

ORIGINAL ARTICLES

*A long-term comparison of nonextraction and  
premolar extraction edgewise therapy in "borderline"  
Class II patients*

David E. Paquette, DDS, MS, MSD,<sup>a</sup> John R. Beattie, DDS, MSD,<sup>b</sup> and  
Lysle E. Johnston, Jr., DDS, MS, PhD<sup>c</sup>

Charlotte, N.C., Orlando, Fla., and Ann Arbor, Mich.

The long-term effects of extraction and nonextraction edgewise treatments were compared in 63 patients with Class II, Division 1 malocclusions who were identified by discriminant analysis as being equally susceptible to the two strategies. A lateral cephalogram, study models, and a self-evaluation of the esthetic impact of treatment were obtained from each of the 33 extraction and 30 nonextraction subjects. The average posttreatment interval was 14.5 years. Although the two strategies produced significant, long-lived differences in the convexity of the profile and the protrusion of the dentition (the nonextraction patients were about 2 mm "fuller"), half of the nonextraction patients and three fourths of the extraction patients ultimately presented with less than 3.5 mm of lower incisor irregularity. The two groups showed an essentially identical pattern of posttreatment relapse/settling that was related more to the differential growth of the jaws than to the posttreatment position and orientation of the denture. Because in the end the various tooth movements tended to cancel one another, excess mandibular growth was also the most important net contributor to the molar and overjet corrections. In the process, both groups showed a marked forward displacement of the mandible, both at the chin and at the condyle. Finally, although it is probable that most of the present sample would today be treated by expansion, the 30 patients who actually received this presumably correct treatment rated their appearance no more highly than did the extraction subjects. On balance, our data provide little support for the popular concept of a single stable incisor angulation and for the troublesome claims that premolar extraction—as opposed to expansion and bite-jumping—must of necessity produce distal mandibular displacement and, in the process, flatten the profile enough to "ruin the face." (AM J ORTHOD DENTOFAC ORTHOP 1992; 102:1-14.)

Orthodontics is a mature specialty. The appliances and strategies that are presently used are the products of nearly 100 years of natural selection at the

hands of dentistry's best and brightest. Unfortunately, many of our nonorthodontic colleagues do not share our satisfaction with the product that has evolved. As part of an exceptionally unpleasant turf war, they have formed what amounts to a parallel universe predicated on treatments and theories that run counter to our collective experience. Crowding? Expand ad libitum; strip every tooth; split the premaxillomaxillary suture. You say human beings don't have one? On second thought, people look better if their teeth stick out. Besides, incisor retraction causes TMD. Class II malocclusion? Bite forward—forever. Moreover, the orthodontic counter-culture appears disconcertingly eager to indict, often in a court of law, the basic strategies that are the

From the Department of Orthodontics, St. Louis University Medical Center. Based in part on theses submitted in partial fulfillment of the degree of master of science in dentistry. Dr. Paquette was the recipient of the Milo Hellman Award for 1991; Dr. Beattie, an Award of Special Merit for the same year. Supported in part by NIDR grant DE08716 and by donations from the Orthodontic Education and Research Foundation (St. Louis) and various friends of the Department.

<sup>a</sup>In private practice, Charlotte, N.C.

<sup>b</sup>In private practice, Orlando, Fla

<sup>c</sup>Professor and Chairman, Department of Orthodontics and Pediatric Dentistry, School of Dentistry, The University of Michigan, Ann Arbor, Mich.

8/1/28171

hallmark of the contemporary orthodontic specialist.

It is argued, for example, that premolar extraction is so likely to "dish in" the profile and cause posterior mandibular displacement that it is almost always an inappropriate strategy, regardless of the tactics chosen to prosecute it (e.g., slot size, bracket prescription, method of space closure, type of anchorage preparation).<sup>1,2</sup> Spearheaded by the occasional lawsuit, this attack has proved remarkably successful, despite an almost complete lack of support in the refereed literature (see, for example, Drobocky and Smith<sup>3</sup>). Indeed, it is as if Tweed and Strang never drew a breath: our extraction rate is shrinking,<sup>4,5</sup> and techniques that most of us have only read about in history books (e.g., expansion and bite jumping) are now seen and sold as important advances, if not for the treatment of patients, at least for the "management" of risk.

It is one thing to make florid claims; it is quite another to generate supporting data. Unfortunately, if one were to attack what seems to be the crux of the issue by comparing the results of extraction and non-extraction therapy, the results would be hopelessly compromised by susceptibility bias: patients treated one way tend at the outset to differ from those treated another.<sup>6-8</sup> Significant long-term differences would therefore defy interpretation. Moreover, the problem is not easily (or ethically) amenable to the time-honored technique of random treatment assignment.<sup>9-11</sup> A randomized trial must start with an honest null hypothesis: there must be true uncertainty as to the better treatment.<sup>12</sup> Most patients, however, are susceptible only to a single treatment; in the face of an informed decision to treat, side effects may well be beside the point.

For example, given a choice between brain surgery and a haircut, most would choose a haircut; however, if you have a slowly growing brain tumor, you are uniquely susceptible to surgery, regardless of its risks. In this context, a blanket condemnation of surgery by enthusiasts of the tonsorial arts would constitute an irresponsible threat to the public health. Similarly, although many dentists and perhaps even a few specialists might disagree, there are some patients whose teeth are so crowded and protrusive that they can only be treated by extraction. As a result, a comparison between extraction and nonextraction treatments can have meaning only for the borderline patient, the patient who is uniquely susceptible to neither treatment and who thus can be treated either way.

Given the ethical requirement that there be uncertainty, it is possible to devise a number of prospective strategies by which treatments are assigned at random

to a sample of borderline patients. If properly designed, such a study would not only minimize susceptibility bias, but would also control for the other biases (e.g., detection, transfer, and proficiency) that often compromise the outcome of a clinical study.<sup>6</sup> Unfortunately, this approach features two major drawbacks: (1) it is doubtful that many would consent to the extraction of premolars were they fully informed that the investigators had determined that nonextraction therapy would work equally well, and (2) an adequate period of post-retention observation (e.g., a decade or so) would almost certainly be accompanied by severe sample attrition, not to mention the probable obsolescence of the original question.

One way to circumvent these problems is to employ a so-called "retrolective-prolective" design<sup>6</sup> in which the admission criteria are similar to those of a comparable prospective trial. As noted by Feinstein:

If all of the important variables that affect a clinician's choice of treatment have been suitably arranged in the prognostic subgroups. . . and if treatments are appraised within these subgroups, the comparisons of nonrandomized treatment should be relatively free from bias.<sup>10</sup>

It will therefore be the purpose of this article to define the anatomic basis of the extraction decision, to use the resulting decision rule to select and recall a sample of borderline patients who had been treated 10 to 20 years ago, and then to compare the long-term stability and esthetic impact of the two strategies.

## PATIENTS AND METHODS

After approval of the present protocol by the Institutional Review Board (IRB) of St. Louis University Medical Center, at least five attempts were made to contact all Class II, Division 1 first premolar extraction and nonextraction edgewise patients treated at St. Louis University between 1969 and 1980 to determine their willingness to return for follow-up records. Because of the passage of 10 to 20 years since the completion of treatment, most could not be reached; however, a total of 238—about one out of every nine patients—agreed to participate. These potential subjects were told that they would be contacted for follow-up records should they meet the empirical admission criteria that would be generated from their initial records.

### Identification of borderline stratum: Discriminant analysis

Given that the goal of the present study was to compare the effects of extraction and nonextraction therapy only in the subset of patients for whom there was empirical evidence of uncertainty, it was necessary to define the extraction/nonex-

**Table 1.** Sample description

Group	Males	Females	Average age (yrs.)		
			Start	Finish	Recall
Extraction	13	20	12.53	14.37	28.78
Nonextraction	19	11	12.60	14.20	28.69

traction "gray area" and then use this information to identify the patients who would actually be recalled. To this end, discriminant analysis\* was used to characterize the anatomic basis of the extraction decision as employed by the clinicians who did the treatment planning.

