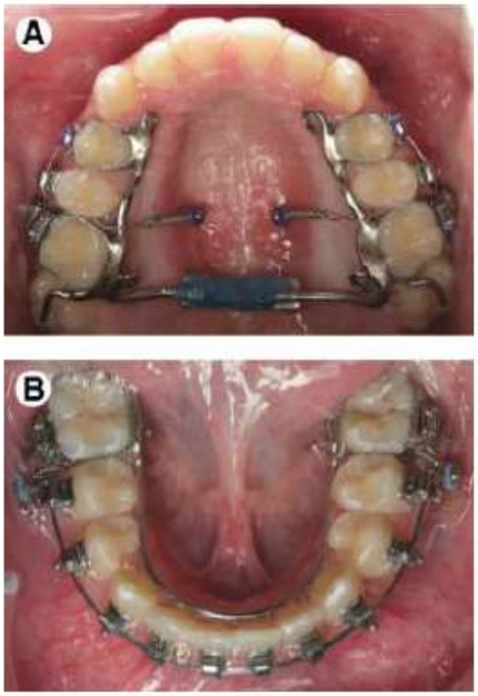

FIGURE 1. Maxillary (*A*) and mandibular (*B*) appliances used for treatment.

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tissue punch. Both MSIs were immediately loaded with an intrusive force of 150g by use of calibrated Sentalloy coils that extended directly to the RPE frame between the first molar and second premolar, following the protocol previously described.[54]

The sites for the mandibular MSIs were prepared by bonding brackets to diverge the roots between the first molars and second premolars. The objective was to widen the site for MSI insertion by use of a 0.016 X 0.022-inch stainless steel wire. After approximately 1 month, a periapical radiograph was taken to evaluate the increase in inter-radicular space attained. If the space was determined to be sufficient for implant placement, the patient was scheduled for MSI insertion; if not, adjustments were made to further widen the implant site. The lower MSIs were placed following the same chlorhexidine rinse protocol used for the maxillary MSIs. The mandibular MSIs were also placed without pilot holes and tissue punch. A double insertion technique was used to insert the MSIs at an angle, with the head of the screw positioned at the level of the mucogingival junction (Fig 2). The lower MSIs were loaded immediately by use of calibrated 150g coils, following the same protocol as in the maxilla. The lower molars bands were prepared for insertion of a removable lower lingual arch, if needed, to control molar torque. Lingual arches were only installed in a few of the cases, especially those in whom the mandibular teeth were actively intruded.

To prevent their extrusion while intruding the posterior teeth, the upper anterior teeth (canine to canine) were not initially bonded with fixed appliances. They were bonded once the upper anterior teeth made contact with the lower teeth, which prevented them from interfering with mandibular autorotation.

Periodontal health was closely monitored during intrusion. The need for the patients to maintain proper hygiene was emphasized throughout treatment. Importantly, there was a temporary shortening of the clinical crowns of the teeth that had been intruded (Fig 3); there was also some tissue bulging, especially on the palate. This was temporary gingival overgrowth that disappeared in all cases after intrusion had been stopped and the teeth had been held in place for 2 to 3 months.

After the required amount of posterior intrusion had been attained, or when the maxillary anterior and posterior occlusal planes had been leveled, the RPE was removed and fixed orthodontic appliances were bonded onto all of the maxillary posterior teeth. After the RPE was removed, a transpalatal arch was fitted to the maxillary first molars to hold the transverse di-

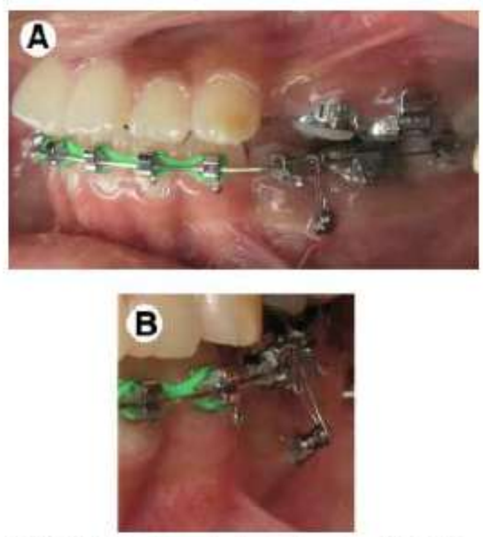

FIGURE 2. *A*, Buccal view showing location of mandibular MSIs. *B*, Frontal view showing insertion angle.

