ORIGINAL ARTICLE

Early treatment of vertical skeletal dysplasia: The hyperdivergent phenotype

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This cephalometric study evaluated an early nonextraction treatment approach for patients with severe vertical skeletal dysplasia and maxillary transverse constriction. Thirty-eight patients, 8.2 years (± 1.2 years) of age, were treated for 1.3 years (± 0.3 years) with lip seal exercises, a bonded palatal expander appliance, and a banded lower Crozat/lip bumper. The bonded palatal expander functioned as a posterior bite-block and was fixed in place throughout treatment. Patients with poor masticatory muscle force (79%) wore a high-pull chincup 12 to 14 hours per day. A control group was matched for age, sex, and mandibular plane angle. Treatment changes for chincup and other patients were not significantly different. Overall, treatment significantly enhanced condylar growth, altered it to a more anterosuperior direction, and produced "true" forward mandibular rotation 2.7 times greater than control values. Posterior facial height increased significantly more in patients than in controls, and the maxillary molars showed relative intrusion. In treated patients, articular angle increased, gonial angle decreased, and the chin moved anteriorly twice as much as in controls. Treatment also led to increased overbite and decreased overjet. Maxillary and mandibular expansion did not cause the mandibular plane angle to increase. The 16 patients with openbite malocclusions exhibited a 2.7 mm increase in overbite and inhibition of growth in anterior lower facial height. The aggregate of individual changes demonstrates a net improvement, indicating this treatment approach may be suited for hyperdivergent patients with skeletal discrepancies in all 3 planes of space. (Am J Orthod Dentofacial Orthop 2000;118:317-27)

Successful treatment of patients possessing a hyperdivergent skeletal phenotype demands prudent diagnosis and careful consideration of treatment mechanics. Patterns of facial growth are established early in development.[1-4] If the hyperdivergent phenotype is left untreated and allowed to progress until the permanent dentition stage of development, the opportunity for growth modification could be lost, and surgical correction may remain as the only option.[5-7] If growth modification is to be successful in the hyperdivergent phenotype, preventative or early interceptive treatment strategies may be required.

Factors associated with "favorable" growth in patients with a hyperdivergent phenotype include an increase in the posterior facial height/anterior facial height ratio, an average or greater amount of "true" forward mandibular rotation, enhanced condylar growth, and a more anterior direction of condylar growth.[8-14] In combination, these factors displace the mandible more anteriorly than inferiorly, which improves the skeletal pattern of the hyperdivergent patient. None of the appliances commonly used in orthodontic treatment rotates the mandible forward and produces more anterior condylar growth; in fact, orthodontic treatment typically redirects condylar growth posteriorly, rotates the mandible backward, and increases anterior facial height.[15,16] Indeed, control of the vertical dimension is probably the single most important factor in the correction of the hyperdivergent case.[17-21]

Orthodontists have attempted to limit vertical dimension increases in growing patients by one or more of the following approaches: (1) high-pull headgear with or without a splint, (2) extraction therapy, (3) bite-blocks (passive or active), (4) vertical-pull chincup, and (5) any combination thereof. High-pull headgear (HPHG) modifies maxillary growth, but compensatory eruption of the mandibular molars prevents autorotation of the mandible and control of anterior facial height.[22-26] High-pull headgear attached to a splint more effectively modifies maxillary growth to a more posterosuperior direction.[21,27-32] Although this may be an effective approach for individuals with ver-

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Table I. Mean chronologic ages and mandibular plane angles of treated and matched control groups

	Control		Treatment	
	Mean	*SD*	*Mean*	*SD*
Age (years)	8.2	1.3	8.3	1.2
MPA (°)	40.1	3.9	40.0	3.9

tical maxillary excess, it does not address mandibular dysmorphology. Extraction therapy produces effective dentoalveolar compensations, but increased molar eruption during space closure could negate potential improvements of facial height and mandibular position.[23,25,33-35] High-pull headgear and extraction therapy combined appears to have a similar effect, with even more eruption of the lower molars.[23,24]

Bite-blocks have been shown to be effective for controlling anterior facial height in both animal models[36-42] and clinical trials.[43-50] Although magnetic bite-blocks produce significant treatment effects, they can also create asymmetric mandibular posture and subsequent unilateral crossbites due to the shearing forces created by repelling magnets.[42,44-46] Increased root resorption due to the excessive intrusive forces for extended periods has also been demonstrated with the use of magnetic bite-blocks.[42]