The data† that fueled the discriminant analysis were obtained from each patient's initial lateral cephalogram and study models (photocopies magnified 21.5%). The key elements of the present cephalometric analysis are summarized in Fig. 1. The model analysis featured standard measures of individual tooth size, arch width (at the canines, second premolars, and first molars), arch length (in two segments, 6-1-6,<sup>13</sup> and four, 6-3-1-3-6), discrepancy (based on the four-segment measure of arch length), lower anterior irregularity,<sup>13</sup> and arch symmetry (separate measures of right and left dental arch width taken relative to the midline). Our goal was to obtain some measure of almost any characteristic that could have been used to arrive at the extraction decision. Of the 89 independent variables that resulted, a linear combination of six, maxillary crowding and protrusion; mandibular crowding, protrusion, and irregularity; and profile convexity, provided a highly significant ( $p < 0.01$ ) discrimination between the 132 extraction and the 106 nonextraction patients. In standardized form, the discriminant function then was used to generate "confounder summarizing" discriminant scores for each of the 238 subjects (Fig. 2).<sup>14</sup> Note that extraction patients tend to have negative scores; nonextraction patients, positive. The larger the absolute value of the discriminant score, the higher the probability that, in practice, only one of the two alternatives would actually be employed. Scores close to zero, however, would be indicative of patients whose malocclusions could have been treated either way and whose follow-up data therefore would support a meaningful between-strategy comparison.

Attempts were then made to recall the 48 extraction and 48 nonextraction patients whose standardized discriminant scores lay within about one standard deviation of zero. Of these 96 former patients, 16 could not be recontacted, 9 reversed their original decision to participate, 4 failed their appointments, 2 had become pregnant, and 2 had gaps in their

initial records. The remaining patients, 30 nonextraction and 33 extraction, signed an IRB-approved consent form and returned for lateral cephalograms, study models, and self-assessments of their perception of the esthetic impact of treatment (Table 1). The average posttreatment interval was about 14.5 years (range, 9 to 20 years).

The extent to which the discriminant functions led to the recall of structurally comparable samples (i.e., subjects relatively free of susceptibility bias) may be judged from the superimposed tracings of the group averages\* depicted in Fig. 3 and the descriptive statistics for the initial values of the various cephalometric and study model variables summarized in Table II (the variables used in the discriminant function are numbered 1 through 6 in italics).

### Cephalometric analysis

For each patient, the posttreatment and recall lateral cephalograms were subjected to the same descriptive analysis that was used in the initial discriminant analysis. The main goal of this analysis was to characterize the skeletal, dental, and soft tissue changes that occurred, both during and after treatment. In addition, detailed regional superimposition was employed to quantify the source of the correction/relapse of the molar relationship and overjet. Although this analysis has been described elsewhere,<sup>15</sup> a brief description is, perhaps, in order.

On the basis of the guidelines developed in Björk's laboratory,<sup>16-18</sup> cranial base, maxillary, and mandibular regional superimposition was used to measure the displacement (as a result of growth, orthopedic changes, or functional shifts) of maxillary and mandibular basal bone relative to cranial base and the movement of the molars and the incisors relative to basal bone. Each landmark was transferred throughout the entire series from the film on which it could best be seen. For example, if SE (the intersection of the averaged greater wings and the sphenoid planum) could be seen most clearly on the posttreatment film, anterior cranial base superimposition on common structures from the anterior margin of sella turcica to foramen cecum was used to carry the point through to both the initial and recall tracings. From the maxillary superimposition, the anteroposterior growth of the maxilla (MAX) was estimated by measuring the distance between SE points, the differential growth and/or functional shift of the mandible relative to maxilla (ABCH) was measured as the

\*Subprogram, DISCRIMINANT, Statistical Package for the Social Sciences, version 3.1 (SPSS, Inc., Chicago, IL) running on a VAX 6210 minicomputer (Digital Equipment Corp., Nashua, N.H.).

†Digitized with a transparent digitizing pad (Scriptel RDT-1212, Scriptel Corp., Columbus, OH) and a commercial cephalometric program (Dentofacial Planner, version 4.22A, Dentofacial Software, Toronto, Canada).

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

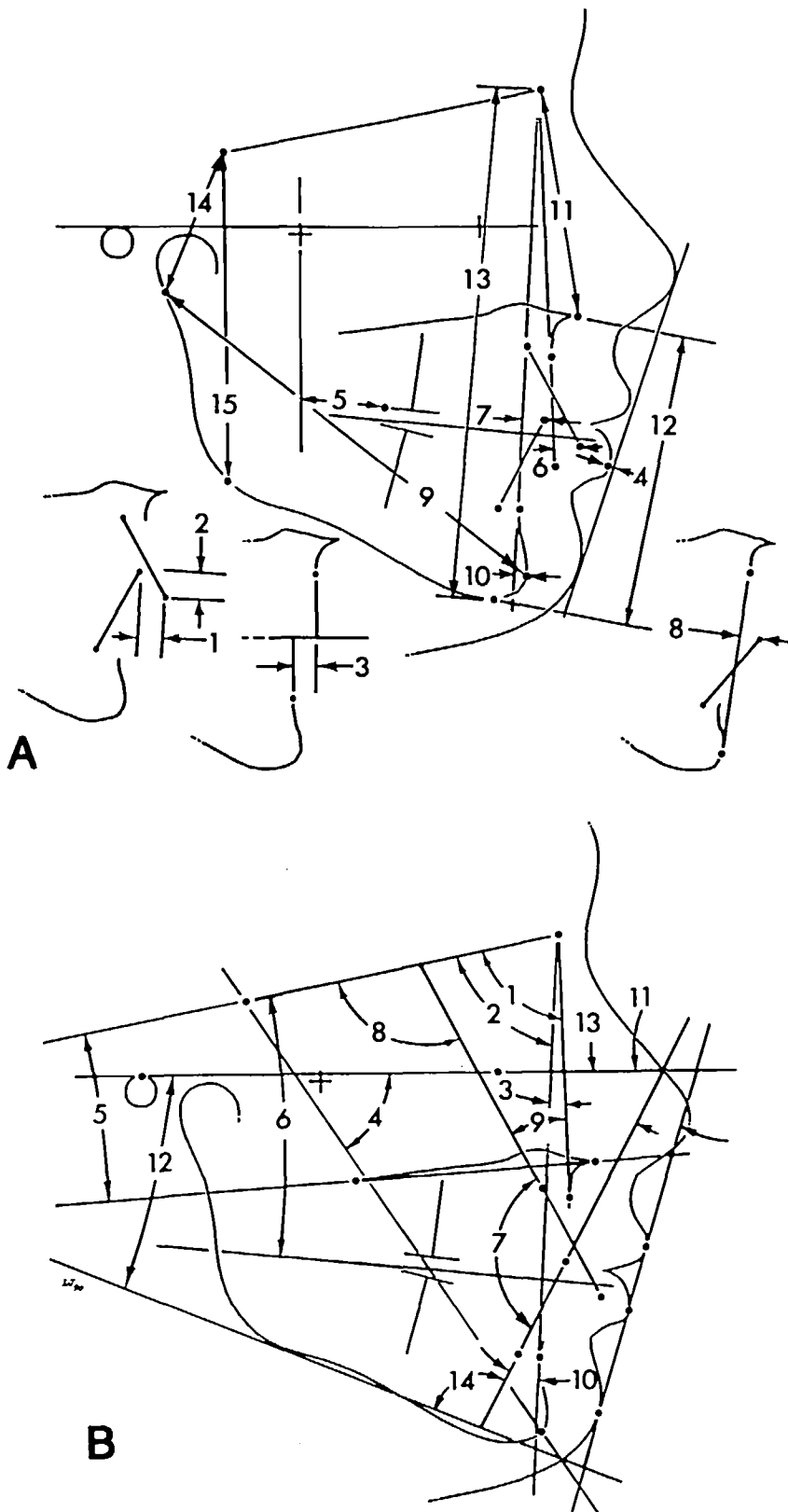
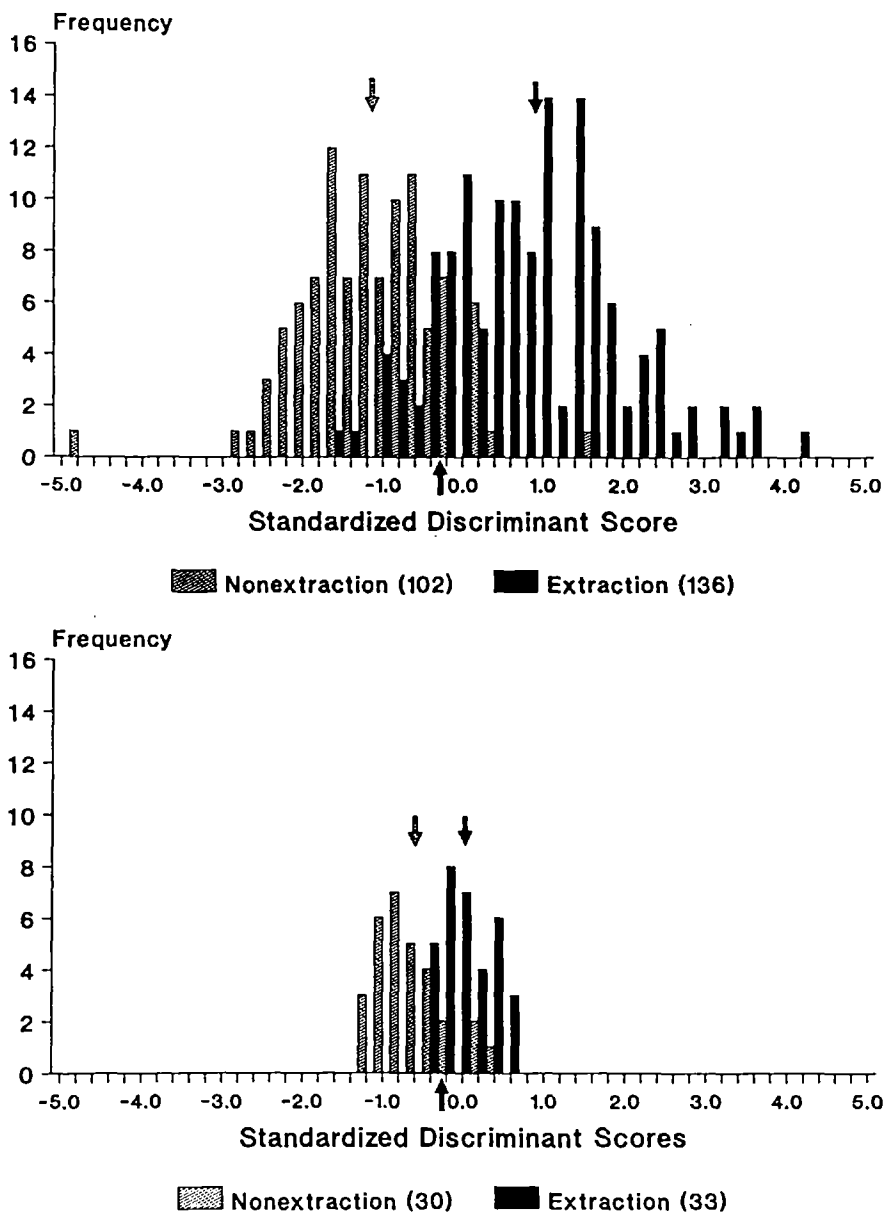