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mension and prevent any unwanted torque of the posterior teeth. The maxillary and mandibular MSIs remained in place until full treatment was completed. They held the vertical dimension of the posterior teeth by use of an 0.010-in stainless steel ligature tied to the palatal sheath in the maxilla and to the arch wire mesial to the first molar band in the mandible.

Treatment Results and Discussion

The subjects were aged 13.2 ± 1.1 years at the start of treatment. The orthopedic phase of treatment lasted for a mean of 1.9 ± 0.3 years; the shortest and longest treatment durations were 1.4 and 2.5 years, respectively. Longer treatment times were required for patients who had impacted canines (n = 2) and extractions (n = 2).

Of the 54 MSIs that have been placed so far, only 2 have failed (Table 3), with 1 failure in each jaw. A failure was defined as an MSI that was unable to hold the force of the coil spring or steel ligature without noticeable mobility of its head. This resulted in a success rate of 96.3%, which is considerably higher than previously reported for MSIs and more closely approximates the success rates of endosseous implants.

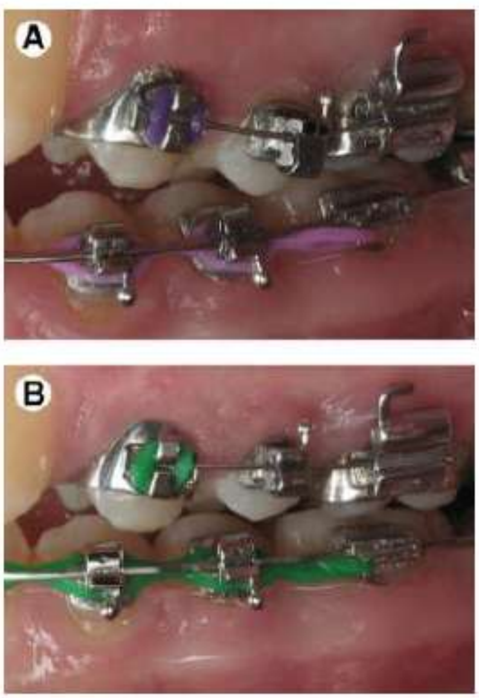

FIGURE 3. Maxillary first molar clinical crown height before (*A*) and during (*B*) active orthodontic intrusion.

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Table 3. NUMBERS OF IMPLANTS PLACED, NUMBER THAT FAILED, AND RELATIVE % STABILITY OF MSIs USED IN STUDY

	No. Placed	No. Failed	% Stability
Maxilla	32	1	96.9
Mandible	22	1	95.4
Total	54	2	96.3

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Before treatment, patients presented with greater mandibular retrusion (sella-nasion-basion [SNB] = 73.8°, Z score = −1.0), greater facial convexity (nasion-A point-pogonion [N-A-Pg] = 9.2°, Z score = 0.7), and substantially more hyperdivergence (mandibular plane angle [MPA] = 43.3°, Z score = 1.6) than exhibited by untreated controls. They also had substantially larger gonial angles (articulare-gonion-menton [Ar-Go-Me] = 134°, Z score = 1.4) than controls.[53]

The treatments produced consistent and substantial effects, which were statistically significant despite the small size of the sample (Table 4). The chin moved forward a mean of 2.4 mm; the maximum anterior movement of the chin was 7.1 mm. The SNB angles increased by 2.1° ± 1.3°, and the mandibular plane angle decreased by a mean of 3.9° ± 1.8°. Hard and soft tissue facial convexities decreased by approximately 3.2°, and the gonial angle decreased by 2.4° ± 1.8°.

