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Treatment strategies for patients with hyperdivergent Class II Division 1 malocclusion: Is vertical dimension affected?

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Introduction: The dilemma of extraction vs nonextraction treatment, along with the uncertain potential of orthodontic treatment to control vertical dimensions, still remains among the most controversial issues in orthodontics. The aim of this study was to evaluate 2 contradictory treatment protocols for hyperdivergent Class II Division 1 malocclusion regarding their effectiveness in controlling vertical dimensions. **Methods:** The subjects were retrospectively selected from 2 orthodontic offices that used contrasting treatment protocols. The patients had similar hyperdivergent skeletal patterns, malocclusion patterns, skeletal ages, and sexes. Group A (29 patients) was treated with 4 first premolar extractions and "intrusive" mechanics (eg, high-pull headgear), whereas group B (28 patients) was treated nonextraction with no regard to vertical control (eg, cervical headgear, Class II elastics). Twenty-seven landmarks were digitized on lateral cephalometric radiographs before and after treatment, and 14 measurements were assessed. Geometric morphometric methods were also implemented to evaluate size and shape differences. **Results:** As expected, the maxillary and mandibular molars translated mesially and the mandibular incisors uprighted in group A but remained approximately unchanged in group B. The vertical positions of the molars and the incisors were similar between groups before and after treatment, although they were altered by treatment or growth. No significant differences were observed in the posttreatment skeletal measurements between the 2 groups, including vertical variables, which remained unaltered. Permutation tests on Procrustes distances between skeletal shapes confirmed these results. **Conclusions:** This study demonstrated the limitations of conventional orthodontics to significantly alter skeletal vertical dimensions. More important factors are probably responsible for the development and establishment of the vertical skeletal pattern, such as neuromuscular balance and function. (Am J Orthod Dentofacial Orthop 2011;140:346-55)

Control of vertical dimensions during orthodontic treatment is of major importance in hyperdivergent patients.[1-8] Despite the many studies that have addressed this issue from various perspectives, the factors that affect vertical dimensions have not been clearly determined.[5-7] Several strategies concerning treatment plan considerations or treatment mechanics have been proposed to control vertical dimensions or guide growth in hyperdivergent patients.[1,2,5,8-10] These include extraction treatment to move molars forward and reduce the "wedge-type effect," high-pull headgear (instead of low-pull headgear), Nance appliance, palatal bar, posterior bite-block or posterior magnet to control vertical molar movement or even intrude molars.[7] In contrast, treatment approaches in low-angle patients might include nonextraction treatment, low-pull headgear, and extensive use of Class II elastics, which are believed to favor vertical development.

Recent research has disputed whether conventional orthodontics can significantly influence vertical dimensions by demonstrating that some of the considered "extrusive" treatment plans or mechanics are not contraindicated in hyperdivergent patients, since they produce similar results compared with the controls or with "intrusive" protocols.[3,6,7,11-14] However, these retrospective studies examined the effect of either 1 protocol that was not always compared with controls or 2 protocols differentiated by only 1 specific part of the treatment plan.

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The purpose of this retrospective cohort study was to evaluate the effect of 2 contrasting treatment strategies on the vertical dimensions of hyperdivergent Class II Division 1 patients with similar pretreatment skeletal patterns, malocclusions, skeletal maturities, and sex distributions. The null hypothesis was that there is no difference in posttreatment skeletal characteristics of hyperdivergent Class II Division 1 patients treated with 4 first premolar extractions and conventional "intrusive" mechanics compared with patients treated nonextraction, with mechanics that are considered "extrusive."

MATERIAL AND METHODS

The files of 2 orthodontic offices, each operated by 1 clinician, were searched to identify appropriate subjects. Both orthodontists had more than 15 years of practice experience and similar educational backgrounds, including certification from accredited orthodontic specialty programs in the United States. These clinicians were selected because they applied different, contrasting treatment protocols to treat a Class II hyperdivergent skeletal pattern regarding the management of the vertical dimensions.

The inclusion criteria were (1) white patients who finished treatment between 1998 and 2008; (2) hyperdivergent Class II Division 1 skeletal pattern (GoGn-SN, >32°; ANB, >3.5°; overjet, >4 mm); (3) dental Class II, defined as more than a half-cusp molar discrepancy on both sides and more than 4 mm of overjet; (4) mild to moderate pretreatment crowding (<6 mm in each arch); (5) late mixed or permanent dentition; (6) adequate growth potential at the start of treatment (skeletal maturation stage CS1 to CS4, as determined by the cervical vertebral maturation [CVM] method[15]); and (7) 1-phase treatment with fixed appliances.

No other inclusion criteria, such as cooperation or outcome of treatment, were used. However, all subjects were successfully treated (Class I molar and canine relationship, normal overbite and overjet). Two patients who discontinued treatment and 1 patient with incomplete records were not included in the study.

Exclusion criteria consisted of (1) patients with missing teeth, congenital malformations, systemic diseases, or syndromic conditions; and (2) when siblings who fulfilled the inclusion criteria were identified (2 cases), only 1 was randomly selected.

A total of 57 Class II Division 1 young adolescent patients with hyperdivergent facial type were identified. Group A, from the first orthodontic office, was composed of 29 patients treated with 4 first premolar extractions and "intrusive" mechanics. Group B, from the second office, was composed of 28 patients treated without extractions and "extrusive" mechanics (Table I).