Fig. 1. Cephalometric analysis. A, linear measures; B, angular measures. The numbered measures correspond to the enumeration of Table II (first column).

### Class II Edgewise



**Fig. 2.** Standardized discriminant scores. Top, parent samples; bottom, borderline subsamples. Note that the recalled subjects came from the area of overlap between the two parent samples and thus represent patients for whom there is empirical evidence of uncertainty.

distance between D points, and the movement of the maxillary central incisors (U1) and the first molars (U6) was determined by measuring the distance between averaged (right/left) mesial contact points and incisal edges. Similarly, mandibular tracings from adjacent films were superimposed (mean functional occlusal plane orientation, D point registration) and the movement of the lower molars (L6) and the incisors (L1) was measured by taking the distance between averaged mesial contacts or incisal edges on adjacent films. In addition, molar

movement was broken down into a bodily component (the displacement of a point bisecting the molar apices) and a tipping component calculated by subtracting the movement of the apices from the movement of the averaged mesial contact points.

Each measurement was executed parallel to the mean functional occlusal plane (MFOP; initial/recall average) and was given a sign appropriate to its impact on the molar or the overjet correction: positive, if it improved the relationships

**Table II.** Start, finish, and recall: Descriptive and inferential statistics for representative cephalometric and study-model measurements

No.	Measure	Start			Finish			Recall		
		Extraction	Nonextraction	<i>t</i>	Extraction	Nonextraction	<i>t</i>	Extraction	Nonextraction	<i>t</i>
<i>Linear (mm)</i>										
1.	Overjet	7.9	7.7	ns	2.8	3.0	ns	4.8	4.3	ns
2.	Overbite	3.9	3.2	ns	1.3	1.3	ns	3.6	2.6	ns
3.	Wits A/B	3.2	2.3	ns	0.4	-0.3	ns	1.7	1.0	ns
4.	Lip to E plane	-0.5	-1.1	ns	-3.6	-1.7	**	-5.9	-4.7	ns
5.	U6-PTV	18.7	18.8	ns	20.9	17.7	**	24.4	21.7	*
6.	UI-NA	5.3	5.5	ns	2.1	4.6	**	2.4	4.3	**
7.	L1-NB (1)	4.5	3.6	ns	3.9	5.7	**	2.7	4.0	*
8.	L1-APog	0.3	-0.1	ns	0.3	2.5	**	-1.3	0.8	**
9.	Ar-Gn	104.6	104.7	ns	109.0	110.2	ns	114.3	115.9	ns
10.	Pog-NB	2.4	2.8	ns	3.8	3.4	ns	4.7	4.0	ns
11.	N-ANS	51.5	50.9	ns	53.5	53.7	ns	55.6	55.6	ns
12.	ANS-Me	65.4	64.1	ns	68.4	67.9	ns	70.7	71.4	ns
13.	N-Me	115.1	113.4	ns	120.5	120.4	ns	124.8	125.8	ns
14.	S-Ar	34.5	33.4	ns	35.8	35.0	ns	37.9	37.1	ns
15.	S-Go	69.4	65.8	*	73.7	74.7	ns	78.8	81.8	ns
	Irregular index (2)	6.5	5.1	*	0.6	0.5	ns	2.9	3.4	ns
<i>Discrepancy</i>										
	Upper (3)	-1.7	-0.4	ns	-0.5	-0.3	ns	0.6	0.8	ns
	Lower (4)	-1.0	0.7	*	-0.1	-0.1	ns	0.4	0.1	ns
<i>Angular (degrees)</i>										
1.	SNA	80.8	80.4	ns	78.5	78.9	ns	79.3	79.5	ns
2.	SNB	75.8	76.3	ns	75.8	76.1	ns	76.0	77.0	ns
3.	ANB	5.0	4.1	ns	3.2	2.8	ns	3.3	2.6	ns
4.	Y axis	56.5	56.2	ns	57.3	57.1	ns	57.7	57.4	ns
5.	Pal. pl.-SN	7.5	7.0	ns	8.3	8.1	ns	7.9	7.7	ns
6.	Occlusal plane-SN	17.0	16.6	ns	19.2	18.5	ns	16.8	18.6	ns
7.	I/I	124.3	124.7	ns	130.8	122.7	**	137.3	131.2	**
8.	UI-SN (5)	106.6	107.3	ns	98.4	104.4	**	97.8	101.8	*
9.	UI-NA	25.8	27.0	ns	19.9	25.5	**	18.5	22.0	*
10.	L1-NB	24.9	24.2	ns	26.1	29.1	*	20.9	23.9	*
11.	Z angle (6)	73.4	74.4	ns	79.5	76.8	*	81.9	80.4	ns
12.	FMA	22.9	24.9	ns	23.3	22.9	ns	22.6	21.1	ns
13.	FMIA	62.1	62.1	ns	60.3	57.4	ns	65.7	62.7	ns
14.	IMPA	94.6	93.1	ns	96.4	99.7	ns	91.7	96.2	*

