

## ORIGINAL ARTICLES

# *A comparison of one-stage and two-stage nonextraction alternatives in matched Class II samples*

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In the treatment of Class II malocclusion, an early phase of functional appliance treatment is commonly used to simplify subsequent fixed appliance therapy and to optimize the development of the facial skeleton. Unfortunately, these expectations enjoy little support in the refereed literature. The present study therefore was undertaken to examine the benefits of a two-stage bionator/edgewise regimen in comparison to the more conventional one-stage edgewise alternative. To minimize proficiency bias, we examined the records of the one- and two-stage Class II nonextraction patients who received treatment between 1980 and 1990 by a single experienced clinician. On the basis of descriptive data from 96 sets of *initial* study models and lateral cephalograms, discriminant analysis was used to identify two subsamples of 36 patients who were relatively similar before treatment and thus equally susceptible to the two treatments. Of these 72 "borderline" patients, 19 subsequently underwent a change in treatment plan (to extraction or surgery), leaving 25 two-stage and 28 single-stage nonextraction patients on whom to base a comparison of treatment effects. Except for a slight posttreatment difference in age (and, hence, size), the two groups underwent skeletal changes that left them essentially indistinguishable at the end of treatment. In both groups, these skeletal changes were largely responsible for molar and overjet corrections that were nearly identical in the two groups. The rates of change, however, differed significantly. As a result, the two-stage treatments started earlier and finished later. Although the present data do not address the relative impact of the two strategies on the 10% to 15% at each tail of the distribution, the early phase of functional appliance treatment conferred no obvious, measurable benefits on the central 75%. Therefore for most nonextraction Class II patients, the choice of treatments may well constitute a practice management, rather than a biologic, decision. (AM J ORTHOD DENTOFAC ORTHOP 1995;108:118-31.)

Throughout the history of the specialty, orthodontists have turned time and again to growth modification as a routine treatment for skeletal Class II malocclusion. As noted by S. Kloehn,<sup>1</sup> children were often treated "... for six or eight years under the impression that we were stimulating growth of the mandible and facial bones." It was not until the advent of the cephalometric technique that the innocent, optimistic assumptions of the bone-growing era could be tested. Unfortunately, the early studies fostered a number of persistent and influential misconceptions.

For example, in the assessment of tooth movement, the use of cranial base superimposition<sup>2</sup> led to the enduring notion that upper molars cannot be moved distally. Similarly, by taking linear growth as a sign of isometry<sup>3</sup> (proportions remain constant *only* if the regression line passes through the origin of the plot<sup>4</sup>; for most facial dimensions, it does not<sup>5</sup>), Brodie concluded that the pattern of growth is unchanging and immutable.<sup>6</sup> In conjunction with the popular assumption that growth is under tight genetic control (the so-called "genetic paradigm"<sup>7</sup>), Brodie's cephalometric studies effectively undercut the biologic rationale for early, growth modification treatment. Perhaps as a result, American orthodontists turned to serial extraction and sophisticated, fixed appliance treatments designed to mask, rather than correct, skeletal disharmonies in adolescents and young adults.

Although American orthodontists practiced with great success within these technically demanding, albeit artificial limits, their European colleagues explored a variety of growth modification

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alternatives descended from the method of Andresen and Häupl<sup>8</sup> of "functional jaw orthopedics." Over the past 20 years or so, however, many American orthodontists, faced by a persistent "busyness" problem and beset by mounting pressures from parents and referring dentists to "do something" (preferably early, often, and without premolar extraction), have turned once again to skeletal modification as a routine treatment for Class II malocclusion. Although many clinicians apparently see early functional appliance treatment as a practical necessity, they also argue that it will serve to produce optimal facial esthetics and, in addition, somehow reduce both the need for extraction and the length and complexity of the subsequent fixed appliance treatment. Unfortunately, there is little in the way of objective support for these supposed advantages (see Johnston<sup>9</sup>), and, to compound the problem, many workers see randomized clinical trials as the only valid source of comparative data.

As has been discussed elsewhere,<sup>10-12</sup> many types of orthodontic clinical trials would be fatally compromised by a variety of ethical and practical problems (time, cost, sample attrition, informed consent). Retrospective studies, in contrast, are quick, cost effective, and ethically unambiguous. In the absence of careful planning, however, their results also tend to be bias ridden and uninterpretable. Fortunately, it is possible to control, or at least minimize, many of these biases. Accordingly, it will be the purpose of this investigation to conduct a relatively bias-free retrospective comparison of single-stage edgewise and two-stage bionator/edgewise treatments.

## PATIENTS AND METHODS

The patients whose records (lateral cephalograms and study models) were analyzed in this investigation were treated by an experienced orthodontist who gave us free access to his files. We sought growing white patients (7 to 14 years), who had bilateral Class II, Division 1 (at least a half step) malocclusions and who had been treated between 1980 and 1990. For all subjects, the clinician's initial intention (as judged by the treatment plan) was nonextraction therapy, either in one stage (edgewise) or in two stage (functional/edgewise). No other inclusion filters (e.g., outcome or "cooperation") were used.

The functional phase of treatment was carried out by means of the bionator, an appliance that McNamara and Brudon<sup>13</sup> have called "perhaps the most widely used functional appliance in the world today." In the version used here (an appliance similar to the California bionator<sup>13</sup>), the acrylic opposing the occlusal and lingual

surfaces of the mandibular molars is trimmed to permit free eruption and mesial migration. Conversely, eruption facets and occlusal stops control the eruption of the maxillary molars and prevent their mesial migration. The maxillary incisors are constrained by an incisal shelf that permits retraction by the labial bow. The fixed appliance treatments were effected with a nontorqued, nonangulated, 0.022-inch edgewise appliance in general adherence to the principles commonly referred to as "Tweed mechanics"—anchorage preparation, directional extraoral traction, and Class II elastics.

In the end, a total of 96 patients, 49 two-stage and 47 one-stage, met the various inclusion criteria and thus formed the "parent" sample. Because these patients were treated by a single orthodontist who documented all outcomes (not just the best) and because we accounted for all 96 patients (not just those for whom the original treatment plan proved adequate), our design served to minimize *proficiency*, *detection*, and *transfer* bias. More significantly, however, if differences in outcome are to be seen as something more than a reflection of the initial differences that may have prompted the original assignment of treatments, it is necessary to compare outcomes in groups of patients who were morphologically similar before treatment. Because treatment plans commonly are based on a multiple inputs, the identification of a "borderline," equally susceptible stratum of patients is a multivariate statistical problem.