Table I. Sample characteristics and *t* test comparisons

	Group A (n = 29)		*Group B (n = 28)*		
	Mean (SD)	*Range*	*Mean (SD)*	*Range*	t *test* P *value*
Age at T1 (y)	11.8 (0.9)	10.2–13.0	11.0 (1.1)	9.5–13.0	0.002*
Age at T2 (y)	15.0 (1.3)	12.7–16.8	13.4 (1.1)	11.4–15.1	0.000*
Treatment time (y)	3.2 (0.6)	2.1–4.4	2.4 (0.8)	1.5–3.9	0.000*

*$P < 0.05$.

The different treatment protocols applied by the 2 clinicians reflected 2 contradictory therapeutic philosophies regarding the potential of conventional orthodontic treatment to control or alter vertical dimensions. The decision for extractions was primarily based on the idea of better control or reduction of the vertical dimension by mesial molar movement: the wedge-effect concept. Furthermore, group A was treated without extrusive mechanics, such as Class II elastics, low-pull headgear, or anterior biteplates. Contrarily, Nance and Goshgarian palatal arches were extensively used. On the other hand, group B was treated as a normodivergent group, with low-pull headgear for every patient, anterior biteplates, and Class II elastics or posterior crossbite elastics, when necessary. No intrusive mechanics such as posterior bite-blocks or additional measures to control molar extrusion, such as Nance and Goshgarian palatal arches, were used in this group. Interproximal reduction of the mandibular incisors was used when needed to prevent flaring of these teeth during correction of crowding. All patients were treated with full preadjusted edgewise appliances, including the second molars (Roth prescription). No patient received skeletal anchorage devices.

Lateral cephalometric radiographs, obtained routinely within 1 month before treatment (T1) and immediately after removal of the appliances (T2), were scanned at 150 dpi, and 28 landmarks (Fig 1) that represented skeletal and dental tissue structures[16] were digitized on screen by using Viewbox 4 software (dHAL Software, Kifissia, Greece). All radiographs were of good quality and were taken in centric occlusion, with lips in the resting position. Also, they included a reference ruler and were corrected for the magnification factor.

Three reference lines and 14 cephalometric measurements representing skeletal tissues and dental components were chosen for the cephalometric analysis[16] (Fig 1). The position of the teeth was evaluated according to a reference system starting from sella, with the x-axis parallel and the y-axis perpendicular to the functional occlusal plane. This system was chosen as the most appropriate for testing the wedge-effect

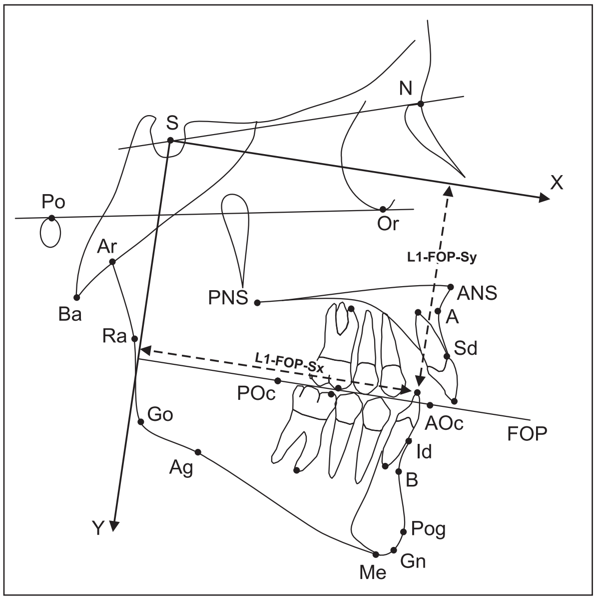

Fig 1. Landmarks, reference lines, and cephalometric measurements used for the study. Skeletal landmarks: *S*, Sella; *N*, nasion; *Ba*, basion; *Po*, porion; *Or*, orbitale; *ANS*, anterior nasal spine; *PNS*, posterior nasal spine; *A*, A-point; *B*, B-point; *Pog*, pogonion; *Gn*, gnathion; *Me*, menton; *Go*, gonion; *Ra*, ramus tangent; *Ar*, articulare; *Ag*, antegonial notch. Dental landmarks: *Sd*, supradentale; maxillary incisor tip; maxillary incisor apex; maxillary molar mesial cusp; maxillary molar mesial apex; mandibular molar mesial cusp; mandibular molar mesial apex; mandibular incisor tip; mandibular incisor apex; *Id*, infradentale; *POc*, posterior occlusal point; *AOc*, anterior occlusal point (occlusal points were placed at arbitrary positions along the functional occlusal plane to define its position and orientation, so that it passed through the occlusal contacts of the first molars and premolars). Reference lines: *SN*; *FH*, Frankfurt horizontal plane defined by points Po and Or; *FOP*, functional occlusal plane; reference coordinate system (x-axis and y-axis) centered at S and aligned with FOP. Skeletal cephalometric measurements: GoGn-SN; lower/total anterior facial height; FMA; ANB; ANS-Me. Dental cephalometric measurements: IMPA; L1-FOP-Sx; L1-FOP-Sy; L6-FOP-Sx; L6-FOP-Sy; U6-FOP-Sx; U6-FOP-Sy; U1-FOP-Sx; U1-FOP-Sy (distances of the maxillary and mandibular incisors [U1 and L1] and the maxillary and mandibular molars [U6 and L6] along the x- and y-axes of the coordinate system, aligned with FOP). Measurements L1-FOP-Sx and L1-FOP-Sy are marked by *dashed lines with double arrows* for illustrative purposes.

concept and the influence of molar position on lower facial height. Alternatively, another reference system, also starting from sella, but with the x-axis parallel and the y-axis perpendicular to the Frankfort horizontal (FH), was used. The results from the second system are not presented, since they were similar to those obtained from the first system.