\**P* < 0.05.\*\**P* < 0.01.**Table III.** Dental-arch dimensions: means and *t* scores for between-treatment differences

Measure	Start			Finish			Recall		
	Extraction	Nonextraction	<i>t</i>	Extraction	Nonextraction	<i>t</i>	Extraction	Nonextraction	<i>t</i>
<i>Arch length<sup>13</sup></i>									
Maxillary	72.6	71.0	ns	61.0	72.7	**	58.7	69.5	**
Mandibular	60.6	60.3	ns	51.5	63.2	**	48.9	59.3	**
<i>Intercanine width</i>									
Maxillary	31.7	31.2	ns	32.6	32.0	ns	31.9	31.9	ns
Mandibular	24.2	24.8	ns	26.4	25.9	ns	25.2	25.3	ns
<i>Intermolar width</i>									
Maxillary	45.9	46.5	ns	45.8	49.3	**	45.0	49.0	**
Mandibular	41.6	43.3	*	41.0	45.1	**	41.2	45.8	**

\**P* < 0.05.\*\**P* < 0.01.

(as would be the case with mesial movement of the lower molar and incisors); negative, if it made them worse (e.g., forward growth of the maxilla or mesial movement of the upper dentition). The present sign convention is such that ABCH minus MAX serves as an estimate of mandibular (i.e., D point) movement relative to cranial base (MAND). More importantly, the various measurements of skeletal and dental change must add up to both the molar and the overjet corrections. For example, the algebraic sum of ABCH (i.e., MAX plus MAND) and molar movement relative to basal bone (U6 plus L6) is equal to the magnitude of the molar correction; the sum of the growth of the jaws and the movement of the incisors is equal to the overjet correction. Because of the technical difficulty of this part of the cephalometric analysis, all tracing, superimposition, and measurement was done by hand (with the aid of digital calipers); no digitization was employed.

Finally, the displacement of the condyle (C point, the center of the pretreatment condyle) was estimated by means of the technique of mandibular regional superimposition (mandibular canal, unerupted molars, symphysis) described by Björk.<sup>16,17</sup> This measurement was included to test the nettlesome argument that premolar extraction commonly displaces the condyles—that is, their “basal bone”—distally.

### Error study

With the aid of a table of random numbers, 10 three-film series (five extraction and five nonextraction) were selected and reanalyzed. 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 of the variables in the analysis.<sup>19</sup> For the general descriptive analysis, the 30 double determinations (10 series  $\times$  3 films) were obtained by digitization. U6-PTV had an  $SD_e$  of 1.6 mm; the remaining linear measures were all under 1 mm. With the exception of the Z angle (3°), the angular measures had an average  $SD_e$  of about 1°. For the hand done analysis of treatment change relative to the mean functional occlusal plane (20 double determinations—10 series  $\times$  2 increments), the various dental measures had  $SD_e$  less than 1 mm (0.4-0.9 mm). Moreover, measurements of skeletal change were almost as reliable: Maxilla, 0.64 mm; condyle (C point), 1.04 mm, ABCH, 1.06 mm; and Mandible, 1.33 mm. The results of this error study compare favorably with other estimates of technical error<sup>20,22</sup> and argue that the present analysis is sufficiently reliable to permit the resolution of between treatment differences that might be of clinical significance to the practicing orthodontists.

### Model analysis

The various measurements of arch length, arch width, discrepancy, and irregularity<sup>13</sup> that were used in the discriminant analysis were obtained as before from digitized photocopies of the occlusal surfaces of the posttreatment and recall models.

### Esthetic evaluation

At the recall appointment, each subject was shown a standard form that depicted, in random order, tracings of his

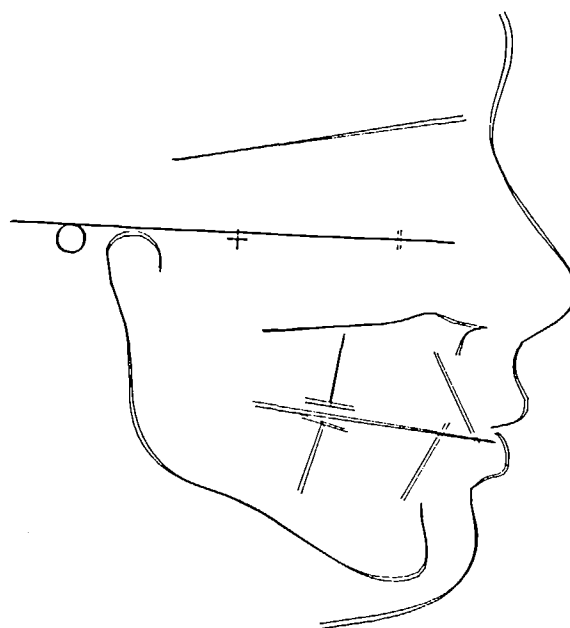
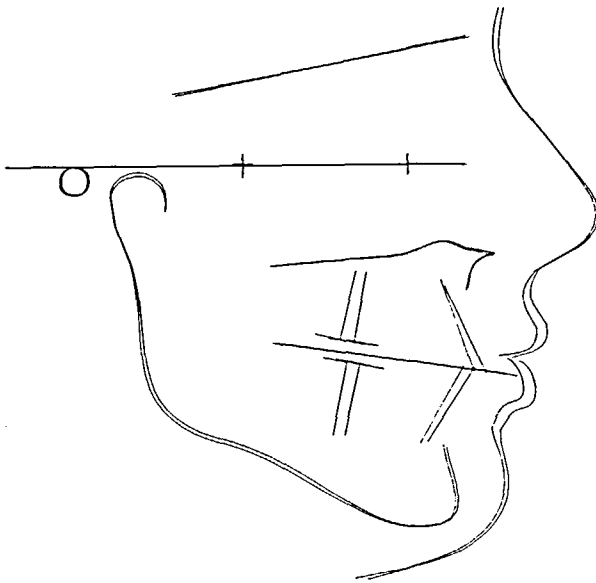


Fig. 3. Superimposition (FH at PTV) of averaged initial cephalometric tracings: red, extraction; blue, nonextraction. Note, on average, the two groups before treatment were essentially identical, both dentally and skeletally, even though they were chosen for recall on the basis of only six measures of dental crowding and protrusion.

or her pretreatment and posttreatment profiles. They were not told that the profiles were theirs (and few recognized them as such) or that the profiles were in any way related to their treatment. The subjects were asked to choose the better looking profile and then to quantify the strength of this preference by placing a mark on a visual analogue scale (VAS),<sup>21</sup> a 100 mm line<sup>24</sup> anchored on the left by “the same” and on the right by “very much better.” The distance between their mark and the left anchor was taken as an estimate of the effect of treatment on facial appearance (confounded, of course, with the impact of growth). The sign of the measurement reflected, the nature of the subject's choice: positive if the posttreatment profile was preferred and negative if the pretreatment profile was preferred. The subjects were then presented a second VAS form that featured their pretreatment and posttreatment frontal photographs and were again asked to express a preference and to mark the VAS in proportion to the strength of the preference. Obviously, in this instance, they were aware of the source of the photographs.