Cranial base superimpositions showed positive orthopedic treatment results for all but 1 of the female patients, who was aged 12.2 years at the start of her non-extraction treatment (Fig 4A). She showed only limited amounts of growth, and her lower molars erupted by approximately the same

Table 4. ORTHOPEDIC CHANGES IN 9 CONSECUTIVE CLASS II HYPERDIVERGENT ADOLESCENTS TREATED WITH MSIs

	Minimum	Mean	SD	Maximum	Probability of Changes
Pg_hor (mm)	−0.7	2.4	2.3	7.1	0.020
SNB (°)	−0.1	2.1	1.3	4.2	0.002
MPA (°)	−1.0	−3.9	1.8	−6.5	0.001
HT convexity (°)	1.3	−3.2	2.4	−6.1	0.007
ST convexity (°)	−0.9	3.15	2.9	8.7	0.017
Gonial angle (°)	0.8	−2.4	1.8	−5.3	0.018

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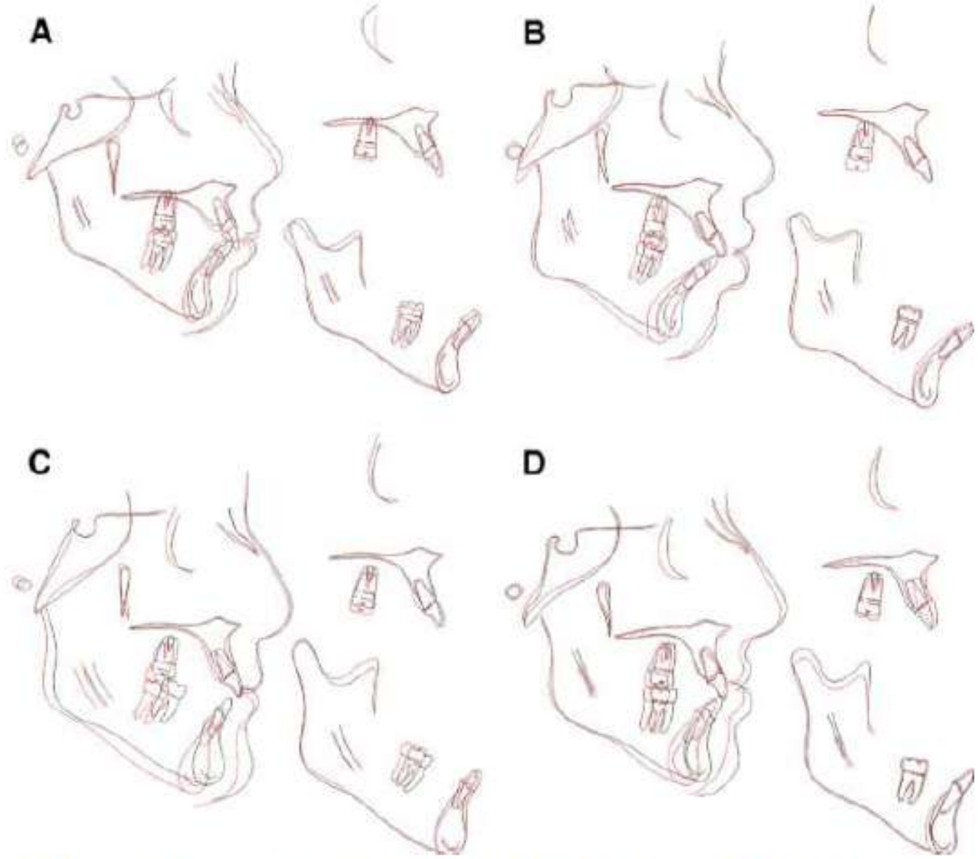

FIGURE 4. *A*, Changes between 12.2 and 13.5 years of age in a female patient (patient 1) treated with non-extraction. *B*, Changes between 13.7 and 15.8 years of age in a female patient (patient 3) treated with extractions. *C*, Changes between 14.2 and 15.9 years of age in a female patient (patient 4) treated with extractions. *D*, Changes between 13.0 and 14.7 years of age in a female patient (patient 4) treated with extractions.