In addition to vertical skeletal excess anteriorly, maxillary transverse constriction is a common characteristic of the hyperdivergent phenotype. However, active expansion may result in unfavorable inferior maxillary and mandibular displacements, which increase anterior facial height.[51-53] Bonded palatal expanders have been shown to minimize the inferior displacement of the posterior maxilla only; inferior displacement of the anterior maxilla is similar for bonded and banded expanders.[54,55] To prevent inferior anterior maxillary displacement and mandibular plane increases, other "countering" strategies must be used.

The chincup may be an effective appliance to incorporate into treatment of patients with vertical dysplasia.[25,46,56-58] Pearson[25] reported a mandibular plane decrease of 3.9° in 20 patients treated with the extraction of 4 premolars and a vertical-pull chincup for 9 months. Majourau and Nanda[59] successfully used a high-pull chincup to prevent increases in anterior facial height and mandibular plane angle in a hyperdivergent patient during maxillary expansion.

This study examines the effects of a novel treatment regimen consisting of a lower Crozat/lip bumper and a bonded palatal expander (BPE) constructed to function as a bite-block, used in conjunction with lip seal exercises and a high-pull chincup; this protocol was used on hyperdivergent patients who demonstrated maxillary constriction and were treated in the mixed dentition.

The purpose of this study was to determine whether this treatment regimen would:

- Change the amount and direction of "true" mandibular rotation
- Alter the amount and the direction of condylar growth
- Control mandibular and maxillary molar eruption
- Improve the vertical skeletal relationship.

MATERIAL AND METHODS

A sample of 38 patients was collected from the private orthodontic practice of Dr Albert H. Owen III in Austin, Tex. Consecutively treated cases were selected on the basis of the following criteria: (1) diagnosis of vertical skeletal dysplasia (hyperdivergence) based on clinical photographs and cephalometric assessment of the mandibular plane angle (MPA) greater than 35°, (2) mixed dentition at the initiation of treatment, (3) treatment of no less than 6 months with the same early vertical treatment protocol, and (4) high-quality cephalometric records. Patients were rejected if there was a history of temporomandibular dysfunction (TMD), maxillofacial trauma, nasopharyngeal obstruction, missing or poor quality lateral cephalograms or poor cooperation with any of the treatment protocol. An openbite was not one of the selection criteria, but 38% of the patients did have openbite malocclusion. The sample comprised 24 females (65%) and 14 males (35%), whose mean ages were 8.2 years (± 1.2 years) and 9.5 years (± 1.2 years) at pretreatment and posttreatment, respectively. The mean treatment duration was 1.3 years (± 0.3 years).

In order to evaluate treatment effects, a control group was drawn from longitudinal data collected by the Human Growth Research Center, University of Montreal, Quebec.[60] This is a nonorthodontic sample with a variety of malocclusions. The control and experimental subjects were matched based on age, sex, and mandibular plane angle (Table I).

Treatment Protocol

The same practitioner performed all treatment according to a standard protocol. Treatment started with lip seal exercises to train the orbicularis oris muscle to become more active in creating an anterior oral seal, thereby diminishing mentalis strain. Patients used a lip disk for 60 consecutive minutes per day, holding their lips together at all times. They were instructed to

Fig 1. Bonded palatal expander and Crozat/lip bumper appliance.

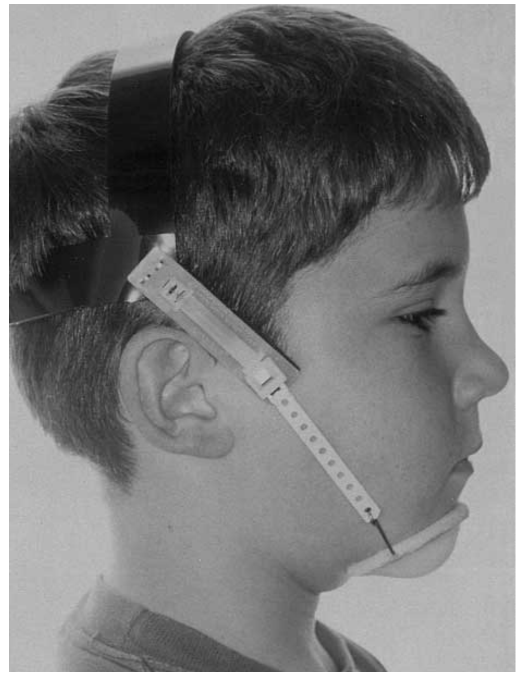

Fig 2. Patient wearing high-pull chincup.

place a hand on the chin while using the lip disk to detect and eliminate mentalis activity.