### Statistical analysis

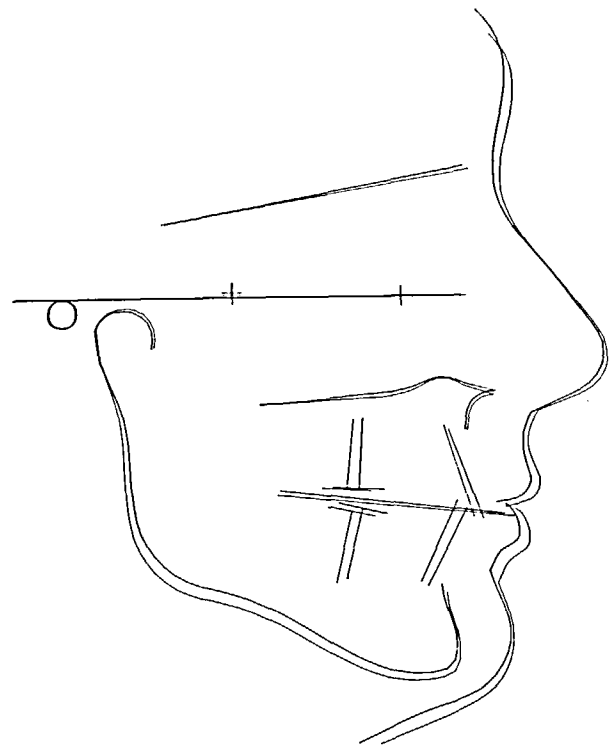
The between-groups differences for the initial, posttreatment, and recall data, and for the treatment, relapse, and overall changes were analyzed either by means of completely randomized  $t$  tests or, in the case of proportions, Z tests. Coefficients of linear correlation ( $r$ ) were used to assess the relationship between differential growth of the jaws (ABCH) and tooth movement (i.e., dentoalveolar compensation), both during treatment and in the years that followed.



**Fig. 4.** Superimposition (*FH at PTV*) of averaged posttreatment cephalometric tracings: red, extraction; blue, nonextraction. Note the incisors and lips of the nonextraction patients are, on average, about 2 mm more procumbent.

## RESULTS

The results of this investigation are straightforward and easily summarized. Although the discriminant function employed only six variables, the two groups it delineated were, at the outset, highly similar with respect to a wide range of craniofacial characteristics (Fig. 3; Tables II and III). At the end of treatment, however, the two groups of patients showed a number of significant differences, most of which—notably, the protrusion of the dentition and convexity of the profile—were still present at recall, a decade or so later (Figs. 4 and 5; Tables II and III). As may be seen in Tables IV to VI, the posttreatment changes were, on average, almost identical. In terms of lower incisor irregularity, both treatments produced results that more often than not could be considered successful: 73% of the extraction patients and 57% of the nonextraction patients had less than 3.5 mm of lower anterior irregularity at recall. Moreover, there was no tendency for one group to relapse toward the other, or, indeed, for both to regress toward some between-treatment mean; instead, the treatment differences tended to persist. Save for a weak tendency for “rebound” in the overbite, overjet, Wits A/B, and irregularity corrections, much of the relapse was correlated not with the specific effects of treatment, but rather with a pattern of posttreatment jaw growth that was common to both groups (Table VII). Contrary to popular nonorthodontic opinion, there was a tendency for mandibular basal bone to undergo



**Fig. 5.** Superimposition (*FH at PTV*) of averaged postretention (recall) cephalometric tracings: red, extraction; blue, nonextraction. Note the differences present at the end of treatment (Fig. 4) are still obvious over a decade later.

forward translation in both groups, approximately 3 mm at the chin (see MAND, Table V) and 2 mm at the condyle (C point). Perhaps most significantly, despite the marked between-groups differences in the fullness of the profiles, the patients themselves showed no statistically significant tendency to prefer the esthetic impact of one strategy over the other (Table VIII).

## DISCUSSION

It has been said that all of fashion tends to end in excess. By the present standards, the extraction rate of 20 to 30 years ago might seem to be a case in point. It can be inferred from the literature that by about 1965 it had reached a rate of perhaps 60% to 80%.<sup>4</sup> Therefore it is not surprising that the present parent sample of 238 features a 57% extraction rate. Most of these patients, although “borderline” when they were treated, would today probably be thought susceptible only to some form of nonextraction therapy. Indeed, it can be argued that the all-or-none nature of extraction would make the present borderline patients especially susceptible to the presumably more easily modulated nonextraction approach. As a result, the 30 patients who had the presumed good fortune to have been treated without extraction might be expected to vindicate the present



practices by displaying superior esthetics, stability, and the like. The present results, however, do not support this reasonable assumption: although the two strategies produced markedly different effects, the pattern of relapse was essentially identical. As a result, most of the between-treatment differences were still evident at recall a decade or so later. Ultimately, however, there were no significant differences in lower incisor crowding and in the patients' perception of the esthetic effects of their treatment.

In terms of the long-term source of the molar and overjet corrections, it should be noted (Table V) that there was a negative net contribution from tooth movement relative to basal bone. Instead, both corrections were ultimately derived from the pattern of maxillo-mandibular growth. Growth potential (i.e., is it likely that a patient of this age and sex will grow during treatment?), however, is rarely considered in the process of treatment planning, even though it constitutes a veritable *deus ex machina* that serves to rescue treatment plans predicated on tooth movements that rarely occur (e.g., distal movement of upper molars in growing extraction patients). In passing, it should be noted that in adults there would be no excess mandibular growth to militate against the distal movement of the upper molars; however, the emergence of a contribution from tooth movement is usually not enough to make up for the lack of differential jaw growth. As a result, the total molar correction is usually smaller in adults.<sup>15</sup>

Indeed, "growth" even has a marked impact on the goals of treatment. At the end of treatment, the extraction patients were considerably closer to the Steiner "compromises"; however, subsequent growth served to upright the lower incisors about 5° in both groups and, in conjunction with other posttreatment changes, "flatten" the nonextraction results so as to bring them more in line with the posttreatment Steiner goals (Table II; italicized data in Fig. 6). As has been long argued in the context of growth prediction, the failure to consider the interaction among initial facial form, the probable impact of treatment, and the usual pattern of growth may lead to the occasional esthetic "horror story" exploited by those responsible for the current stampede toward expansion and bite-jumping.

As has been noted, the posttreatment changes were essentially the same in both groups (see Tables IV through VI). Given that the dentitions of the two samples were nearly the same before treatment and very different after, this finding denies the existence of a single optimal incisor position/angulation that can, in and of itself, ensure long-term stability and "optimum" esthetics; apparently there is a range of positions that will serve the patient equally well. Moreover, in support of an earlier report by Simons and Joondeph,<sup>25</sup> the re-

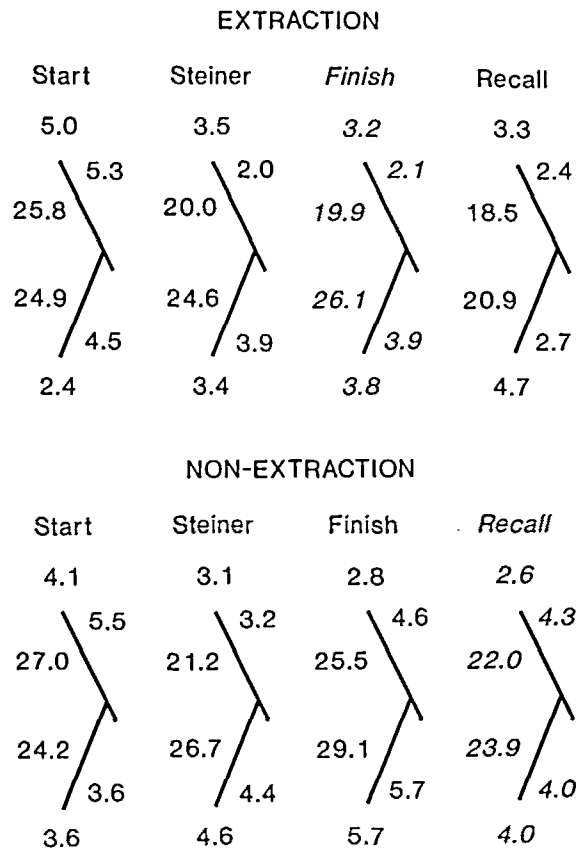


Fig. 6. Mean outcome (posttreatment and recall) and Steiner "compromises" for the two treatment strategies.

lapse of the overbite correction was unrelated to the strategy of treatment. In general, much of the relapse seen here can perhaps most easily be interpreted as a dentoalveolar compensation for a shared pattern of maxillo-mandibular differential growth (ABCH). On the basis of the correlation coefficients summarized in Table VII, the more the mandible outgrows the maxilla, the greater the probability that the upper molars and the upper incisors will tip forward, that the lower incisors will tip lingually, and that lower molar anchorage will be preserved. From the vantage point of the molar and the overjet corrections, all of these effects detract from the corrections produced by treatment. It must be emphasized that, in contrast to the "functional orthodontic" concept of mandibular distal displacement/entrapment caused by changes in tooth position, our interpretation assumes a more conventional direction of dependency, i.e., that jaw growth is the independent variable and, as such, is the efficient cause of the dental compensations.