Stepwise discriminant analysis (Subprogram DISCRIMINANT, Statistical Package for the Social Sciences, version 3.1, SPSS, Inc., Chicago, Ill.) was used to characterize the anatomic basis of the initial treatment decision. Of the 56 pretreatment descriptive variables that fueled the discriminant analysis, 41 were obtained from the initial lateral cephalograms that were digitized with a transparent digitizing pad (Scriptel RDT-1212, Scriptel Corp., Columbus, Ohio) and a commercial cephalometric program (Dentofacial Planner, version 5.32, Dentofacial Software, Toronto, Canada) 13 from the initial study models (photocopies magnified about 20% to reduce the impact of digitization error), and 2 (age and sex) from the examination forms. The cephalometric analysis has been described elsewhere<sup>10-12</sup>; its key features are summarized in Table I. The model analysis featured standard measures of arch width (at the canines, second premolars, and first molars), arch length (in two segments, 6-1-6<sup>14</sup>), available space (in four segments, 6-3-1-3-6), arch depth, and lower anterior irregularity.<sup>14</sup> Of these 56 descriptive variables, a linear combination of three, age and linear measures of overjet and the severity of the Class II molar relationship, produced an highly significant ( $p < 0.01$ ) discrimination between the 49 two-stage and the 47 one-stage patients.

In standardization form, the discriminant function was of the form,  $D_z = 0.88 (\text{age}) - 0.64 (\text{OJ}) + 0.38 (\text{molar relationship})$ , where  $D_z$  is the "confounder summarizing"<sup>15</sup> discriminant score calculated for each of the 96 subjects. As may be seen in Fig. 1, *A*, the two-stage

**Table 1.** Descriptive cephalometric analysis

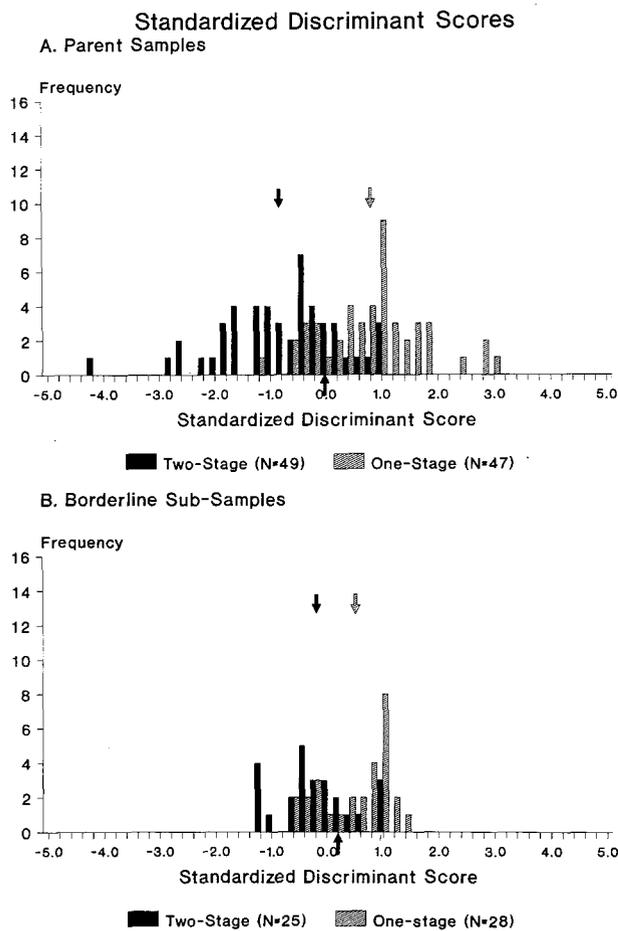
Measure	Description
<i>Maxillary position</i>	
SNA	Angle sella-nasion-A
A-Na vertical	A point to nasion vertical (perpendicular to FH through Na)
<i>Maxillary size</i>	
PNS-A	Posterior nasal spine to A (more reliable A-P than ANS)
<i>Mandibular position</i>	
SNB	Angle sella-nasion-B
Y-axis	Angle between FH and S-Gn
B-Na vertical	B-point to Nasion Vertical
Po-NaB	Pogonion to nasion-B
Po-Na vertical	Pogonion to nasion vertical
S-Ar	Sella to articulare—a crude measure of condylar position
<i>Mandibular size</i>	
Ar-Gn	Articulare to gnathion
Co-Gn	Condylion to Gnathion
<i>Maxillary dentition</i>	
U1-SN	Angle between long axis $\bar{1}$ and sella-nasion line
U1-NA	Angle between long axis $\bar{1}$ and nasion-A line
UI-NA	Facial surface of averaged $\bar{1}$ to nasion-A line
PTV-U6	Pterygoid vertical to distal $\bar{6}$ , parallel to FOP (Ricketts)
<i>Mandibular dentition</i>	
L1-NB	Angle between long axis 1 and nasion-B line
FMIA	Angle between Frankfort line and long axis 1
IMPA	Angle between mandibular plane (Downs) and long axis 1
L1-APo	Incisal edge of 1 to A-pogonion line
L1-NB	Facial surface of 1 to nasion-B line
<i>Maxillomandibular relationship</i>	
ANB	Angle A-nasion-B
1 to 1	Interincisal angulation
Wits (FOP)	A-point to B-point, parallel to function occlusal plane (FOP)
OJ (FOP)	Distance between incisal edges of $\bar{1}$ and 1 taken along FOP
OB (FOP)	Distance between incisal edges of $\bar{1}$ and 1 taken perp. to FOP
Molar Rel	Distance between mesial contact pts. $\bar{6}$ and 6 taken along FOP
<i>Vertical</i>	
SN-PP	Angle between sella-nasion and ANS-PNS lines
SN-FOP	Angle between sella-nasion and FOP
FMA	Angle between FH and mandibular plane (tangent)
S-Go	Distance between sella and gonion—posterior face height
N-ANS	Distance between nasion and ANS—upper anterior face height
ANS-Me	Distance between ANS and menton—lower anterior face height
N-Me	Distance between nasion and menton—total anterior face height
<i>Profile</i>	
Nasolabial angle	Angle between columella and upper lip
Upper Z angle	Angle between FH and tangent to soft-tissue chin and upper lip
L lip-E plane	Distance between lower lip and E-plane (nose-chin tangent)

patients tend to have negative discriminant scores. In our sign convention, a Class II molar relationship (measured along the functional occlusal plane from mesial  $\bar{6}$  to mesial  $\bar{6}$ ) would be given a negative sign; the usual Class II overjet, a positive sign. As a result, the two-stage patients tended to be younger and more severely affected.