The mandibular arch was treated with a banded Crozat/lip bumper appliance to achieve expansion. The Crozat/lip bumper appliance was cemented in place with a 2 to 3 mm activation; it remained in place for 8 weeks. It was reactivated 1 mm every 8 weeks. Simultaneously, the upper arch was treated with a BPE and expansion was performed slowly (1/4 turn per week, 1 mm per month) for approximately 6 months. The BPE was constructed to infringe on the freeway space 2 to 3 mm and was ramped to create progressively thicker occlusal coverage on the palatal half of the appliance (Fig 1). Whether the patient wore a chincup was judged clinically at ensuing appointments on the basis of the appearance of bite marks on the BPE acrylic; if no marks were apparent, the patient was fitted with a high-pull chincup delivering 16 to 20 ounces of force per side. A total of 30 (79%) patients were fitted for the chincup. The instructions were to wear the chincup at least 14 hours per day and to record the time worn on a time card. The direction of pull was approximately 45° upward and backward in relation to the occlusal plane (Fig 2).

Measurements

All lateral cephalograms were traced and digitized by the same technician. The pretreatment (T1) and posttreatment (T2) cephalograms of the treatment and control group were corrected for radiographic magnification. An intensifying screen positioned over the temporomandibular joint (TMJ) region was used for every cephalogram to enhance resolution of condylion. Intensifying screens were not used for the control group, which was selected based on the visibility of the condyle on the cephalogram. Sixteen landmarks were

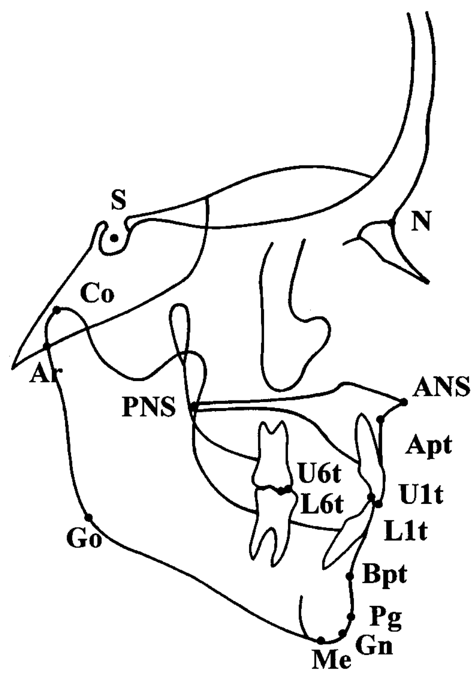

Fig 3. Cephalometric landmarks digitized: (S) sella, (N) nasion, (ANS) anterior nasal spine, (Apt) A point, (U1t) maxillary incisor tip, (U6t) maxillary molar tip, (L6t) mandibular molar tip, (L1t) mandibular incisor tip, (B pt) B point, (Pg) pogonion, (Gn) gnathion, (Me) menton, (Go) gonion, (Ar) articulare, (Co) condylion, (PNS) posterior nasal spine.

Table II. Traditional measures: Pretreatment and posttreatment values and treatment changes of hyperdivergent patients