Interestingly enough, although ABCH, anteroposterior mandibular advancement relative to the maxilla, bore a significant correlation to almost every posttreat-

**Table IV.** Treatment, after treatment, and net change: descriptive and inferential statistics for representative cephalometric and study-model measurements

Measure	Treatment change			Posttreatment change			Net change		
	Extraction	Nonextraction	t	Extraction	Nonextraction	t	Extraction	Nonextraction	t
<i>Linear (mm)</i>									
Overjet	-5.1	-4.7	ns	1.9	1.3	ns	-3.2	-3.5	ns
Overbite	-2.6	-1.9	ns	2.3	1.3	ns	-0.3	-0.6	ns
Wits A/B	-2.8	-2.6	ns	1.3	1.3	ns	-1.5	-1.3	ns
Lip to E plane	-3.1	-0.5	**	-2.4	-3.0	ns	-5.5	-3.5	**
U6-PTV	2.3	-1.1	**	3.5	3.9	ns	5.7	2.9	**
UI-NA	-3.2	-0.9	**	0.3	-0.2	ns	-2.9	-1.1	**
L1-NB	-0.6	2.1	**	-1.2	-1.7	ns	-1.8	0.4	**
L1-APog	0.1	2.6	**	-1.6	-1.8	ns	-1.6	0.9	**
Irregularity index	-5.9	-4.7	ns	2.4	3.0	ns	-3.6	-1.7	*
<i>Discrepancy</i>									
Upper	1.2	0.1	ns	1.1	1.1	ns	2.3	1.2	ns
Lower	0.9	-0.8	*	0.5	0.3	ns	1.4	-0.6	**
Ar-Gn	4.4	5.5	ns	5.3	5.7	ns	9.7	11.2	ns
Pog-NB	1.4	0.7	**	0.9	0.6	ns	2.3	1.3	**
N-ANS	2.0	2.8	ns	2.0	1.8	ns	4.0	4.7	ns
ANS-Me	3.0	3.9	ns	2.3	3.5	ns	5.3	7.3	*
N-Me	5.4	7.0	ns	4.3	5.4	ns	9.7	12.3	*
S-Ar	1.3	1.6	ns	2.1	2.1	ns	3.4	3.7	ns
S-Go	4.4	8.9	*	5.1	7.2	ns	9.4	16.1	**
<i>Angular (degrees)</i>									
SNA	-2.3	-1.5	*	0.9	0.7	ns	-1.4	-0.9	ns
SNB	-0.5	-0.2	ns	0.7	0.9	ns	0.3	0.7	ns
ANB	-1.8	-1.4	ns	0.1	-0.2	ns	-1.7	-1.6	ns
Y axis	0.8	0.9	ns	0.4	0.3	ns	1.2	1.1	ns
Pal. pl.-SN	0.8	1.2	ns	-0.4	-0.5	ns	0.5	0.7	ns
Occlusal plane-SN	2.2	1.9	ns	-2.3	-2.9	ns	-0.2	-1.0	ns
I/I	6.5	-2.0	**	6.5	8.6	ns	13.0	6.6	**
UI-SN	-8.2	-3.0	*	-0.6	-2.6	ns	-8.7	-5.5	ns
UI-NA	-5.9	-1.5	*	-1.4	-3.5	ns	-7.3	-5.0	ns
L1-NB	1.2	4.8	*	-5.2	-5.1	ns	-4.0	-0.3	**
Z angle	7.1	2.4	**	2.4	3.6	ns	9.5	6.0	*
FMA	0.3	-2.0	**	-0.6	-1.8	ns	-0.3	-3.8	**
FMIA	-1.8	-4.7	ns	5.3	5.3	ns	3.5	0.6	ns
IMPA	1.8	6.6	**	-4.7	-3.5	ns	-2.9	3.2	**

\* $P < 0.05$ .\*\* $P < 0.01$ .

ment molar and incisor change, it was unrelated to the reappearance of lower incisor irregularity ( $r = 0.02$ , n.s.). Shields, Little, and Chapko<sup>26</sup> have reported similar findings in a long-term retrospective study of premolar-extraction patients, "... growth as determined from measures of mandibular length and 'chin' displacement on the overall superimposition failed to show any influence on postretention mandibular anterior irregularity." This lack of correlation may constitute a by-product of extraneous variation, say, in the length and type of retention or in patient cooperation; it may also imply that the factors that cause lower incisor irregularity cannot be inferred from study models and lateral cephalograms.

As may be seen in Tables III and VI, the average changes in the intermolar and intercanine dimensions were generally small and, with the exception of 2.5 mm of net intermolar expansion in the nonextraction patients, were consistent with the normal pattern of occlusal maturation in untreated subjects with "clinically 'good' occlusion,"<sup>27</sup> modified by the anteroposterior movement of the teeth into wider and narrower parts of the arch. Perhaps as a result of this relative lack of canine expansion, 73% of our extraction patients and 57% of our nonextraction patients returned with less than 3.5 mm of irregularity. In passing, it may be noted that because the extraction patients started out with slightly more irregularity and ended up with

**Table V.** Dental and skeletal components of the molar and overjet correction

Measure	Treatment change			Posttreatment change			Net change		
	Extraction	Nonextraction	t	Extraction	Nonextraction	t	Extraction	Nonextraction	t
<i>Skeleton—jaw displacement relative to cranial base</i>									
MAX	-1.3	-1.1	ns	-1.3	-1.6	ns	-2.6	-2.7	ns
MAND	3.2	3.5	ns	2.7	3.2	ns	5.9	6.7	ns
Net skeletal (ABCH)	1.9	2.5	ns	1.4	1.6	ns	3.3	4.1	ns
<i>Dentition—molar movement/relapse relative to basal bone</i>									
U6									
Bodily	-3.1	0.0	**	-0.4	-0.5	ns	-3.5	-0.6	**
Tipping	0.6	1.0	ns	-2.2	-2.6	ns	-1.6	-1.6	ns
L6									
Bodily	4.6	1.6	**	0.3	0.7	ns	4.9	2.3	**
Tipping	-1.3	-1.7	ns	0.3	0.2	ns	-1.0	-1.5	ns
Net 6	0.8	0.9	ns	-2.0	-2.2	ns	-1.2	-1.3	ns
<i>Dentition—incisor movement/relapse relative to basal bone</i>									
U1	5.2	1.2	**	-1.2	-0.8	ns	3.9	0.4	**
L1	-1.8	1.2	**	-2.0	-2.3	ns	-3.8	-1.0	**
Net 1	3.4	2.4	ns	-3.2	-3.0	ns	0.1	-0.6	ns
<i>Total correction—ABCH plus Net 6; ABCH plus Net 1</i>									
6/6	2.8	3.4	ns	-0.6	-0.6	ns	2.2	2.8	ns
Overjet	5.3	4.9	ns	-1.8	-1.4	ns	3.5	3.5	ns

\**P* < 0.05.