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amount that the upper molars were intruded, which explains why she did not display the forward rotation and chin projection that was planned. Approximately half of the remaining subjects exhibited forward rotation and anterior chin projection with little or no growth. The positive treatment effects that they exhibited were due primarily to intrusion of the upper molars and either relative intrusion (ie, holding the vertical dimension) (Fig 4B) or actual intrusion (Fig 4C) of the lower molars. The remaining subjects showed positive treatment effects due to good growth, intrusion of the upper molar, and intrusion or relative intrusion of the lower molars. For example, a 13-year-old female patient treated for 1.7 years with extractions showed a substantial decrease in her mandibular plane angle and over 5 mm of chin projection (Fig 4D). Given her good growth potential, she actually needed less intrusion of her upper molars and only relative intrusion of the lower molars.

Orthodontists need to closely and continuously monitor these cases to determine whether they are exhibiting the desired treatment changes. This is done clinically by evaluating changes in interarch dental and overbite/overjet relationships. If growth or intrusion is occurring, the case should exhibit a shift in the molar and premolar relationships from Class II to Class I (Fig 5). If such a shift is not evident within 4 to 6 months, then the orthodontist should plan on greater amounts of intrusion of the upper molars and, perhaps, even intrusion of the lower molars. In actively growing individuals, it is