On the basis of each patient's discriminant score, the extreme 25% (patients with scores greater than  $\pm 1.3$ ) were then discarded (Fig. 2), leaving a central 75% (36

one-stage, 36 two-stage) that were similar at the outset and thus relatively free of *susceptibility* bias. Examination of their posttreatment records, however, revealed that 19 of these 72 patients (8 one-stage, 11 two-stage) subsequently underwent a change in treatment plan, either to premolar extraction or surgery. In the end therefore the study was based on an analysis of data from the 25 two-stage and 28 one-stage patients (Fig. 1, B) for whom the original treatment plan proved adequate.

The extent to which the discriminant function led to

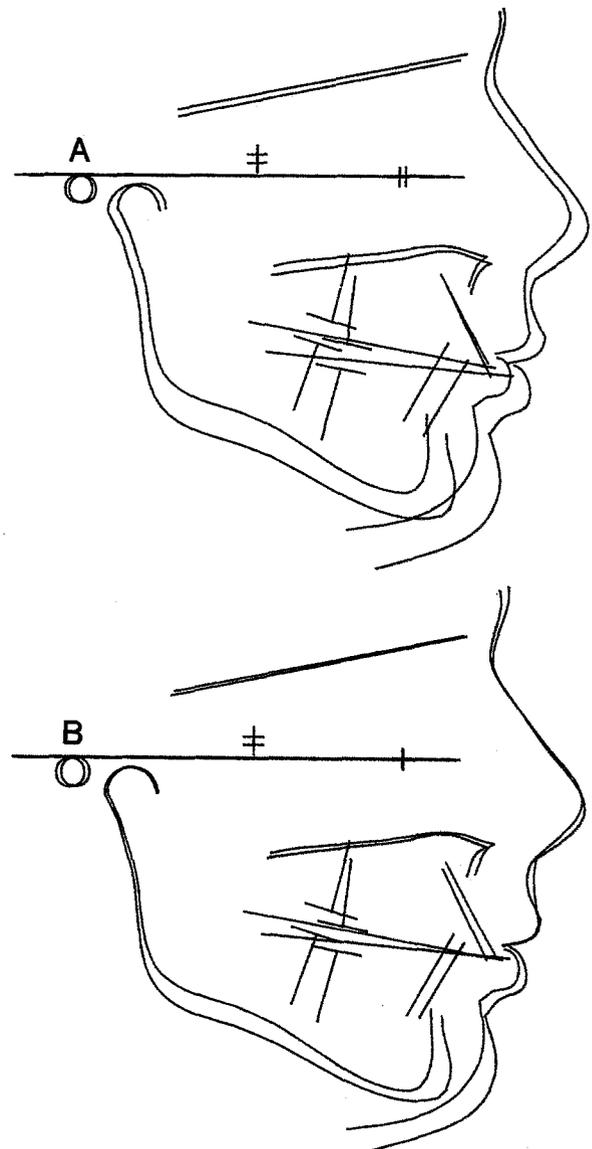


**Fig. 1.** Discriminant scores. **A**, Parent samples. **B**, Borderline subsamples, patients for whom nonextraction therapy proved adequate. Arrows denote group centroids.

the identification of structurally comparable samples (i.e., subjects relatively free of susceptibility bias) may be judged from the superimposition of group averages\* depicted in Fig. 3, *A* and the descriptive statistics for the initial values of the various cephalometric and study model variables summarized in Table II. Even after the sample had been trimmed, the single-stage patients were still, on average, a year older and thus slightly larger. However, there was very little difference in form: If the two-stage patients are enlarged 3% (a shape preserving linear transformation whose magnitude was inferred from the pretreatment means), the two groups become almost identical (Fig. 3, *B*).

#### Posttreatment analysis

To characterize the skeletal, dental, and soft-tissue changes that occurred during the one- or two-stage of treatment, progress (end of functional phase for the



**Fig. 2.** Initial tracings—group averages for extreme patients. **A**, Unadjusted. **B**, Two-stage patients enlarged 5%. Note that extreme bionator/edgewise patients, in addition to being smaller at outset (**A**), tended to present with more severe skeletal discrepancy (**B**), due in large measure to relatively small mandible. In this and all subsequent figures, red = two-stage treatments; blue = one-stage treatments.

early, two-stage treatments) and after treatment (end of edgewise treatment in both groups) lateral cephalograms and study models were subjected to the same descriptive analysis used to generate the discriminant function. In addition, detailed regional superimposition, described elsewhere,<sup>10-12,16</sup> was used to quantify the source of the molar and overjet corrections: tooth movement (incisor and molar movement relative to basal bone) and skeletal change—maxillary (Max) and mandibular growth (Mand) relative to cranial base and the net effect of this

\*Prepared with the aid of "Average," a customization of Dentofacial Planner, v 4.22, Dentofacial Software, Toronto, Canada.

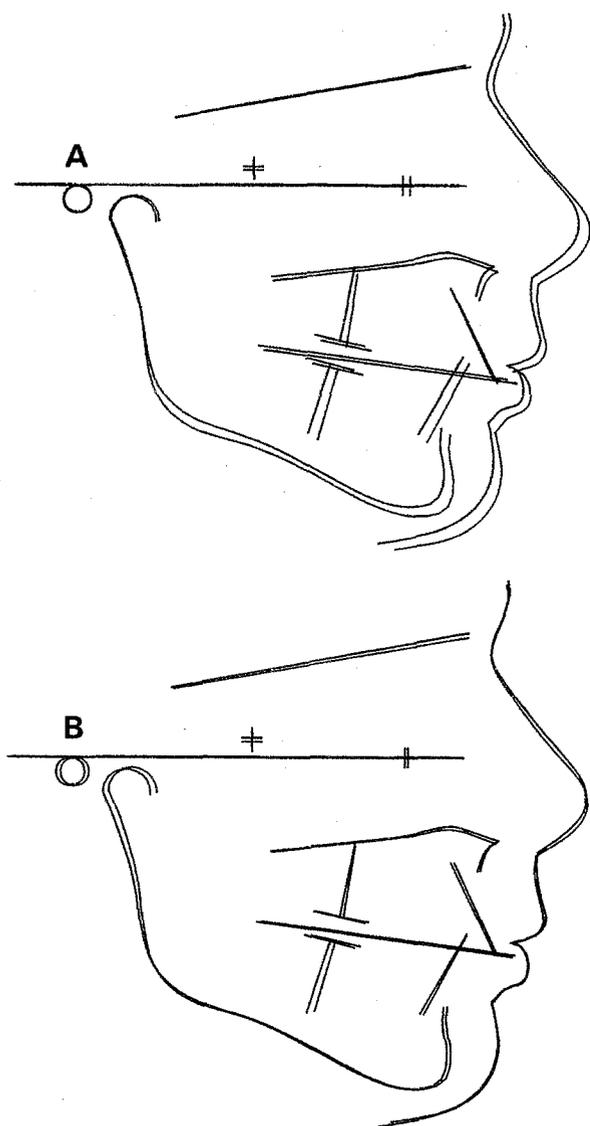
**Table II.** Borderline subsample: Descriptive and inferential statistics for selected pretreatment cephalometric and demographic variables