\*\**P* < 0.01.

**Table VI.** Change in dental-arch dimensions: means and *t* scores for between-treatment differences

Measure	Treatment change			Posttreatment change			Net change		
	Extraction	Nonextraction	t	Extraction	Nonextraction	t	Extraction	Nonextraction	t
<i>Arch length<sup>13</sup></i>									
Maxillary	-11.5	1.8	**	-2.3	-3.2	ns	-13.8	-1.5	**
Mandibular	-9.1	2.9	**	-2.6	-3.9	**	-11.7	-1.0	**
<i>Inter canine width</i>									
Maxillary	0.9	0.8	ns	-0.7	-0.1	*	0.2	0.7	ns
Mandibular	2.2	1.1	**	-1.2	-0.7	*	1.0	0.4	ns
<i>Inter molar width</i>									
Maxillary	0.0	2.9	**	-0.8	-0.3	ns	-0.8	2.5	**
Mandibular	-0.5	1.8	**	0.1	0.7	ns	-0.4	2.5	**

\**P* < 0.05.

\*\**P* < 0.01.

slightly less (Table II), the net change favors premolar extraction (Table IV). Although the difference is statistically significant, it is quite small (less than 2 mm). We would therefore suggest that it be interpreted provisionally as an argument against the single-sided hypothesis that extraction treatments are generally inferior. In any event, the results of both treatments are somewhat more favorable than the various reports by Little and associates,<sup>28,29</sup> who report "unacceptable" long-term results (i.e., more than 3.5 mm of lower incisor irregularity) in about 70% of their extraction

patients at 10 years and in 90% at 20 years. Indeed, at recall the present patients had about the same mean irregularity as has been reported for patients who began treatment with generalized spacing.<sup>30</sup> Although these differences may well be technique related, it is clear that they may also reflect the fact that the present findings come from a carefully selected, conservatively treated sample of borderline patients with Class II malocclusions rather than from a random sample in which malocclusions of various types and degrees of severity are commingled.

**Table VII.** Coefficients of linear correlation (*r*) for the relationship between apical base change (ABCH) and tooth movement during and after treatment (both groups combined; *n* = 63)

Measure	Treatment change	Posttreatment change
<i>Molars</i>		
Upper 6	-0.14	-0.63**
Bodily	0.20	-0.04
Tipping	-0.43**	-0.53**
Lower 6	-0.49**	-0.72**
Bodily	-0.19	-0.32*
Tipping	-0.42**	-0.42**
Molar correction	0.36**	0.44**
<i>Incisors</i>		
Upper 1	-0.31*	-0.65**
Lower 1	-0.31*	-0.75**
Irregularity	-0.16	0.02
Overjet	0.03	-0.02

\**P* < 0.05.\*\**P* < 0.01.

Despite the relative stability of the irregularity correction, most patients showed at least some relapse (overall average, 2 to 3 mm). Long-term studies, however, have generally failed to implicate the factors commonly invoked to explain this type of relapse. For example, the present study and others before it<sup>31,32</sup> have failed to detect a relationship between canine expansion and lower incisor crowding. These negative reports, however, cannot be used to justify a return to expansion as a generalized answer to crowding. A correlation coefficient is an index of shared variability; if one variable is held relatively constant, by definition there will be no correlation. In effect, the heretofore generally-accepted rule that arch width be maintained has served to ensure that most samples will feature so little deliberate expansion that a correlation with relapse would escape detection. We would suggest, however, that the nonextraction treatments of 1935 featured no such restriction. As a result, Tweed probably saw and reacted to a marked correlation between expansion and subsequent relapse. By returning to expansion as a routine treatment, it is clear that we have forgotten our history; in a few years, we will probably be forced to repeat it.

Perhaps to counterbalance a residual collective doubt about the long-term stability of expansion, it is today practically an article of faith that nonextraction therapy will produce superior facial esthetics (and presumably a modicum of immunity to lawsuits charging iatrogenic distal displacement of the condyles and the like). This popular rationalization, however, does not square with the present results: the extraction patients perceived that they had undergone every bit as much

**Table VIII.** Esthetic evaluations: frontal and profile VAS scores—group means and percentage of subjects improved

Group	Profile		Frontal*	
	VAS score	Improved (%)	VAS score	Improved (%)
Extraction	11.1 mm	58	33.5 mm	69
Nonextraction	3.0 mm	50	13.4 mm	57
Significance	ns	ns	ns	ns

\*Six frontal photographs missing.

improvement in their appearance as had their nonextraction counterparts—perhaps even more if contemporary attitudes are factored in as prior probabilities (Table VIII). Indeed, at recall neither group tended to show the esthetic stigmata that are so often said to accompany a brush with conventional orthodontics.

Bowbeer<sup>1,2</sup> has published a variety of measures and guidelines designed to codify the functional orthodontic ideals of bimaxillary protrusion as a key to “facial beauty and TMJ health.” In his cephalometric/photo analysis, the angulation of the upper lip and the anteroposterior position of the mental crease, the upper incisors, and the points A and B are measured relative to Frankfort horizontal perpendiculars erected through nasion and through the bridge of the nose (BNV, “Bowbeer Nasion Vertical”). As an exercise in reality testing, this analysis was applied to the present patients and to the “Bolton Standards” for ages 12, 14, and 18.<sup>33</sup> The results of this project are summarized in Table IX and show clearly that “esthetic norms” of Bowbeer define profiles that are every bit as protrusive as those of the present patients with Class II malocclusions before treatment and much more procumbent than the carefully selected, “optimum” faces depicted in the Bolton templates. For those whose esthetic tastes are less extreme, it may be noted that both the extraction and nonextraction patients studied here ended up more or less in the middle.

Finally, although our critics rail at the marked arch narrowing and distal condylar displacement that are said routinely to attend the extraction of premolars and the use of “backward-pulling headgear” and Class II elastics, the present extraction/nonextraction comparison shows that, at recall, both groups presented with essentially identical maxillary and mandibular intercanine widths (Table III). More to the point, neither treatment tended to produce distal mandibular displacement; on the average, both groups of patients experienced and benefitted from forward translation of the chin and the condyle during treatment. It would seem, then, that the

**Table IX.** "Bowbeer" analysis

Measure*	Bowbeer norms <sup>1,2</sup>	Bolton norms <sup>3,3</sup>			Extraction			Nonextraction		
		12	14	18	Start	Finish	Recall	Start	Finish	Recall
Upper lip to BNV angle	15-35°	27.0	31.0	29.0	30.0	29.0	15.0	29.0	34.0	22.5
Mental crease to BNV	±2 mm	-2.5	-0.5	-1.5	0.0	-1.0	-1.5	-0.5	0.0	-1.0
U1-A	4-6 mm	1.5	2.0	1.5	6.0	1.5	2.0	5.5	4.0	3.5
A-B	3-6 mm	6.5	6.0	5.0	6.5	6.0	6.0	6.5	5.5	5.5

\*BNV, Bowbeer nasion vertical; NV = nasion vertical (nasion perpendicular).

negative effects of conventional edgewise therapy, both extraction and nonextraction, have been greatly overstated. Given that many of the stated goals and effects of functional orthodontics seem to be based more on wishful thinking than on real-world data, this outcome should come as no surprise.

In simpler times, our findings would support several useful conclusions. For example, if growth is the usual long-term source of the molar and the overjet corrections, a decision to extract upper first premolars with an eye toward leaving the molars in a Class II relationship would seem an eminently logical approach to the treatment of a nongrowing adult. Moreover, given that much of the relapse seen here took the form of dentoalveolar compensations for posttreatment jaw growth, one might also infer the type and the minimum duration of the retention program required for the average adolescent patient. Indeed, the present findings even argue for a cautious modification of the extraction/nonextraction borderline of the 1960s and 1970s. Unfortunately, it is almost too late for reason and logic. The claims that the methods of the orthodontic specialist commonly produce unsightly flattening of the profile and distal displacement of the mandible have had a marked chilling effect on orthodontic treatment planning. It must therefore be emphasized that the present findings do not support this viewpoint and imply instead that the rising popularity of nonextraction-at-any-cost treatments may well represent a threat to the public health. In short, we appear to have been bullied into fixing something that was not broken.