Kolmogorov-Smirnov tests showed that the cephalometric measurements did not depart from a normal distribution, so parametric tests were used. Pretreatment and posttreatment conditions, and treatment changes were determined for the samples; paired or unpaired 2-sample *t* tests were used to determine significant differences between groups and to evaluate changes caused by treatment or growth (StatsDirect, StatsDirect, Cheshire, United Kingdom). Differences in pretreatment and posttreatment CVM stages were assessed by the nonparametric Mann-Whitney U test (PAST software[17]). Furthermore, 2-dimensional geometric morphometric methods including Procrustes superimposition were implemented to identify and visualize shape differences between the groups.[18,19] The geometric morphometric approach treats the whole landmark configuration as a single unit and describes its shape comprehensively, overcoming some limitations of traditional cephalometry. Also, Procrustes superimposition removes the parameters of size, position, and orientation and is thus different from conventional cephalometric measurements or superimpositions. Therefore, comparisons with cephalometric measurements presented in the tables must be done in this context. Shape differences were tested for significance by permutation tests on Procrustes distances between group means (Viewbox 4). They were assessed for the whole shape (skeletal and dental landmarks) and for skeletal landmarks only. Size differences between groups were assessed by unpaired *t* tests on the logarithm of centroid size of skeletal configurations only (Viewbox 4).[18] Because linear cephalometric measurements are affected by size differences, the measurements related to tooth position and the ANS-Me distance were adjusted according to centroid size to perform valid comparisons between groups A and B at T1 and T2. Differences between the groups in the amount of growth from T1 to T2 were assessed by evaluating centroid size changes with unpaired *t* tests (StatsDirect).

To estimate the error of the method, 20 cephalometric radiographs (5 from each group) were selected randomly and were redigitized and reanalyzed 30 days later by the same examiner (N.G.). Random error was evaluated with Dahlberg's formula.[20] Systematic errors were evaluated by paired *t* tests applied to the cephalometric measurements and to the x and y coordinates of all points.[20] Because of the large number of *t* tests needed, the Bonferroni adjustment was applied to prevent type I error.[21] Finally, to estimate the error of the CVM method, all radiographs were reevaluated 30 days

Table II. CVM stages and intergroup comparisons

	Group A (n = 29)		Group B (n = 28)		Mann-Whitney U-test
	Median	Range	Median	Range	P value
CVM stage at T1	2	1–4	2	1–4	0.460
CVM stage at T2	5	3–6	4	2–6	0.062

later by the same examiner (N.G.). Random intraobserver error was evaluated by the weighted kappa statistic regarding all subjects. Systematic error of the CVM method was estimated by using the Wilcoxon signed rank test between repeated measurements (StatsDirect).

RESULTS

The average random error of the x and y point coordinates was 0.32 mm (range, 0.17–0.46 mm). Concerning cephalometric measurements, the average random errors were 0.40 mm (range, 0.32–0.57 mm) for linear measurements and 0.25° (range, 0.10°–0.52°) for angular measurements. Regarding the CVM method, random intraobserver error was estimated by the weighted kappa statistic and showed almost perfect agreement between the 2 evaluations ($\kappa = 0.92$). No systematic error at $P = 0.01$ was detected for any point coordinate or cephalometric measurement and at $P = 0.05$ for the assessment of skeletal maturation stage.

The 2 groups included balanced numbers of male and female patients (group A, 13 boys, 16 girls; group B, 14 boys, 14 girls). Skeletal age at the initiation of treatment was similar between the 2 groups (Table II), but chronologic age and treatment duration were slightly different (Table I). Although extraction treatment lasted 9 months longer compared with nonextraction treatment (Table I), differences in skeletal age at the end of treatment were marginally nonsignificant (Table II). Differences in size between groups were marginally significant ($P = 0.08$) at T1 and clearly significant ($P = 0.02$) at T2, with group A larger in both cases. However, the amount of growth in the groups from T1 to T2 was similar ($P = 0.18$) (Table III).