Measure	$SD_E$ ( $n = 22$ )	2-stage ( $n = 25$ )		1-stage ( $n = 28$ )		$t$
		Mean	SD	Mean	SD	
<i>Maxillary position</i>						
SNA	1.0	82.4	3.8	82.4	2.8	0.04
A-NA vertical	1.1	-0.6	3.9	-0.7	2.9	0.03
<i>Maxillary size</i>						
PNS-A	0.8	51.4	2.5	51.8	2.6	-0.64
<i>Mandibular position</i>						
SNB	0.8	76.0	3.2	77.1	2.3	-1.31
Y-Axis	1.4	56.1	2.2	55.7	2.3	0.61
B-Na vertical	1.4	-11.2	5.3	-9.7	3.9	-1.17
Po-NaB	0.5	1.5	1.5	1.7	1.7	-0.50
Po-Na vertical	1.7	-11.5	6.5	-9.5	4.7	-1.28
S-AR	0.8	34.7	3.0	34.8	3.0	-0.21
<i>Mandibular size</i>						
Ar-Gn	0.6	103.2	4.9	105.9	4.9	-2.02*
Co-Gn	0.9	110.5	4.7	113.8	4.9	-2.48*
<i>Maxillary dentition</i>						
U1-SN	1.7	104.4	8.1	106.0	6.6	0.80
U1-NA	1.8	21.9	8.0	23.6	6.9	-0.81
U1-NA	0.9	3.2	2.7	3.8	2.6	0.87
PTV-U6	1.3	12.7	3.0	14.7	3.6	-2.16*
<i>Mandibular dentition</i>						
L1-NB	1.4	26.0	6.4	24.5	6.5	0.86
FMIA	1.7	60.6	6.3	62.6	7.0	-1.10
IMPA	1.8	97.0	6.1	96.1	7.0	0.52
L1-APo	0.6	-0.6	1.8	-0.9	2.3	-0.34
L1-NB	0.6	4.3	1.9	3.8	2.2	0.84
<i>Maxillomandibular relationship</i>						
ANB	0.6	6.4	1.8	5.4	1.9	2.03*
1 to 1	1.9	125.6	9.6	126.6	9.3	-0.36
Wits (FOP)	1.0	3.9	2.2	2.5	2.1	2.28*
OJ (FOP)	0.8	8.1	2.0	7.8	2.0	0.57
OB (FOP)	0.7	4.4	2.5	4.1	2.3	0.55
Molar Rel	0.4	-1.8	1.3	-1.4	1.1	-1.18
<i>Vertical</i>						
SN-PP	1.2	7.9	2.6	7.6	2.7	0.38
SN-FOP	1.3	18.3	3.5	17.7	3.3	0.68
FMA	1.1	22.4	3.6	21.3	4.4	0.98
S-Go	2.4	69.0	5.3	71.8	5.4	-1.92
N-ANS	1.2	51.4	2.5	52.4	3.5	-1.08
ANS-Me	2.2	63.8	5.3	64.3	6.1	-0.27
N-Me	2.4	112.7	5.8	114.4	5.7	-1.11
<i>Profile</i>						
Nasolabial angle	2.2	119.9	8.4	117.6	7.6	1.04
Upper Z angle	1.3	70.0	4.2	71.9	4.7	-1.60
L lip-E plane	0.5	0.3	2.1	-0.3	2.7	0.92
Age	-	10.4	1.05	11.4	1.3	-3.11**

\* $p < 0.05$ ; \*\* $p < 0.01$ .

growth, apical base change (ABCH). Each measurement was executed parallel to the mean functional occlusal plane (FOP; pretreatment/posttreatment average) and was given a sign appropriate to its impact, positive, if it helped to correct the molar relationship or reduce the

overjet (as would be the case, say, with mesial movement of the lower molars and incisors), and negative, if it made them worse (e.g., forward growth of the maxilla or mesial movement of the upper dentition). Given this convention, the algebraic sum of the anteroposterior skeletal

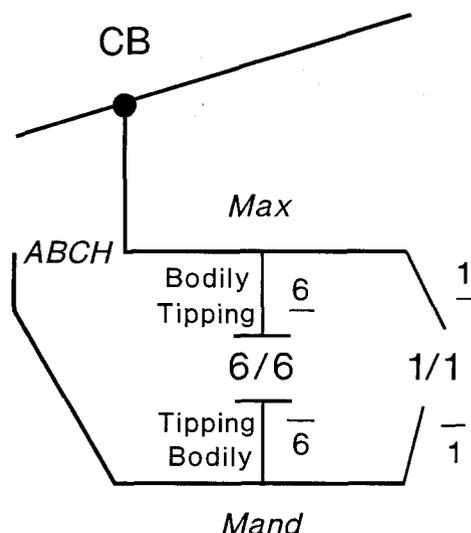


**Fig. 3.** Initial tracings—borderline group averages. **A**, Unadjusted. **B**, Two-stage patients enlarged 3% to compensate for residual mean age-difference of 1 year.

and dental effects must equal the change in molar relationship and overjet (Fig. 4). Accordingly, this accounting supports a between-treatment or between-phase comparison, not only of the magnitude of these two corrections, but also of their source (i.e., skeletal or dental). Because of the technical difficulty of this part of the cephalometric analysis, all tracing, superimposition, and measurement were done by hand; no digitization was used.