	Pretreatment		*Posttreatment*		*Change (T2-T1)*	
Measures	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Angles (°)						
SNA	79.8	3.5	79.3	3.7	–0.5	1.9
SNB	75.6	3.1	75.9	3.2	0.3	1.9
ANB	4.2	2.4	3.3	2.1	–0.8*	1.4
PP/SN	4.1	3.0	4.4	2.9	0.3	1.9
NS/Gn (Y-axis)	69.8	3.1	69.9	3.3	0.1	1.5
MPA	40.0	3.9	39.7	3.8	–0.3	1.7
Ar-Go-Me	133.7	5.3	132.6	5.3	–1.1*	1.7
Co-Go-Me	114.7	4.7	114.0	4.7	–0.7	1.7
S-Ar-Go	129.9	6.3	130.7	6.8	0.7	2.2
Facial heights (mm)						
S-Co	17.0	2.6	17.0	2.6	0.1	1.5
Co-Go	45.6	3.5	47.3	3.1	1.7*	1.9
S-Go	60.0	3.8	61.8	3.6	1.8*	1.5
N-ANS	44.4	3.4	45.3	3.4	0.9	1.1
ANS-Me	58.8	2.8	59.5	3.3	0.7	1.8
N-Me	99.8	4.7	101.9	5.1	2.2*	2.0
Dental relationships (mm)						
Overbite	0.6	3.0	1.9	2.2	1.3*	2.0
Overjet	4.5	2.2	3.8	1.8	–0.8*	2.2
Molar relationship	–1.5	1.7	–1.5	2.0	0.1	1.6
Mandibular length (mm)						
Co-Pg	93.0	5.2	95.7	4.8	2.7*	2.5

*$P < .05$.

digitized (Fig 3). Intraexaminer reliability was assessed by replicate measurements of 13 cephalograms. Differences between replicates showed no significant systematic error. Random measurement error, evaluated using the method error statistic,[61] averaged 0.7 mm and ranged between 0.2 and 1.5 mm.

Treatment was evaluated with the following: (1) 19 traditional measures, including 9 angular and 10 linear, (2) the horizontal and vertical displacements of 11 landmarks using a cranial base superimposition, and (3) a mandibular superimposition to measure the true mandibular rotation[62] (true rotation is based on stable mandibular structures and is not the same as mandibular plane rotation), mandibular dental movements (eruption and migration), condylar growth, and horizontal and vertical drift of mandibular landmarks.

After the traditional measures were calculated, the lateral cephalograms were superimposed on stable cranial and cranial base reference structures.[12] The tracings were oriented according to a "best fit" strategy using the following structures: (1) the contour of the anterior wall of sella turcica, (2) the anterior contours of the middle cranial fossa, (3) the intersection of the lower contours of the anterior clinoid process and the contour of the anterior wall of sella, (4) the inner surface of the frontal bone, (5) the contour of the cribiform plate, and (6) the contours of the frontoethmoidal crests. A cranial reference axis (CRA), oriented along S-N minus 7° (SN^7) and registered on sella, was marked on the T1 tracing and transferred to the superimposed T2 tracing. The horizontal and vertical (H/V) positional changes of each landmark were evaluated parallel and perpendicular to the CRA, respectively. Finally, the T1 and T2 mandibles were superimposed[12] using the following natural reference structures: (1) the anterior contour of the chin, (2) the inner contour of the cortical plate at the lower border of the symphysis, (3) distinct trabecular structures in the symphysis, and (4) the contour of the mandibular canal.

The skewness and kurtosis statistics showed that all the variables were distributed normally. Patients were initially divided into subsamples based on presence or absence of an openbite and based on whether the chincup was worn; 16 of 38 patients had an openbite, whereas 30 of 38 patients were treated with the chincup. Due to the relatively small number of patients in each subsample, nonparametric tests (Mann-Whitney) were used to test the differences between the subsamples. Paired *t* tests were used to detect significant treat-

Table III. Traditional measures: Between-sample comparisons of treatment effects

Measures	Treatment Mean	Treatment SD	Control Mean	Control SD	Group difference
Angles (°)					
SNA	–0.5	1.9	–0.8	1.4	0.3
SNB	0.3	1.9	–0.4	1.1	0.8*
ANB	–0.8	1.4	–0.4	1.3	–0.5
PP-SN	0.3	1.9	0.1	1.0	0.2
NS/Gn (Y-axis)	0.1	1.5	0.5	1.2	–0.4
MPA	–0.3	1.7	–0.2	2.1	–0.1
Ar-Go-Me	–1.1	1.7	0.2	2.8	–1.3*
Co-Go-Me	–0.7	1.7	0.0	2.5	–0.7
S-Ar-Go	0.7	2.2	–0.7	2.4	1.5*
Facial heights (mm)					
S-Co	0.0	1.5	0.7	2.3	–0.7
Co-Go	1.7	1.9	1.1	1.4	0.6
S-Go	1.8	1.5	1.4	1.5	0.4
N-ANS	0.9	1.1	1.3	0.9	–0.4
ANS-Me	0.7	1.8	1.1	1.6	–0.4
N-Me	2.2	2.0	2.5	1.8	–0.3
Dental relationships (mm)					
Overbite	1.3	2.0	0.0	0.2	1.3***
Overjet	–0.8	2.2	0.9	0.2	–1.6**
Molar relationship	–0.1	1.6	–0.1	0.9	0.0
Mandibular length (mm)					
Co-Pg	2.7	2.5	2.8	1.8	0.1