The hyperdivergent pattern of the whole sample was confirmed by GoGn-SN (mean, 38.8°; SD, 3.8°) and FMA (mean, 31.5°; SD, 4.1°) and was corroborated by ANS-Me (mean, 64.4 mm; SD 4.9 mm) measurements. The pretreatment ratio of lower anterior facial height to total facial height was not considerably increased (mean, 55.5%; SD, 2.2%) because of the orientation of the jaw complex, which was rotated clockwise relative to the FH. Thus, the value of lower anterior facial height appeared to be decreased when measured by tangent projections of landmarks N, ANS, and Me on a line perpendicular to FH. The cephalometric data and intergroup comparisons at T1 are shown in Table IV. No skeletal variable differed significantly at T1. After size adjustment of group B to the same centroid size as group A, statistically significant differences were identified for the 2 dental parameters related to the anteroposterior position of the molars. There was marginally significant difference ($P = 0.058$) in the horizontal position of the mandibular incisors. These teeth were approximately 2 mm more forwardly positioned in group A. The horizontal position of the maxillary incisors and the vertical positions of the incisors and the molars were similar between the groups.

Descriptive analyses and statistics used for assessing the differences in the T2 cephalometric measurements are given in Table V. IMPA and the anteroposterior position of the molars differed significantly at T2.

The changes in linear and angular measurements brought about by treatment or growth (T2–T1) and the relevant statistics are presented in Table VI. Comparisons within each group showed that no skeletal parameters, except ANB and ANS-Me, were significantly altered by treatment or growth. In contrast, almost all dental parameters were significantly different at T2 compared with the T1 values.

The 2 treatment modalities imposed significantly different changes during treatment only on IMPA and the 4 dental parameters that determine the anteroposterior positions of the incisors and the molars (Table VI). The maxillary incisors were retracted in both groups, but the retraction was 2 mm more in group A. The mandibular incisors were retracted by 1.5 mm in group A but were protracted in group B by a similar amount. The maxillary molars moved 2.5 mm mesially in group A but 1 mm distally in group B. The mandibular molars were placed approximately 5 mm mesially in group A, whereas in group B they moved mesially approximately 2 mm.

Geometric morphometric methods confirmed the results provided by traditional cephalometric measurements. Pretreatment Procrustes superimposition and permutation tests on the 16 skeletal landmarks (Fig 1) showed almost full matching of the skeletal structures and slight differences in the anteroposterior positions of the molars and mandibular incisors (Fig 2, Table VII). Complete skeletal matching remained at the T2 comparison (Fig 3, Table VII), even though the treatment protocols resulted in significantly more anteriorly positioned molars in group A. Growth and treatment changes for each group are shown in Figures 4 and 5; intragroup differences between T1 and T2 were statistically significant in both the skeletal and the overall landmark configurations, as determined by permutation tests (Table VII).

Table III. Centroid size and *t* test comparisons

	Group A (n = 29) *Mean (SD)*	*Group B (n = 28)* *Mean (SD)*	*Difference*	P *value*
Centroid size at T1 (mm)	181.6 (8.6)	177.8 (7.8)	2.14%	0.083
Centroid size at T2 (mm)	192.2 (10.9)	186.5 (7.0)	3.06%	0.024[*]
Centroid size T2–T1 (mm)	10.6 (6.0)	8.8 (3.9)	20.45%	0.179

[*] $P < 0.05$.

Table IV. Descriptive analyses and statistics for T1 cephalometric measurements

		Group B			
Measurement	*Group A* *Mean (SD)*	*Mean (SD)*	*Mean (SD), size-adjusted*[†]	P *value*	P *value, size-adjusted*[†]
Skeletal					
GoGn-SN (°)	38.4 (3.8)	39.1 (3.8)	–	0.451	–
Lower/total facial height (%)	55.5 (2.2)	55.5 (2.1)	–	0.894	–
FMA (°)	31.3 (4.2)	31.6 (4.0)	–	0.779	–
ANB (°)	5.8 (1.8)	6.0 (1.8)	–	0.728	–
ANS-Me (mm)	64.7 (4.9)	64.0 (4.9)	65.3 (4.9)	0.588	0.615
Dental					
IMPA (°)	95.1 (7.5)	93.0 (7.1)	–	0.291	–
L1-FOP-Sx (mm)	78.1 (3.6)	74.2 (5.0)	75.8 (5.16)	0.002[*]	0.058
L1-FOP-Sy (mm)	45.2 (6.6)	44.7 (3.9)	45.7 (4.0)	0.763	0.720
L6-FOP-Sx (mm)	50.6 (3.3)	47.2 (4.6)	48.2 (4.7)	0.002[*]	0.030[*]
L6-FOP-Sy (mm)	48.1 (6.1)	47.5 (3.5)	48.5 (3.6)	0.651	0.758
U1-FOP-Sx (mm)	84.8 (3.6)	82.0 (4.9)	83.8 (5.0)	0.0197[*]	0.402
U1-FOP-Sy (mm)	47.0 (6.7)	47.0 (4.2)	48.0 (4.3)	0.963	0.535
U6-FOP-Sx (mm)	51.2 (3.2)	47.9 (4.5)	48.9 (4.6)	0.002[*]	0.030[*]
U6-FOP-Sy (mm)	48.6 (6.1)	48.1 (3.4)	49.1 (3.5)	0.707	0.690

[*] $P < 0.05$; [†] Linear measurements of group B were scaled to a centroid size equal to that of group A.

DISCUSSION

We did not assess a highly specific appliance or treatment plan but compared the effects of 2 contradictory treatment approaches focusing on the potential of conventional orthodontics to control vertical dimensions. The treatment protocols were applied to young adolescent hyperdivergent patients who had the greatest possible growth potential and were characterized by the most common malocclusion pattern of modern people (Class II Division 1).[22] In these patients, the issue of control of the vertical dimension is of major importance.