#### Error study

With the aid of a table of random numbers, nine sets of records (five one-stage and four two-stage) were selected and reanalyzed. This process produced 22



$$\text{skeletal change} = ABCH = \text{Max} + \text{Mand}$$

**Fig. 4.** Scheme of regional superimposition—pitchfork diagram. Algebraic sum of skeletal changes (measured relative to CB, anterior cranial base registered at SE point) and molar and incisor movement relative to basal bone equals molar (6/6) and overjet (1/1) corrections. Note also that total upper and lower molar crown-movements (displacement of mesial contact points of  $\bar{6}$  and  $\bar{6}$ ) are decomposed into bodily (root-apex) and tipping components, where tipping = total - bodily.

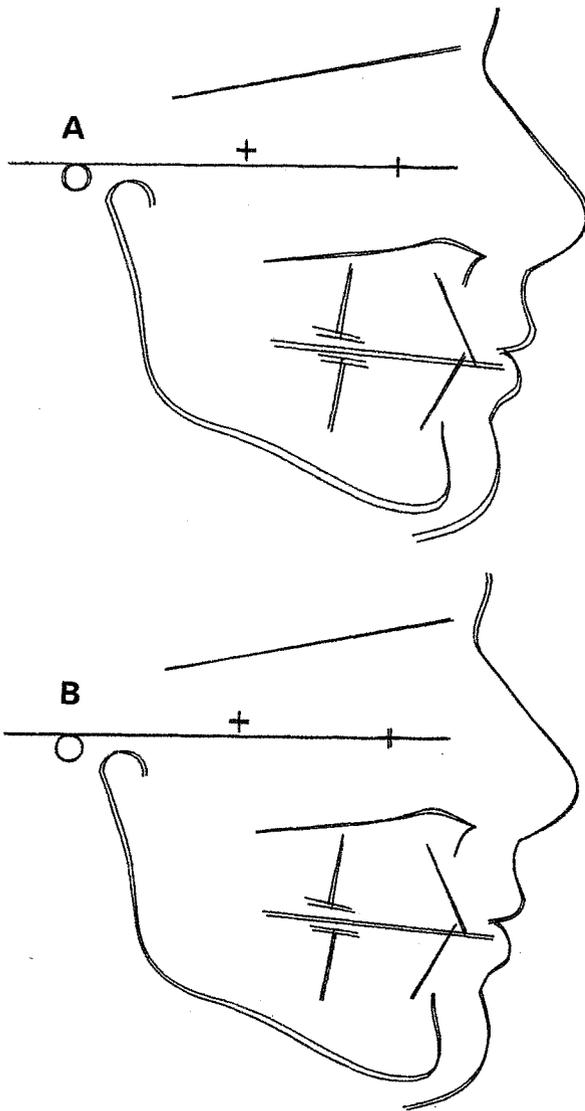
double determinations for the descriptive analyses and 13 for the various measurements of change inferred from regional superimpositions. Dahlberg's formula,  $SD_E = \sqrt{\sum D^2 / 2N}$ , where  $D$  is the difference between double determinations, was then used to calculate the error standard deviations for each variable.<sup>17</sup>

#### Statistical analysis

Descriptive statistics (means and standard deviations) were calculated for all measurements. Between-means differences for initial and final facial form, treatment change, and differences between changes during the first and second phases of the two-stage treatments were analyzed by means of completely randomized  $t$  tests. Multiple contrasts can lead to inflated Type I error rates and thus must be interpreted with caution. As will be seen, however, relatively few contrasts proved significant, and those that did were not widely scattered, but instead fell into a small number of easily interpretable categories.

#### RESULTS

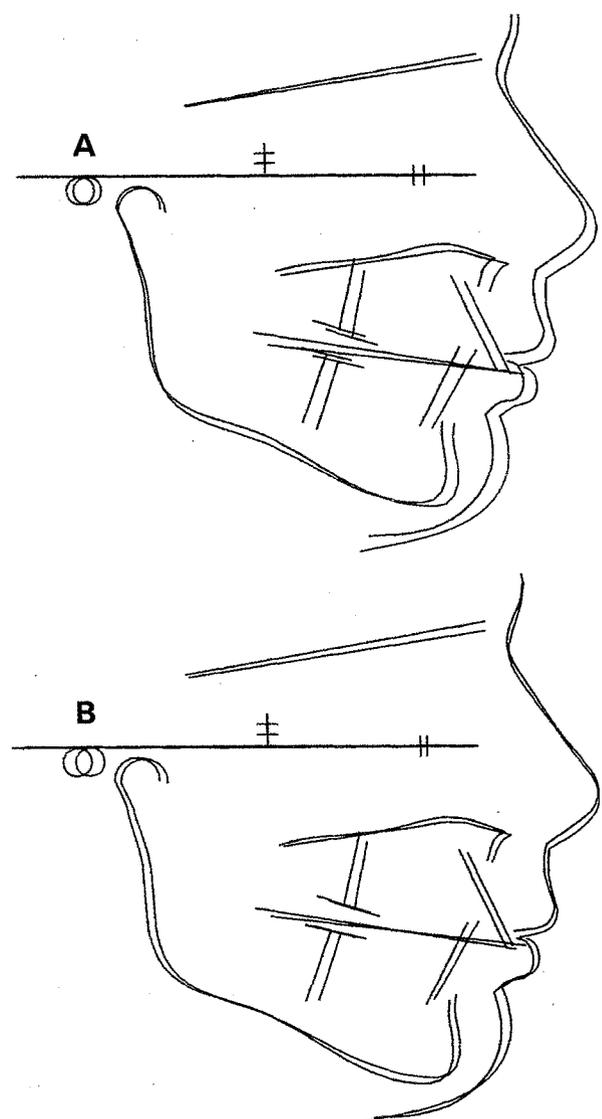
Although the discriminant function employed only three variables, it identified two groups of Class II patients whose faces were morphologically similar before treatment (Tables II and III; Fig. 3, B). Despite having been subjected to different regimens, the two groups were essentially identical



**Fig. 5.** Posttreatment tracings—borderline group averages. **A**, Unadjusted. **B**, One-stage patients enlarged 1% to compensate for residual age differences of 6 months.

at the end of treatment (Tables IV and V; Fig. 5, *A*). Indeed, although the two-stage patients started a year earlier, they were on average 6.5 months older (and thus a bit larger) at the end of treatment. As may be seen in Fig. 5, *B*, after a 1% enlargement of the one-stage average (a transformation whose size was inferred from the descriptive data of Table IV), the group tracings superimpose almost exactly.