*$P < .05$; **$P < .01$; ***$P < .001$.

ment-associated changes. Student *t* tests were used to compare the control and treatment groups.

RESULTS

The Mann-Whitney test showed no significant differences between the chincup and non–chincup groups for the 19 traditional measures, 22 cranial base superimposition measures, or 9 mandibular superimposition measures. Because the chincup produced no measurable difference, the 2 groups were combined for the comparison with controls.

Table II describes the treatment changes of the combined groups. Of the angular measures, only the ANB and gonial angles changed significantly during treatment. The ANB angle decreased 0.8° whereas the gonial angle decreased 1.1°. Total anterior facial height (N-Me) increased 2.2 mm, including a 0.7 mm increase of lower facial height (ANS-Me) and a 0.9 mm increase of upper facial height (N-ANS). The upper-to-lower anterior facial height ratio (UAFH:LAFH) increased from 75.5% to 76.1% during treatment. Ramus height (Co-Go) also increased significantly (1.7 mm), accounting for most of the 1.8 mm increase of total posterior facial height (S-Go). The overbite and overjet relationships improved 1.3 mm and 0.8 mm, respectively, and the molar relationship remained essentially unchanged. Mandibular length showed a significant 2.7 mm increase.

Group comparisons showed significant treatment effects for 5 of the 19 traditional measurements (Table III). The SNB angle increased slightly with treatment, and it decreased in controls. The gonial angle (Ar-Go-Me) decreased more than expected during treatment, and the articular angle increased more than expected. None of the facial height measurements showed significant group differences, although there was a tendency for anterior facial heights to decrease and posterior facial heights to increase in the treatment group. The overbite and overjet improvements in the treatment group were highly significant ($P < .01$).

On the basis of the horizontal and vertical movements measured from the cranial base superimposition, all the mandibular measures except mandibular molar demonstrated significantly greater-than-expected anterior displacement (Table IV). Group differences were similar for the anterior and posterior aspects of the mandible. Only 3 of the 11 vertical displacements showed significant group differences. Gonion was displaced 0.6 mm more inferiorly in the treatment group, indicating posterior facial height increases. The upper molar showed 1.0 mm less inferior displacement with treatment. Finally, the

Table IV. Cranial base superimposition: Horizontal and vertical movements of key landmarks

	Treatment		*Control*		
Landmarks	*Mean*	*SD*	*Mean*	*SD*	*Group difference*
Horizontal (mm)					
Pg	1.7	1.7	0.7	1.7	1.0**
Gn	1.7	1.7	0.7	1.8	1.0**
Me	1.9	2.2	0.9	1.7	1.0*
Go	–0.1	1.5	–0.9	1.4	0.8*
Co	–0.1	1.3	–1.0	1.1	0.9**
ANS	0.8	1.3	0.8	1.2	0.0
PNS	–0.2	1.2	–0.4	0.9	0.1
U1	1.2	1.9	1.0	1.1	0.3
U6	1.3	1.2	0.7	0.9	0.7**
L6	1.5	1.7	0.9	1.2	0.7
L1	1.9	1.5	0.7	1.4	1.3**
Vertical (mm)					
Pg	2.6	1.8	2.6	2.0	0.1
Gn	2.4	1.4	2.5	1.7	0.0
Me	2.6	1.5	2.6	1.8	0.0
Go	2.0	1.2	1.4	1.5	0.6*
Co	0.3	1.5	0.4	2.0	0.1
ANS	1.3	1.0	1.5	1.0	0.0
PNS	1.3	0.9	1.2	0.7	0.1
U1	2.5	1.4	2.1	2.0	0.4
U6	0.8	1.2	1.9	1.9	1.0*
L6	1.9	1.3	1.5	1.8	0.3
L1	0.8	1.5	1.6	1.5	0.7*

*$P < .05$; **$P < .001$.