We compared 2 treatment approaches that are viewed as contrasting in their effects on vertical dimensions, especially in hyperdivergent skeletal patterns: extraction treatment along with “intrusive” mechanics vs nonextraction treatment with “extrusive” mechanics. The ideal experimental setup for such a comparison would be a randomized clinical trial. In a more feasible retrospective cohort study such as this, we took measures to minimize bias and achieve an acceptable level of evidence.

Proficiency bias was controlled by selecting orthodontists with equivalent clinical experiences and similar educational backgrounds. The opposing philosophies adopted by the 2 orthodontists were derived from the classic controversy of how and to what extent conventional orthodontics can effectively alter vertical dimensions. Randomization of treatment protocols to both orthodontists might seem to eliminate proficiency bias, but we considered that it would be almost impossible for a clinician with inevitably influenced views on the subject to provide equal support to such contradictory approaches of the same problem. In that case, a different type of proficiency bias would be present, probably with ethical issues.

Matching of groups is essential when testing the effects of 2 treatment approaches. The comparison can be considered valid when the patients who receive each protocol have the same growth and developmental potential and the same initial dentoskeletal pattern so as to be similarly affected by factors imposed by treatment. In this study, the 2 groups were selected with narrow

Table V. Descriptive analyses and statistics for T2 cephalometric measurements

		Group B			
Measurement	*Group A* *Mean (SD)*	*Mean (SD)*	*Mean (SD), size- adjusted*†	*P value*	*P value, size-adjusted*†
Skeletal					
GoGn-SN (°)	38.2 (4.1)	39.3 (4.5)	–	0.369	–
Lower/total facial height (%)	55.6 (2.3)	55.6 (2.0)	–	0.996	–
FMA (°)	31.1 (4.7)	31.7 (4.3)	–	0.644	–
ANB (°)	4.7 (1.9)	4.0 (1.9)	–	0.200	–
ANS-Me (mm)	68.7 (5.5)	67.3 (4.9)	69.3 (5.1)	0.315	0.643
Dental					
IMPA (°)	90.0 (6.3)	93.9 (6.7)	–	0.028*	–
L1-FOP-Sx (mm)	76.6 (4.3)	75.9 (5.6)	78.2 (5.8)	0.614	0.228
L1-FOP-Sy (mm)	53.6 (6.1)	52.7 (3.8)	54.3 (3.9)	0.525	0.588
L6-FOP-Sx (mm)	55.4 (3.9)	48.9 (5.3)	50.4 (5.4)	0.000*	0.000*
L6-FOP-Sy (mm)	55.0 (6.0)	53.6 (3.6)	55.3 (3.7)	0.292	0.853
U1-FOP-Sx (mm)	79.8 (4.4)	78.9 (5.5)	81.3 (5.6)	0.528	0.240
U1-FOP-Sy (mm)	55.9 (6.1)	54.3 (3.7)	56.0 (3.9)	0.257	0.936
U6-FOP-Sx (mm)	53.7 (4.0)	47.0 (5.3)	48.4 (5.5)	0.000*	0.000*
U6-FOP-Sy (mm)	55.6 (6.0)	54.2 (3.6)	55.8 (3.7)	0.282	0.866

*P <0.05; †Linear measurements of group B were scaled to a centroid size equal to that of group A.

Table VI. Changes in linear and angular measurements during treatment and intergroup comparisons

	Group A: T2–T1			*Group B: T2–T1*			
Measurement	*Mean*	*SD*	*P value*	*Mean*	*SD*	*P value*	*t test P value*
Skeletal							
GoGn-SN (°)	−0.15	2.50	0.749	0.14	1.74	0.675	0.616
Lower/total facial height (%)	0.10	0.89	0.545	0.17	1.49	0.541	0.822
FMA (°)	−0.19	2.53	0.685	0.06	2.45	0.906	0.709
ANB (°)	−1.13	1.56	0.000*	−1.96	1.60	0.000*	0.052
ANS-Me (mm)	4.04	4.47	0.000*	3.35	3.19	0.000*	0.506
Dental							
IMPA (°)	−5.05	5.24	0.000*	0.89	7.56	0.539	0.001*
L1-FOP-Sx (mm)	−1.47	2.68	0.006*	1.72	2.67	0.002*	0.000*
L1-FOP-Sy (mm)	8.45	5.94	0.000*	8.02	4.26	0.000*	0.754
L6-FOP-Sx (mm)	4.87	3.25	0.000*	1.76	2.64	0.001*	0.000*
L6-FOP-Sy (mm)	6.92	4.83	0.000*	6.13	3.45	0.000*	0.481
U1-FOP-Sx (mm)	−5.01	3.05	0.000*	−3.12	3.12	0.000*	0.024*
U1-FOP-Sy (mm)	8.87	5.32	0.000*	7.39	4.19	0.000*	0.248
U6-FOP-Sx (mm)	2.46	3.24	0.000*	−0.86	3.26	0.172	0.000*
U6-FOP-Sy (mm)	6.97	4.89	0.000*	6.04	3.49	0.000*	0.412

*P <0.05.

criteria, resulting in adequately matched pretreatment data (similar hyperdivergent Class II Division 1 skeletal pattern, skeletal maturity, mild to moderate crowding, and balanced numbers of each sex). Skeletal cephalometric measurements did not show any significant differences between the groups at T1 (Table IV). The similar pretreatment skeletal pattern was also corroborated by permutation tests based on Procrustes distances between skeletal group means (Table VII, Fig 2). Regarding dental parameters at T1, after size adjustment, group A differed from group B at the horizontal position of the maxillary and mandibular molars by approximately 2 mm (Table IV, Fig 2). This was essentially the only difference at T1 and was not considered to have a significant influence on our results.