Treatment effects inferred from regional superimposition are summarized in Table VI. Because the two-stage treatments took, on average, a year and a half longer, Table VII shows the various treatment effects expressed as yearly rates. With



**Fig. 6.** Pretreatment tracings—group averages for one- and two-stage patients lost to extraction or surgery. **A**, Unadjusted. **B**, Two-stage patients enlarged 3% as in Fig. 3 to compensate for residual age-differential.

respect to the molar and overjet corrections, the single phase edgewise treatment proved significantly more “efficient.” Finally, as may be seen in Tables VIII and IX, the functional phase of the two-stage treatments was responsible for the majority of the molar correction; the remainder of the treatment effects were approximately evenly divided between stages.

## DISCUSSION

### Experimental design

On the basis of the discriminant function (and the testimony of clinician who treated the patients),

**Table III.** Borderline subsamples: Descriptive and inferential statistics for selected pretreatment study-model measures

Measure	SD <sub>E</sub> (n = 22)	2-stage (n = 25)		1-stage (n = 28)		t
		Mean	SD	Mean	SD	
<i>Arch length</i>						
Maxilla	0.5	73.0	4.9	74.2	4.8	-0.89
Mandible	0.3	61.5	5.3	63.5	4.3	-1.41
<i>Arch depth</i>						
Maxilla	0.3	29.9	2.2	29.6	2.9	0.40
Mandible	0.2	24.5	1.7	24.8	2.2	0.62
<i>Available space</i>						
Maxilla	1.1	76.4	4.5	77.7	5.0	-0.98
Mandible	0.5	67.0	3.6	68.2	5.0	-0.97
<i>Inter canine width (3-3)</i>						
Maxilla	0.5	29.4	1.9	30.5	3.1	-1.50
Mandible	0.2	24.7	1.9	24.9	2.3	0.34
<i>Inter premolar width (5-5)</i>						
Maxilla	0.4	39.6	2.4	41.5	3.4	-2.30*
Mandible	0.3	36.3	2.1	37.1	2.7	-1.13
<i>Inter molar width (6-6)</i>						
Maxilla	0.4	45.0	2.1	46.7	3.6	-2.12*
Mandible	0.4	41.6	2.0	42.6	3.3	-1.22
<i>Irregularity index</i>						
Mandible	0.6	5.7	4.3	4.8	1.8	1.00

\*p < 0.05.

it may be inferred that there was a tendency for younger patients with more severe malocclusions to be treated in two stages. In practice, however, it is likely that the treatment decisions were not quite so clear cut. Perhaps as a result, there was enough noise in the system to produce considerable overlap between groups (Fig. 1). Given this overlap, it was possible to delineate samples that were similar in terms of pretreatment facial form (Fig. 3) and thus relatively free of contamination by susceptibility bias.

Furthermore, all the patients who met the study's inclusion criteria were accounted for. An examination of those lost to extraction or surgery reveals no obvious morphologic differences that would serve to bias the outcome (Fig. 6). It must be emphasized, however, that nonextraction treatment proved inadequate in fully a quarter of the borderline subsamples. The present results come, therefore, from the most successful three quarters of a slightly trimmed sample and thus probably represent something of an overstatement of the "management" potential of both forms of nonextraction treatment.

Finally, all our patients were treated by a single experienced clinician, presumably with a common degree of skill and diligence, both in executing the treatment and in documenting its outcome. We

must emphasize, however, that we cannot specify the extent to which this common level of clinical proficiency and the specific clinical methods and goals used here are comparable to those of an "average" practitioner faced with the management of an "average" Class II patient. In other words, we do not know the extent to which the present results can be generalized. All we can say is that our design generates between-treatment comparisons that are relatively bias free and thus of potential clinical interest to the specialty.

#### Treatment comparisons

At the completion of treatment, the two groups were essentially identical. Ultimately, there was no significant cephalometric and study-model differences, and the two groups underwent almost identical molar and overjet corrections. Tooth movement served to correct irregularity, but commonly contributed little, if anything, to the improvement of anteroposterior dental relationships. For both treatments, the source of these changes was differential jaw growth (ABCH), the magnitude of which was significantly greater in the two-stage patients. This finding, however, is misleading, given that the two-stage treatments, on average, took more than a year and a half longer to complete. Clearly, one way to see a lot of growth is to treat a long time. Given

**Table IV.** Borderline subsamples: Descriptive and inferential statistics for selected posttreatment cephalometric and demographic variables

Measure	2-stage (n = 25)		1-stage (n = 28)		t
	Mean	SD	Mean	SD	
<i>Maxillary position</i>					
SNA	81.1	4.4	80.6	2.7	0.49
A-Na Vertical	-2.3	4.8	-2.6	3.0	0.36
<i>Maxillary size</i>					
PNS-A	53.1	3.0	52.5	2.4	0.80
<i>Mandibular position</i>					
SNB	77.3	3.7	77.4	2.3	-0.12
Y-axis	56.3	2.1	55.7	3.6	0.78
B-NA vertical	-10.1	6.5	-9.7	4.2	-0.26
Po-NaB	2.3	1.5	2.5	2.0	-0.35
Po-Na vertical	-9.3	7.6	-8.7	5.3	-0.34
S-Ar	36.9	3.7	35.9	3.1	1.11
<i>Mandibular size</i>					
Ar-Gn	114.3	7.0	112.3	5.2	1.17
Co-Gn	121.4	7.3	119.7	5.2	1.02
<i>Maxillary dentition</i>					
U1-SN	102.3	5.6	104.5	4.9	-1.52
U1-NA	21.2	6.6	23.9	5.0	-1.70
U1-NA	2.3	2.6	3.0	1.8	-1.15
PTV-U6	15.7	3.8	15.1	3.7	0.64
<i>Mandibular dentition</i>					
L1-NB	28.5	5.2	27.2	5.7	0.86
FMIA	59.8	6.0	60.9	6.9	-0.60
IMPA	98.2	5.7	97.6	6.9	0.35
L1-APo	1.5	1.7	1.8	1.6	-0.63
L1-NB	5.0	2.0	4.8	2.1	0.26
<i>Maxillomandibular relationship</i>					
ANB	3.8	1.8	3.2	1.9	1.19
1 to 1	126.6	7.8	125.8	5.6	0.43
Wits (FOP)	1.9	1.9	1.0	1.8	1.77
OJ (FOP)	3.0	0.8	2.9	0.9	0.62
OB (FOP)	2.1	1.1	1.7	1.1	1.17
Molar relation	1.8	1.3	2.3	1.3	-1.55
<i>Vertical</i>					
SN-PP	8.9	3.2	8.5	2.5	0.49
SN-FOP	16.2	4.0	16.3	3.3	-0.02
FMA	22.0	4.0	21.5	5.8	0.32
S-Go	77.1	6.7	76.0	6.1	0.62
N-ANS	55.9	3.3	55.2	3.7	0.82
ANS-Me	69.7	6.7	67.8	6.8	1.06
N-Me	123.9	7.6	121.3	7.4	1.22
<i>Profile</i>					
Nasolabial angle	117.8	9.4	115.8	8.1	0.81
Upper Z angle	76.9	4.4	77.6	5.7	-0.49
L lip-E plane	-2.7	2.5	-2.7	2.3	-0.08
Age	14.5	1.5	14.0	1.1	1.50

the marked difference in treatment time, it would seem appropriate to examine the efficiency of the two strategies by analyzing treatment change expressed on a per-year basis.