Table V. Mandibular superimposition: Horizontal and vertical movements of key landmarks

	Treatment		*Control*		
Landmark	*Mean*	*SD*	*Mean*	*SD*	*Group difference*
Horizontal (mm)					
Co	0.0	2.0	–0.6	1.4	0.6
Go	–1.2	1.2	–0.9	1.1	–0.3
L1	0.9	1.0	0.7	0.9	0.2
L6	0.7	1.5	0.5	0.9	0.2
Vertical (mm)					
Co	3.8	2.0	2.6	1.8	1.2**
Go	1.8	1.7	1.5	1.4	0.3
L1	1.3	0.8	0.8	0.7	0.5*
L6	0.8	1.0	0.6	1.2	0.3
True rotation (°)	–1.6	1.5	–0.6	2.2	–1.0**

*$P < .05$; **$P < .01$.

lower incisor was displaced 0.7 mm more inferiorly in the control group, suggesting that the treated subjects had greater eruption of the lower incisors or less vertical skeletal growth.

Group comparisons of changes measured from the mandibular superimposition showed highly significant differences in vertical condylar growth, incisor eruption, and true mandibular rotation (Table V). The treatment groups showed 3.8 mm vertical condylar growth over the treatment period, which was 1.2 mm greater than expected from the untreated controls. There was also a tendency for less posterior condylar growth, with the difference (0.6 mm) closely approaching significant levels. The lower incisor also demonstrated 0.5 mm more eruption in the treatment group than in the untreated control group. Importantly, true mandibular forward rotation was almost 3 times greater in the treatment group than in controls (1.6° versus 0.6°).

Finally, the comparison of overbite and openbite patients showed 5 significant differences (Table VI). The openbite group demonstrated a greater (1.2°) reduction of the ANB angle and a greater (2.6 mm) increase in overbite. Lower face height (ANS-Me) increased significantly in the overbite group, but not in the openbite group. The cranial base superimposition showed that the horizontal displacement of ANS was 0.9 mm less and the vertical displacement of the upper incisor tip inferiorly was 1.2 mm more in the openbite group than in the overbite group.

DISCUSSION

Although early orthopedic approaches have been established in the anteroposterior[63-65] and transverse dimensions,[66-70] the treatment approach for vertical skeletal dysplasia remains controversial (Table VII). The early treatment regimen under study led to increased condylar growth, altered direction of condylar growth, increased true forward mandibular rotation, increased posterior facial height, and decreased anterior facial height for openbite patients; it also displaced the chin anteriorly, controlled maxillary and mandibular molar eruption, increased overbite, and decreased overjet. Given this sample of patients with severe vertical skeletal dysplasia who had been treated with maxillary expansion to resolve their transverse deficiencies, and based on the assumption that treatment should be evaluated based on success or failure of all treatment objectives, this novel treatment must be considered one of the better approaches currently available.

Studies of active bite-block therapy suggest that mandibular autorotation can be achieved, resulting in an actual reduction of anterior facial height (AFH).[43,46,49,50] Autorotation also occurred in our sample, as indicated by the true mandibular rotation observed. Rotation for the overbite subsample, which was centered around the incisors, did not decrease AFH. However, autorotation had a pronounced positive effect on lower AFH in the openbite subsample, resulting in no significant increases over the treatment period. In both subsamples, bony remodeling masked

Table VI. Comparison of treatment changes between openbite (≤ 0 mm) and overbite (> 0 mm) subgroups

	Openbite (n = 16)		*Overbite (n = 22)*			
Measures	*Mean*	*SD*	*Mean*	*SD*	*Group difference*	*Significance*
ANB (°)	–1.5	1.4	–0.3	1.2	1.2	0.008
Overbite (mm)	2.7	1.7	0.1	1.4	2.6	<0.001
ANS-Me (mm)	0.1	1.7	1.2	1.6	1.6	0.02
ANS_{Hor} (mm)*	0.2	1.1	1.1	1.3	0.9	0.02
$U1_{Ver}$ (mm)*	3.2	1.4	2.0	1.1	1.2	0.004

*Cranial base superimposition.