An unequal distribution of dental Class II severity between groups might also have influenced these results, but this was not the case. At the start of treatment, the maxillary first molar cusp was located mesially to the mandibular molar cusp by 0.6 and 0.7 mm in groups A and B, respectively (Table IV). The same relationship, and similar dental Class II severity between the groups,

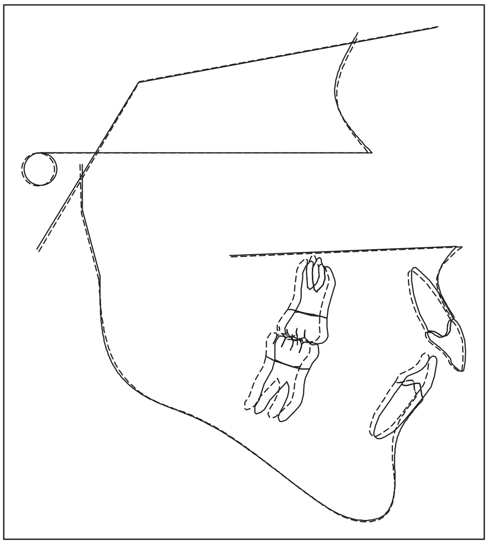

Fig 2. Procrustes superimposition of mean T1 skeletal patterns of the groups: *solid line*, group A; *dotted line,* group B.

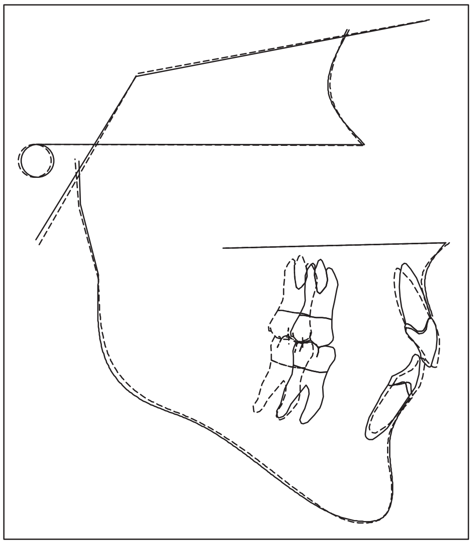

Fig 3. Procrustes superimposition of mean T2 skeletal patterns of the groups: *solid line*, group A; *dotted line,* group B.

Table VII. Permutation tests on Procrustes distances between group means

	P *value (10.000 permutations)*	
Groups	*Skeletal and dental landmarks*	*Skeletal landmarks*
Group A vs group B at T1	0.030*	0.490
Group A vs group B at T2	0.000*	0.262
Group A: T1 vs T2	0.000*	0.009*
Group B: T1 vs T2	0.000*	0.003*

$^{*}P < 0.05$.

was demonstrated by the Procrustes superimposition on skeletal landmarks at T1 (Fig 2).

The reference system used for the evaluation of tooth positions could be considered unreliable, since occlusal plane inclination can change during treatment or growth. However, this reference system is probably the most relevant for the study to evaluate the position of teeth relative to the craniofacial complex and to test the wedge-type effect. Teeth probably move parallel to the occlusal plane, and, if the wedge effect is valid, it is attributed to this movement. Also, the alternative reference system (based on FH), which is not influenced by the inclination of the functional occlusal plane, provided similar results. We are aware that, as everything changes, especially during growth, there is no ideal reference plane. To prevent this weakness, we used geometric morphometric methods that evaluated the positions of teeth relative to the whole craniofacial landmark configuration.

As expected, extraction treatment lasted approximately 9 months longer compared with nonextraction (Table I).[13,23] Despite this, skeletal maturation was not significantly different between the groups at the end of treatment, although it was close to the level of significance (Table II). Ideally, the duration of treatment along with skeletal and chronologic ages at T2 should be identical in both groups. However, because of the protocols applied, this was impossible in this study. Nevertheless, it was not expected that differences that were not evident during the specific treatment intervals would occur if those intervals were the same for both groups. Furthermore, the amounts of growth that occurred during the specific intervals were similar for both groups (Table III).