As may be seen in Table VII, the yearly rates of change for skeletal improvement (ABCH), molar correction, and overjet reduction favor single-phase edgewise. Indeed, even when the functional phase

**Table V.** Borderline sample: Descriptive and inferential statistics for selected posttreatment study-model measures

Measure	2-stage (n = 25)		1-stage (n = 28)		t
	Mean	SD	Mean	SD	
<i>Arch length</i>					
Maxilla	70.6	3.7	72.1	3.8	-1.41
Mandible	60.1	3.4	60.8	3.3	-0.76
<i>Arch depth</i>					
Maxilla	27.4	1.8	27.8	1.7	-0.77
Mandible	22.8	1.9	23.1	1.5	-0.67
<i>Available space</i>					
Maxilla	75.4	3.9	76.8	4.1	-1.23
Mandible	64.5	3.5	65.8	3.4	-1.24
<i>Inter canine width (3-3)</i>					
Maxilla	32.2	1.8	32.8	2.2	-1.12
Mandible	24.9	1.3	25.1	1.8	-0.26
<i>Inter premolar width (5-5)</i>					
Maxilla	42.7	2.0	44.0	3.0	-1.65
Mandible	36.3	2.0	36.9	2.4	-0.89
<i>Inter molar width (6-6)</i>					
Maxilla	47.2	2.2	48.4	3.5	-1.50
Mandible	41.9	2.1	42.7	2.8	-1.06
<i>Irregularity index</i>					
Mandible	2.4	2.0	2.4	1.7	-0.02

of the two-stage treatment is compared with single-phase edgewise, the difference in mandibular advancement relative to cranial base (2.9 and 2.4 mm per year, respectively) is not statistically significant. Both rates, however, are somewhat higher than the 1.7 to 1.8 mm per year reported for untreated controls,<sup>18</sup> a finding that agrees with earlier claims<sup>9</sup> that both fixed and functional appliances may produce a slightly elevated rate of mandibular advancement. Our use of the word *advancement* rather than *growth* acknowledges the obvious fact that the present method of regional superimposition cannot distinguish between mandibular growth and bodily functional shifts.

Examination of the raw data for Co-Gn, a direct measure of mandibular length, implies that during the functional-appliance phase there was a slightly greater rate of mandibular growth (3.2 mm per year;  $p < .05$ ) than that seen during the one-stage edgewise treatments (2.3 mm per year). As has been noted, however, this 0.9mm per year of extra growth did not have a comparable differential impact on symphyseal advancement measured parallel to the mean functional occlusal plane (0.5 mm, nonsignificant). McNamara and associates<sup>19</sup> have reported similar findings: Increases in the rate of mandibular growth of 1.2 and 1.8 mm per year in

two Fränkel appliance samples resulted in a lesser rate of advancement of pogonion (relative to nasion vertical, 0.7 and 1.3 mm per year, respectively). Of greater significance, however, is the question of whether the present two-stage treatment, as a whole, produces mandibular growth effects that go beyond those seen during a single-phase edgewise treatment.

Ultimately, there were no significant between-means differences in mandibular length (Co-Gn), both in terms of annual rate (two-stage, 2.6 mm per year; single-stage, 2.3 mm per year) and final size (Table IV). Further, the two groups did not differ in terms of the overall rate of symphyseal advancement during treatment (Mand, Table VII). However, Mand showed a significant between-stage difference: 2.9 mm per year during the functional phase and 1.6 mm per year during the fixed phase (Table IX). Thus, it can be hypothesized that the bionator phase produced a measurable anterior functional shift and that condylar growth in the second phase (proceeding at a relatively constant rate) served gradually to re-establish condyle-fossa relationships without contributing to a comparable advancement of the chin. In support of this interpretation, it should be noted that the rate of increase in mandibular length (Co-Gn) was 3.2 mm

**Table VI.** Overall treatment change for the skeletal and dental components of the molar and overjet corrections

Measure	$SD_E$ ( $n = 13$ )	2-stage ( $n = 25$ )		1-stage ( $n = 28$ )		$t$
		Mean	SD	Mean	SD	
<i>Skeleton</i>						
Maxilla (max)	0.7	-2.4	1.7	-1.4	1.1	-2.53**
Mandible (mand)	1.0	8.2	4.1	5.9	1.8	2.73**
Apical base change (ABCH)	0.7	5.8	2.8	4.5	1.5	2.19*
<i>Dentition</i>						
U6 relation to max						
Bodily	0.6	-1.2	1.7	-0.6	2.3	-1.01
Tipping	0.9	-1.2	1.5	-0.0	2.0	-2.45*
Total	0.3	-2.4	1.9	-0.7	1.8	-3.45**
L6 relation to mand						
Bodily	1.1	2.7	2.1	2.2	1.9	0.90
Tipping	1.1	-2.0	2.7	-1.9	2.1	-0.07
Total	0.6	0.7	1.6	0.3	1.4	1.08
U1 relation to max	0.5	0.5	2.8	1.2	1.9	-1.09
L1 relation to mand	0.6	-1.3	2.2	-0.9	1.8	-0.81
<i>Total correction</i>						
Molar (6 6)	0.5	4.1	1.9	4.1	1.6	0.01
Overjet (1 1)	0.6	5.0	2.2	4.8	2.1	0.26
<i>Treatment time</i>	—	49.5	16.7	30.9	9.5	5.06**

\* $p < 0.05$ ; \*\* $p < 0.01$ .**Table VII.** Treatment efficiency (change per year) for the skeletal and dental components of the molar and overjet corrections