Table VII. Efficacy ratings* of various modes of treatment on the maxilla, mandible, and dentition

Effect site	*HPHG*	*HPHG + splint*	*Extraction*	*HPHG + extraction*	*Passive PBB*	*VCC*	*Active PBB*	*Treatment under study*
Condylar growth/amount	–	–	0	0	0	?	0	+
Condylar growth/direction	0	0	0	0	–	?	0	+
Mandibular rotation	0	0	0	0	+	+	+	+
Maxillary position	+	++	0	0	+	?	+	+
Posterior face height	–	–	0	0	+	?	0	+
Anterior face height	0	0	0	0	+	?	+	0
Skeletal AP relations	+	+	0	0	+	?	+	+
U6 position	++	++	–	++	+	+	+	+
L6 position	—	0	–	—	+	+	+	+
Overbite	0	0	+	++	++++	+	+	+
OJ	+	+	+	++	+	?	+	+

*+, Improvement; –, worsening; ?, insufficient data.
HPGH, High-pull headgear.
PBB, Posterior bite-block.
VCC, Vertical chincup.

the true rotation that occurred during treatment. It has previously been suggested that the lack of anterior contact may allow autorotation if the freeway space can be increased through intrusion of posterior teeth.[39,45]

Studies have indicated that banded maxillary expansion predictably displaces the maxilla inferiorly 1 to 2 mm, and more variably in a slightly anterior direction.[51-53,55] In a long-term study of maxillary expansion, Wertz and Dreskin[53] showed permanent increases of maxillary vertical position, mandibular plane angulation, and AFH resulting from banded maxillary expansion. The long-term consequences were most detrimental for the long-faced patients included in their sample. Permanent mandibular plane angle increases may be more significant considering the mandibular plane remodeling that probably occurred, partially masking the actual increase.[71-74] Our results showed no increased vertical displacement for either PNS or ANS, as previously suggested by Majourau and Nanda[59] for a case treated with a high-pull chincup during active expansion, and no increase in the MPA.

Although inhibiting the growth of anterior facial height results in an improved skeletal pattern in the hyperdivergent patient, augmenting posterior facial height may be an equally important goal.[9,10,12,13,75,76] The early treatment regimen under study had a significant orthopedic effect on condylar growth, a major contributor to posterior facial height development. Condylar growth was greater for the treated patients than for controls (3.8 mm vs 2.6 mm). The observed 3.8 mm of condylar growth places the treated patients somewhere between the 75th and 90th percentiles on the incremental chart for condylar growth.[77] A greater increase in posterior facial height would have occurred if the glenoid fossa (S-Co) had descended as previously described.[26,77-79] In comparison, Baumrind et al[26] reported that growth of ramus height and mandibular length were significantly reduced with HPHG treatment.

The amount of true forward mandibular rotation observed also indicates a significant orthopedic response: true forward rotation was 2.7 times the amount observed in the control group. The fact that the condyles grew more and changed to a more anterosuperior direction, compared with the more posterior growth direction seen in the control group, supports the association previously established[11] between forward rotation, increased condylar growth, and redirection of condylar growth. This may be an important finding, given that orthopedic appliances augmenting condylar growth have been shown to redirect growth more posteriorly, which may not be advantageous in the hyperdivergent phenotype.[11,12,18] Counterbalancing rotation[80] may explain why condylar growth was significantly greater in the treated group, whereas mandibular length changes showed no differences among groups.

Although treatment was directed at the vertical dimension, it clearly produced an effective orthopedic response for AP chin position. The landmarks on the chin were displaced anteriorly almost twice as much in the treated group as in the controls, without any effective increases in mandibular length. Such a treatment effect cannot be achieved with a HPHG, which may change the maxillomandibular AP relationship but will not improve mandibular AP position.[26] The observed changes in AP chin position may be attributed to: (1) the BPE appliance that was designed to infringe on the freeway space and, when combined with the high-pull chincup, acted as a functional appliance/bite-block (active bite-blocks have previously been shown to improve AP relations[45,46,49,50]),(2) the lip seal exercises, and (3) normal muscle forces/mandibular posture or the high-pull chincup, either of which may have augmented forward mandibular rotation, mandibular growth, and closure of the gonial angle.