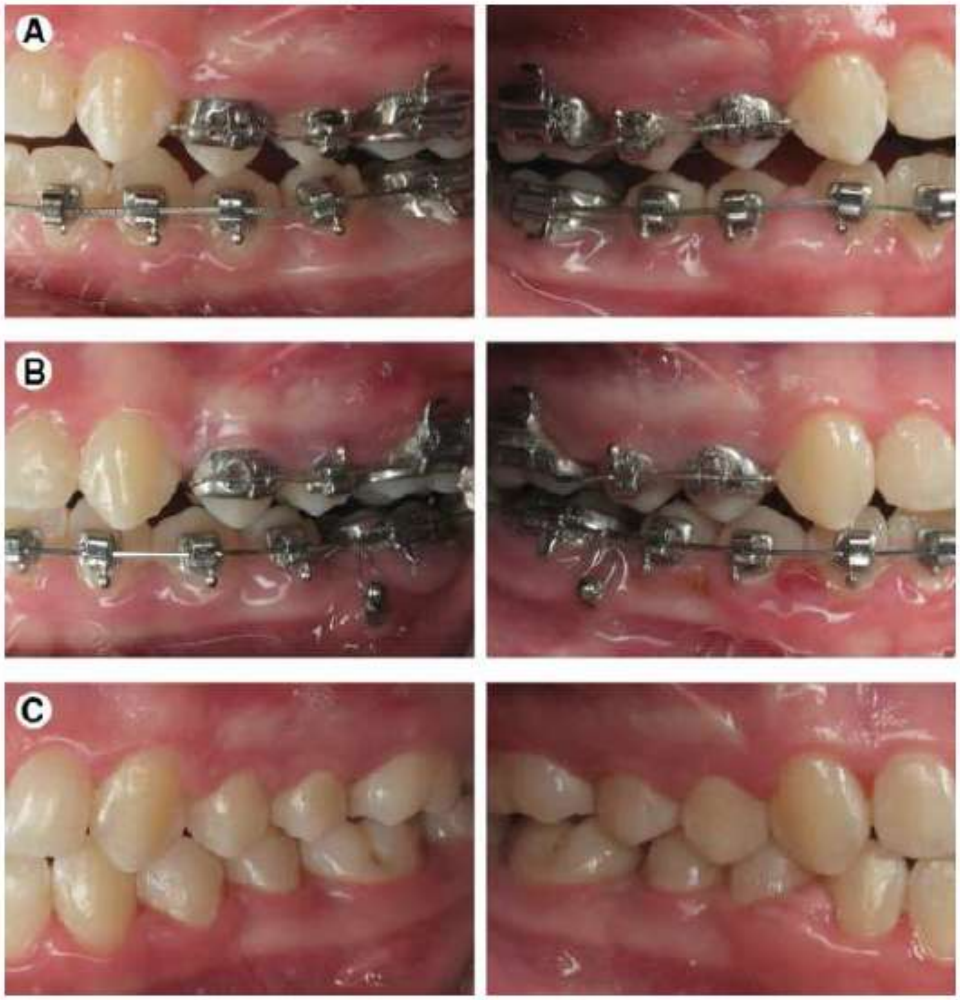

FIGURE 5. Clinical assessment of treatment effects on day of RPE cementation (*A*), after 5 months of active intrusion (2 months with maxillary MSI and 5 months with mandibular MSIs) (*B*), and at debonding (*C*). Note deepening of the bite and Class II correction associated with autorotation of the mandible.

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usually sufficient to intrude the upper posterior teeth and hold the lower posterior teeth in place so as to prevent them from erupting.

Subjective Self-Assessments

When the patients were initially asked about each of the appliances that were to be used, they substantially overestimated the amount of pain that they expected to have with each appliance (Table 5). Approximately 36%, 45%, and 50% of the patients expected braces, expanders, and MSIs, respectively, to be moderately or very painful. At the end of treatment, none of the patients reported that MSIs were either moderately or very painful; about 8% reported that braces were moderately painful, and 17% felt that the expanders were moderately or very painful.

The patients also initially overestimated the amount of discomfort that they associated with each of the appliances, especially for the MSIs and expanders. Approxi-

Table 5. PRETREATMENT AND POST-TREATMENT PERCENTAGES OF SUBJECTS REPORTING PAIN AND DISCOMFORT ASSOCIATED WITH BRACES, EXPANDERS, AND MSIs, ALONG WITH POST-TREATMENT PERCENTAGES OF HOW MUCH THEY WOULD RECOMMEND THEIR TREATMENT TO FRIENDS AND FAMILY

	Not at All		Somewhat		Moderately		Very			
	Pretreatment	Post-treatment	Pretreatment	Post-treatment	Pretreatment	Post-treatment	Pretreatment	Post-treatment	Very Much	Extremely
How painful are the appliances?										
Braces	22.7	58.3	40.9	33.3	22.7	8.3	13.6	0		
Expander	27.3	41.7	27.3	41.7	31.8	8.3	13.6	8.3		
MSIs	9.1	91.7	40.9	8.3	13.6	0	36.4	0		
How uncomfortable are the appliances?										
Braces	4.5	8.3	36.4	83.3	27.3	8.3	13.6	0		
Expander	22.7	16.7	22.7	50.0	27.3	25.0	27.3	8.3		
MSIs	4.5	66.7	36.4	25.0	27.3	8.3	31.8	0		
How much would you recommend your treatment to your friends and family?	0		16.7		25.0				16.7	41.7

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mately 59% of the patients thought that the MSIs would be moderately or very uncomfortable, 55% thought that the expanders would be moderately or very uncomfortable, and 41% thought that the braces would be moderately or very uncomfortable. After treatment, only 8% of the patients thought that the MSIs and braces were uncomfortable; none reported them to be very uncomfortable. Approximately 25% and 8% thought that the expanders were moderately and very uncomfortable, respectively.

Perhaps most important, the majority of the patients indicated that they would recommend the treatment that they had received to their friends and relatives. Approximately 17% said that they would recommend

FIGURE 6. Treatment- and growth-related mandibular rotation, producing orthopedic effects that reshape the mandible and improve the facial profile.

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the treatment "very much," and 42% said that they would recommend it "extremely much." No one said that they would not recommend the treatment.

These preliminary results indicate that our novel approach is effective for addressing the primary skeletal treatment objectives of growing hyperdivergent, retrognathic patients (Fig 6). Major orthopedic changes were produced, including substantial advancement of the chin and autorotation of the mandible, along with decreases in the gonial angle, all of which combined to reshape the mandible and improve facial profile. The treatment was accomplished by titrating the amount of orthodontic intrusion performed based on the individual's growth potential. This treatment approach was not painful or uncomfortable; the majority of the patients indicated that they were very likely to recommend the treatment to others.

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