At posttreatment, statistically significant differences were detected only for IMPA (mandibular incisors more upright in group A) and for 2 additional dental measurements that determine the anteroposterior position of maxillary and mandibular molars. In both groups, the incisors were placed in the same position at T2 (Table V, Fig 3). This implies that both orthodontists had the same treatment goals. In group B, the mandibular incisors were not moved markedly forward to relieve crowding, because of the regular application of interproximal reduction. Also, in this group, maxillary crowding was relieved by distalization of the molars, mainly distal tipping, expansion, or interproximal

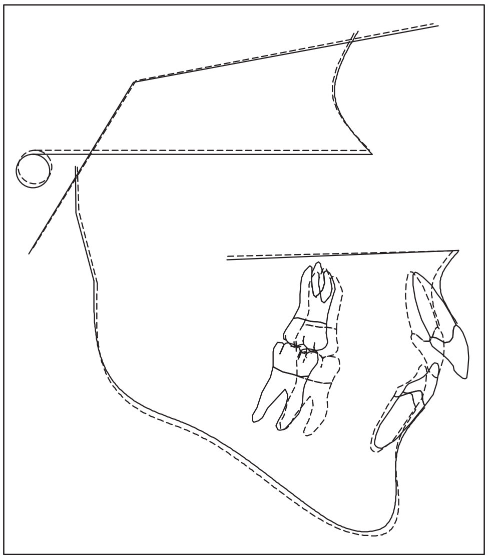

Fig 4. Procrustes superimposition of mean skeletal patterns of group A: *solid line*, T1; *dotted line*, T2.

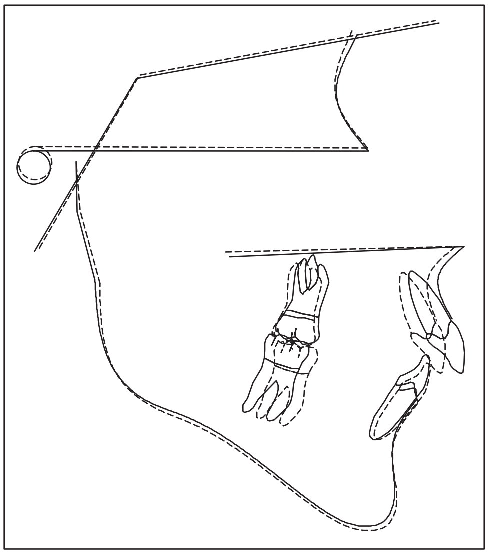

Fig 5. Procrustes superimposition of mean skeletal patterns of group B: *solid line*, T1; *dotted line*, T2.

reduction. At T2, as was the case at T1, skeletal structures were similar between groups (Tables IV, and V, Figs 2 and 3).

Within-group comparisons between T1 and T2 showed significant changes only for ANB and ANS-Me as far as skeletal measurements were concerned. All dental parameters were also altered from T1 to T2 in both groups (Table VI, Figs 4 and 5), except for IMPA and U6-FOP-Sx for group B (Table VI, Fig 5). This is in contrast to the results of Sivakumar and Valiathan,[13] who found no changes in the vertical positions of teeth caused by treatment.

In our study, none of the parameters that determine skeletal relationships or vertical movements of teeth were altered in a different way or magnitude by the different protocols (Table VI). The combined effect of treatment and growth significantly affected most of these parameters, although not including vertical skeletal measurements (except ANS-Me), but the changes were similar in each group (Table VI, Figs 4 and 5). Treatment or growth caused different changes only to IMPA and to the anteroposterior positions of the incisors and molars (Table VI). However, all incisors ended up at the same position in both groups (Table V). Overall, treatment resulted in a differential anteroposterior movement of the molars of approximately 3.5 mm between the 2 groups. Although the final vertical positions of the teeth were similar in both groups, the considerably different anteroposterior movement of the molars did not affect the skeletal components in a different way (Table VI, Fig 3); thus, the wedge-type effect was not evident.

The concept of the wedge effect is based on the assumption that anteroposterior movements of maxillary and mandibular posterior teeth occur parallel to the maxillary and mandibular planes, respectively. Based on this assumption, total maxillary and mandibular dentoalveolar height remains constant and forms an effective wedge that regulates mandibular inclination and anterior facial height, depending on its anteroposterior position relative to the hinge, the temporomandibular joint. Our results show that this concept was not operational in our sample; rather, the teeth seemed to translate parallel to the occlusal plane, increasing their vertical height as they translated mesially. On the other hand, it is questionable whether the same result would be observed in extreme hyperdivergent patients with anterior open bite and diverging, noncoincident occlusal planes. In such cases, the wedge concept seems more plausible. However, such extreme skeletal patterns are usually based on neuromuscular problems, which cast doubt on the long-term stability of any favorable treatment result that might be obtained with an extraction protocol.

Excluding dental landmarks, permutation tests based on Procrustes distances between group means showed that the 2 groups were characterized by similar skeletal statuses before and after treatment (Figs 2 and 3), even though treatment and growth changed the 2 patterns significantly (Table VII, Figs 4 and 5). This means that the skeletal changes were in the same magnitude and direction in both groups, independent of the treatment protocol, and were also independent of the

Table VIII. Characteristics of relevant studies from the literature and their conclusions