The patients who were treated with the chincup did not differ from those who were not. This lack of difference may support the treatment protocol that moved patients who did not show bite marks on the acrylic into the chincup therapy. Those who did have adequate bite marks were assumed to have more or less normal muscular forces and mandibular posture. On the other hand, the patients with no bite marks on the acrylic may have had inadequate muscular masticatory force and abnormal posture, which has been associated with excessive vertical facial development.[83-88] The chincup may provide a suitable alternative for normal muscular forces applied to the craniofacial skeleton.

In addition to the beneficial treatment-related skeletal changes observed, significant therapeutic changes were found in both the posterior and anterior aspects of the dentition. Treatment produced 1.0 mm relative upper molar intrusion. Although as much as 2.2 mm of relative intrusion has been reported for HPHG,[81] Brown[33] found significantly more eruption (1.5 mm) of the lower molar, which compares well with other studies showing increased compensatory mandibular molar eruption during HPHG therapy.[22-25] All other forms of vertical treatment, with the exception of posterior bite-blocks, have shown increased lower molar eruption.

In contrast, our treated sample showed only 0.8 mm of lower molar eruption, which was not significantly different from the control values and compares well with previous descriptions of untreated samples.[79,82] Although the lower molars did not demonstrate the absolute intrusion reported with the vertical-pull chincup[25] and magnetic posterior bite-blocks,[39,45,46] their eruption was controlled. Furthermore, instability of absolute intrusion has been reported after 4 months,[45] suggesting the molars compensated for a posterior openbite created by re-erupting into occlusion after treatment.

Overbite and overjet also improved significantly with treatment. The 16 patients with openbite in our sample showed an overbite increase of 2.7 mm, which is only slightly less than increases reported for overbite patients treated with active bite-blocks.[45,46,49,50] In addition to the posterior dental intrusion, the overbite increase may have been due to the separation of the dentition with acrylic and subsequent increases in soft tissue and facial muscular force, which may have encouraged incisor eruption and lingual uprighting.[40,45,46,49,50] The lip seal exercises may also have acted similarly to augment incisor uprighting and extrusion.

Of course, the long-term effects of the treatment regimen under study have not been established. The only vertical studies measuring posttreatment changes indicate that a relapse potential exists. Kuster and Ingervall[49] found a 50% relapse of the overbite, complete relapse of the gonial angle change, and a 33% relapse of the true forward rotation after 1 year of magnetic bite-block therapy. Rowe and Carlson[41] showed that the gonial angle remodeled and reverted toward pretreatment values after bite-block therapy was discontinued in the *Macaca mulatta* monkey. Further studies with our novel treatment approach are needed to corroborate the findings of this study and evaluate the long-term stability of these treatment effects.

CONCLUSIONS

Treatment of hyperdivergent transversely deficient mixed dentition patients with a Crozat/lip bumper, BPE, lip seal exercises, and high-pull chincup results in the following:

1. A significant orthopedic effect consisting of increased true forward mandibular rotation, decreased gonial angulation, increased condylar growth, and changes in the direction of condylar growth. The forward rotation significantly improved the AP chin position, which will help the

skeletal Class II hyperdivergent patient. Maxillary expansion did not increase the patients' vertical dimensions, indicating this may be an effective treatment protocol for those very difficult hyperdivergent patients exhibiting skeletal discrepancies in all 3 planes of space.

2. Inhibited anterior facial height growth in the openbite subsample. The anterior vertical dimension did not increase beyond what would have been expected for the overbite subsample, despite the maxillary skeletal and mandibular dental expansion. The posterior vertical dimension showed improvement, with a significant inferior displacement of gonion.
3. Relative intrusion of the upper molar, vertical control of the lower molar, and increased eruption of the upper and lower incisors. These changes resulted in significant improvements in overjet and overbite.

When the aggregate of all the individual changes are considered, the net effect on the hyperdivergent phenotype implies improvement in all 3 planes of space. The results support the axiom, "the whole is greater than the sum of its parts." If greater amounts of treatment changes are required or desired, it may be necessary to extend treatment or delay it until orthognathic surgery is appropriate. Although surgery may be the only way to alter the large vertical skeletal discrepancies, orthodontists will inevitably be faced with the situation of attempting nonsurgical approaches in borderline patients with vertical skeletal dysplasia. The early orthopedic approach presented is a promising direction for such patients.

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