**SUMMARY AND CONCLUSIONS**

Discriminant analysis was used to identify and recall a restricted stratum of borderline Class II nonextraction and premolar-extraction patients who had been treated 10 to 20 years ago. Because the treatments had been performed and documented by a large number of clinicians working in a university setting, and because there was empirical evidence of uncertainty as to the better treatment, the resulting follow-up data are as-

sumed to represent a relatively bias-free comparison of the long-term effects of the two treatment strategies. The results of this study are as follows:

1. For the present parent sample of 238 patients with Class II, Division 1 malocclusions, the extraction decision was based on profile convexity and on upper and lower anterior protrusion and crowding.
2. For the borderline patient, nonextraction treatment produced a significantly more protrusive denture (about 2 mm), both at the end of treatment and at recall over a decade later.
3. Despite the significant between-treatment differences, the majority of the subjects in both groups showed less than 3.5 mm of lower anterior irregularity.
4. In general, the pattern of relapse was unrelated to the type of treatment or to the posttreatment position and orientation of the denture and, instead, appears to constitute a dentoalveolar compensation produced by the differential growth of the jaws following treatment.
5. Ultimately, both the overjet and molar corrections were derived almost entirely from the differential growth of the jaws, rather than tooth movement relative to basal bone.
6. There was no evidence that either treatment tended to produce a distal displacement of the basal bone of the mandible or its condyles.
7. Despite a significantly "flatter" profile, the extraction patients proved as likely to view their outcome as an improvement as did their nonextraction cohorts.

We thank Dr. Dennis Killiany for organizing the data base employed in this study and Dr. Frank Sobkowski for his helpful suggestions during the preparation of this manuscript.

**REFERENCES**

1. Bowbeer GRN. Saving the face and the TMJ. Part 2. *Funct Orthod* 1986;3:9-39.
2. Bowbeer GRN. The seventh key to facial beauty and TMJ health. Part 2: proper condylar position. *Funct Orthod* 1990;7:4-32.

3. Drobocky OB, Smith RJ. Changes in facial profile during orthodontic treatment with extraction of four first premolars. *AM J ORTHOD DENTOFAC ORTHOP* 1989;95:220-30.
4. Weintraub JA, Vig PS, Brown C, Kowalski CJ. The prevalence of orthodontic extractions. *AM J ORTHOD DENTOFAC ORTHOP* 1990;96:462-6.
5. O'Connor B. Contemporary trends in orthodontic practice: a national survey. [Thesis] St. Louis: Department of Orthodontics, St. Louis University Medical Center, 1990.
6. Feinstein AR. Clinical epidemiology: the architecture of clinical research. Philadelphia: WB Saunders, 1985:43-50.
7. Horwitz RI, McFarlane MJ, Brennan TA, Feinstein AR. The role of susceptibility bias in epidemiologic research. *Arch Intern Med* 1985;145:909-12.
8. Little RM, Riedel RA, Stein A. Mandibular arch length increase during the mixed dentition: postretention evaluation of stability and relapse. *AM J ORTHOD DENTOFAC ORTHOP* 1990;97:393-404.
9. Feinstein AR. An additional basic science for clinical medicine: II. The limitations of randomized trials. *Ann Intern Med* 1983;99:544-50.
10. Feinstein AR. An additional basic science for clinical medicine: III. The challenges of comparison and measurement. *Ann Intern Med* 1983;99:705-12.
11. Feinstein AR. The clinician as scientist. In: McNamara JA Jr., Carlson DS, Vig PS, Ribbens KA, eds. Science and clinical judgment in orthodontics. Monograph 18. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, The University of Michigan, 1986:1-14.
12. Freedman B. Equipoise and the ethics of clinical research. *N Engl J Med* 1987;31:141-5.
13. Little RM. The irregularity index: A quantitative score of mandibular anterior alignment. *AM J ORTHOD* 1975;68:554-63.
14. Miettinen OI. Stratification by a multivariate confounder score. *Am J Epidemiol* 1976;104:609-20.
15. Johnston LE Jr. A comparative analysis of Class II treatments. In: McNamara JA Jr., Carlson DS, Vig PS, Ribbens KA, eds. Science and clinical judgment in orthodontics. Monograph 18. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, The University of Michigan, 1986:103-48.
16. Björk A. Prediction of mandibular growth rotation. *AM J ORTHOD* 1969;55:585-99.
17. Björk A, Skieller V. Normal and abnormal growth of the mandible. A synthesis of longitudinal cephalometric implant studies over a period of 25 years. *Eur J Orthod* 1983;5:1-46.
18. Björk A, Skieller V. Postnatal growth and development of the maxillary complex. In: McNamara JA Jr, ed. Factors affecting the growth of the midface. Monograph 6. Craniofacial Growth Series. Ann Arbor: Center for Human Growth and Development, The University of Michigan 1986:61-99.
19. Björk A. The face in profile: an anthropological X-ray investigation on Swedish children and conscripts. *Svensk Tandläk-Tidskr* 1947;40(Suppl. 5B):1-180.
20. Baumrind S, Frantz RC. The reliability of head film measurements: 2. Conventional angular and linear measures. *AM J ORTHOD* 1971;60:505-17.
21. Gravely JF, Benzie PM. The clinical significance of error in cephalometry. *Br J Orthod* 1974;1:95-101.
22. Chaconas SJ, Jacobson RL, Lemchen MS. The DigiGraph Work Station: Part 3. Accuracy of cephalometric analysis. *J Clin Orthod* 1990;24:467-71.
23. Aitken RCB. Measurement of feelings using visual analogue scales. *Proc R Soc Med* 1969;62:989-93.
24. Revill SI, Robinson JO, Rosen M, Hogg MIJ. The reliability of a linear analogue for evaluating pain. *Anaesthesia* 1976;31:1191-8.
25. Simons ME, Joondeph DE. Change in overbite: a ten-year post-retention study. *AM J ORTHOD* 1973;64:349-67.
26. Shields TE, Little RM, Chapko MK. Stability and relapse of mandibular anterior alignment: a cephalometric appraisal of first-premolar-extraction cases treated by traditional edgewise orthodontics. *AM J ORTHOD* 1985;87:27-38.
27. Sinclair PM, Little RM. Maturation of untreated normal occlusions. *AM J ORTHOD* 1983;83:114-23.
28. Little RM, Wallen TR, Riedel RA. Stability and relapse of mandibular anterior alignment—first premolar extraction cases treated by edgewise orthodontics. *AM J ORTHOD* 1981;80:349-65.
29. Little RM, Riedel RA. Postretention evaluation of stability and relapse—mandibular arches with generalized spacing. *AM J ORTHOD DENTOFAC ORTHOP* 1989;95:37-41.
30. Little RM, Riedel RA, Årtun J. An evaluation of changes in mandibular anterior alignment from 10 to 20 years postretention. *AM J ORTHOD DENTOFAC ORTHOP* 1988;93:423-8.
31. Groesch CW. Prediction of mandibular incisor relapse. [Thesis.] St. Louis: St. Louis University Department of Orthodontics, 1978.
32. Harper DL. The effects of pre-treatment morphology, treatment change, and post-treatment growth on relapse. [Thesis.] St. Louis: St. Louis University Department of Orthodontics, 1986.
33. Broadbent BH Sr, Broadbent BH Jr, Golden WH. The Bolton standards of dentofacial developmental growth. St. Louis: CV Mosby, 1975:62-5.

*Reprint requests to:*

Dr. Lysle E. Johnston, Jr.  
Department of Orthodontics and Pediatric Dentistry  
School of Dentistry  
The University of Michigan  
Ann Arbor, MI 48109-1078