Measure	2-stage ( $n = 28$ )		1-stage ( $n = 25$ )		$t$
	Mean	SD	Mean	SD	
<i>Skeleton</i>					
Maxilla (max)	-0.5	0.3	-0.5	0.5	-0.19
Mandible (mand)	2.0	0.7	2.4	0.8	-1.93
Apical base change (ABCH)	1.5	0.6	1.9	0.8	-2.29*
<i>Dentition</i>					
U6 relation to max					
Bodily	-0.3	0.4	-0.2	0.9	-0.16
Tipping	-0.3	0.5	0.0	0.8	-1.88
Total	-0.6	0.4	-0.2	0.7	-2.30*
L6 relation to mand					
Bodily	0.7	0.6	0.9	0.8	-1.08
Tipping	-0.4	0.8	-0.9	0.9	1.87
Total	0.3	0.5	0.0	0.5	1.56
U1 relation to max	0.2	0.7	0.5	0.9	-1.23
L1 relation to mand	-0.3	0.6	-0.4	0.8	0.70
<i>Total correction</i>					
Molar (6 6)	1.2	0.8	1.8	0.9	-2.54*
Overjet (1 1)	1.4	1.0	2.0	0.9	-2.23*

\* $p < 0.05$ .

per year in the functional phase and 2.6 mm per year in the fixed phase; the difference was nonsignificant. Thus our data support Korkhaus' earlier explanation of the mode of action of the activator

in correcting Class II molar relationships.<sup>20</sup> It also matches Wieslander's characterization of the relationship between mandibular changes occurring during<sup>21</sup> and after Herbst-appliance therapy (see

**Table VIII.** Two-stage treatment: Treatment change by stages for the skeletal and dental components of the molar and overjet corrections (n = 21)

Measure	First stage		Second stage		t
	Mean	SD	Mean	SD	
<i>Skeleton</i>					
Maxilla (max)	-1.2	1.0	-1.2	1.2	0.12
Mandible (mand)	4.7	2.3	3.7	2.9	1.23
Apical base change (ABCH)	3.5	1.8	2.5	2.1	1.69
<i>Dentition</i>					
U6 relation to max					
Bodily	-0.5	1.4	-0.9	1.5	0.86
Tipping	-0.4	1.5	-1.0	1.5	1.34
Total	-0.9	1.6	-1.9	1.5	2.10*
L6 relation to mand					
Bodily	1.2	1.2	1.5	1.6	-0.73
Tipping	-1.1	1.3	-1.0	1.9	-0.20
Total	0.1	1.1	0.6	1.0	-1.28
U1 relation to max	-0.0	1.6	0.2	2.4	-0.34
L1 relation to mand	-0.5	1.2	-0.7	1.6	0.47
<i>Total correction</i>					
Molar (6 6)	2.8	2.1	1.2	1.5	-2.84**
Overjet (1 1)	3.0	1.8	1.9	2.3	1.61
Treatment time (mo)	23.6	12.4	29.0	12.3	-1.44

\*p < 0.05; \*\*p < 0.01.

**Table IX.** Two-stage treatment: Rate of treatment change (per year) by stages for the skeletal and dental components of the molar and overjet corrections (n = 21)

Measure	First stage		Second stage		t
	Mean	SD	Mean	SD	
<i>Skeleton</i>					
Maxilla (max)	-0.6	0.6	-0.5	0.4	-0.95
Mandible (mand)	2.9	1.8	1.6	1.2	2.81**
Apical base change (ABCH)	2.3	1.6	1.1	0.9	2.87**
<i>Dentition</i>					
U6 relation to max					
Bodily	-0.0	0.9	-0.4	0.6	1.54
Tipping	-0.3	1.3	-0.4	0.6	0.33
Total	-0.4	1.1	-0.8	0.6	1.71
L6 relation to mand					
Bodily	0.8	1.3	0.7	0.8	0.16
Tipping	-0.7	1.1	-0.4	0.7	-0.74
Total	0.1	0.7	0.3	0.5	-0.91
U1 relative to max	0.1	1.1	0.0	0.8	0.26
L1 relative to mand	-0.1	0.8	-0.3	0.8	0.89
<i>Total correction</i>					
Molar (6 6)	2.1	2.3	0.6	0.6	2.83**
Overjet (1 1)	2.1	2.3	0.8	0.8	2.61*

\*p < 0.05; \*\*p < 0.01.

his Fig. 3, B).<sup>22</sup> More to the point, our findings mirror the negative outcomes of several recent studies of the long-term effect of the Herbst appliance on mandibular growth.<sup>22,23</sup> The fact that some functional-appliance advocates now emphasize the

midface rather than the mandible<sup>22,24</sup> implies a need to re-evaluate the role of growth modification, especially mandibular growth modification, in contemporary dental practice.

Our particular failure to detect any major treat-

ment differences, it must be noted, comes from an analysis of the patients whose discriminant scores made up the central 75% of the parent sample, not from those on either end of the distribution. At one extreme, this exclusion is probably of little significance, given that two-stage treatments are less commonly used in older patients with milder Class II malocclusions. At the other extreme, however, one finds the young, severe 10% to 15% for whom growth modification would be most desirable and who, perhaps as a result, are most likely to be treated in two stages. Thus, despite the present data, many probably still would use a functional-appliance phase in severely affected patients. Although an effect that can be detected only in the severely affected patient would represent a biologically inexplicable discontinuity, growth modification in patients with severe Class II malocclusions perhaps warrants further investigation. The present results, however, are not encouraging.

In addition to taking 18 months longer, the two-stage treatments averaged 10 more appointments, although the overall appointment rate (13 per year) was lower than for the single-phase edge-wise (17 per year). This difference was due to a more leisurely pace during the functional phase of treatment. Therefore, for a few years, a practice can accommodate more two-stage patient starts. However, because finishing them will ultimately take more time and require more appointments, this initial advantage would soon be lost. Moreover, because the two-stage treatment times were significantly more variable ( $SD = 16.7$  months vs 9.5 months;  $F = 3.1$ ,  $p < 0.01$ ), early treatment may represent something of a challenge to the orderly management of a busy practice.

For the average orthodontist, a bit of disorder and some extra time may not be a problem. In the event of a generalized increase in "busyness," however, it remains to be seen whether two-stage treatments would continue to compete successfully for orthodontic favor against what may well be equally good, but more efficient and predictable, alternatives. Although the question seems to be self-answering, things are rarely so simple. We suspect that the decision to use functional appliances is fundamentally a practice-management problem whose solution will probably come neither from the world of biology nor the data of this investigation. Further discussion therefore would seem beside the point.

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