Study	*Sample*	*Compared groups*	*Bias*	*Differential vertical effect*
Staggers, 1990[29]	Class I and Class II Division 1	Extraction (14, 24, 34, 44) vs extraction (17, 27, 37, 47)	Unmatched pretreatment groups (eg, age, skeletal pattern)	Yes
Yamaguchi and Nanda, 1991[5]	Class I and Class II	Extraction (?) vs nonextraction	Unmatched pretreatment groups (eg, sex, malocclusion pattern)	Yes
Klapper et al, 1992[9]	Dolichofacial and brachyfacial	Extraction (which premolars?) vs nonextraction	Insufficient data for pretreatment groups (eg, skeletal characteristics), small sample size	Yes
Paquette et al, 1992[24]	Class II Division 1, normodivergent	Extraction (14, 24, 34, 44) vs nonextraction	Inadequate treatment information, unmatched sex groups	No
Chua et al, 1993[30]	Class I and Class II	Extraction (?) vs nonextraction	Unmatched pretreatment groups (eg, sex, skeletal pattern)	Yes
Cusimano et al, 1993[12]	Class I and Class II, hyperdivergent	Extractions (14, 24, 34, 44)	No comparison or control group, inadequate treatment information	No
Staggers, 1994[25]	Class I	Extraction (14, 24, 34, 44) vs nonextraction	Unmatched pretreatment groups (eg age, skeletal pattern)	No
Baumrind, 1998[23]	Class I and Class II	Extraction (?) vs nonextraction	Unmatched pretreatment groups (eg, sex, skeletal and dental parameters)	Yes
Kocadereli, 1999[26]	Class I	Extractions (14, 24, 34, 44) vs nonextraction	Unmatched pretreatment groups (eg, skeletal parameters)	No
Basciftci et al, 2003[27]	Class I and Class II Division 1	Extraction (which premolars?) vs nonextraction	Unmatched pretreatment groups (eg, skeletal parameters)	No
Hayasaki et al, 2005[4]	Class I and Class II Division 1, normodivergent	Extraction (14, 24, 34, 44) vs nonextraction	No differential mesial molar movement, small sample size	No
Kim et al, 2005[7]	Class I hyperdivergent	Extraction (14, 24, 34, 44) vs extraction (15, 25,35, 45)	Minimal differential mesial molar movement (1 mm)	No
Al-Nimri, 2006[28]	Class II Division 1, normodivergent	Extraction (14, 24, 34, 44) vs extraction (14, 24, 35, 45)	Inadequate evaluation of molar positions, small differential mesial molar movement (1.8 mm) only in mandibular arch	No
Sivakumar and Valiathan, 2008[13]	Class I, normodivergent, late teenagers	Extraction (14, 24, 34, 44) vs nonextraction	Unmatched pretreatment groups (eg, sex, duration of treatment, dental status)	Yes

anteroposterior position of the molars. When dental landmarks were included in the analysis, all compared groups were significantly different (Table VII).

Several studies that addressed issues similar to those that we analyzed were identified in the literature (Table VIII). Some studies generally agreed with our findings,[4,7,12,24-28] and others disagreed.[5,9,13,23,29,30] Most studies examined the effect of extraction vs nonextraction treatment on vertical dimensions, whereas we examined the effects of 2 contradictory treatment protocols and also included the extraction issue. The main problem, evident in most of these studies, was that they did not adequately manage the selection bias, thus comparing groups that were not fully matched.[5,9,13,23-27,29,30] Other considerations were related to small sample sizes,[4,9] insufficient data provided at pretreatment,[9,12] inadequate information regarding treatment,[24] and no comparison or control group.[12]

Few studies attempted to test the wedge-effect concept and successfully manage bias. However, the authors of these studies did not observe significant differential mesial molar movements between the compared groups.[4,7,28]

Other studies provide indirect evidence in favor of our hypothesis. Ozaki et al[14] examined the effects of 4 premolar extractions followed by 4 first molar extractions, in high-angle Class II Division 1 patients and found no significant difference in FMA from pretreatment to retention. Phan et al[31] investigated the effects of nonextraction treatment on rotation and displacement of the mandible in Class II Division 1 normodivergent patients compared with untreated matched controls. They concluded that occlusal or vertical movement of the maxillary and mandibular molars was not correlated to mandibular rotation or horizontal displacement of pogonion. When compared with the controls, the treated group had occlusal movement of the maxillary molars, but no significant difference in mandibular rotation. Taner-Sarisoy and Darendeliler[3] studied mesiodivergent and hyperdivergent patients treated with extraction of 4 first premolars and with or without headgear and observed that neither treatment changed the growth pattern significantly. Haralabakis and Sifakakis[6] studied the effect of cervical headgear on patients with high and low mandibular plane angles and reported no difference in FMA changes between the 2 groups.

CONCLUSIONS

Data from this study, in agreement with conclusions drawn from the literature, provide strong evidence to dispute the concept of the wedge-type effect. Control of vertical dimensions might no longer be a reason for adopting an extraction treatment protocol. It seems that extraction treatment should be chosen primarily based on dentoalveolar or other criteria related to the anteroposterior positions of the teeth. These are usually easier to define and could lead to more accurate predictions of the accomplishment of treatment goals.

This study also demonstrated the limitations of conventional orthodontics to significantly alter skeletal vertical dimensions. The craniofacial complex, including the masticatory system, is highly complicated and should not be perceived as a simple articulator. There are probably more important factors than tooth numbers or orthodontic treatment mechanics responsible for the establishment of the vertical positions of the teeth and the associated skeletal patterns, such as neuromuscular balance and function.

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