Quantitative analysis of the orthodontic and orthopedic effects of maxillary traction

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This article analyzes differences in displacement of ANS and of the upper first molar when different vectors of force are delivered to the maxilla in non-full-banded Phase I mixed-dentition treatment of Class II malocclusion. The sample is identical to that for which we have previously reported differences in change in several key measures of mandibular and facial shape.[14, 15] It includes a cervical-traction group, a high-pull-to-upper-molar group, a modified-activator group, and an untreated Class II control group. Using newly developed computer-conducted procedures, which are described, we have been able to partition the ortho*dontic* and ortho*pedic* components of upper molar displacement and also to isolate treatment effects from those attributable to spontaneous growth and development.

In the region of ANS, small but statistically significant and clinically meaningful differences were noted between treatments. When the intercurrent effects of growth and development had been factored out (Table III), ortho*pedic* distal displacement of ANS was significantly greater in the high-pull and cervical groups than in the activator group. Ortho*pedic* downward displacement of ANS was seen to be significantly greater in the cervical group than in the high-pull and activator groups. In the region of the first molar cusp, mean *distal* displacement of the tooth as an ortho*pedic* effect was found to be almost identical in the cervical and high-pull groups (although variability was greater in the cervical group), but the mean ortho*dontic* effect was significantly greater in the high-pull group than in the cervical group. In the cervical group, where relatively light forces were used for relatively long treatment periods on average, more of the total distal displacement of the upper molar was of an ortho*pedic* character than of an ortho*dontic* character. Conversely, in the high-pull group, in which relatively heavier forces tended to be used for briefer treatment periods, most of the distal displacement at the upper molar was of an ortho*dontic* character. These observations are contrary to expectations from conventional orthodontic theory. In the activator-treated group, roughly equal components of the treatment-associated distal displacement of the upper molar were of the ortho*dontic* and ortho*pedic* types. As concerns changes in the vertical direction in the region of the molar cusp, significant *intrusion* of both the ortho*pedic* and ortho*dontic* types was seen in the high-pull sample as compared to each of the other groups examined. The intraoral group also showed a tendency toward molar *intrusion* as compared to the untreated control group, but the trend did not reach statistical significance in this multiple-comparison test. The cervical-traction group showed significant mean *extrusive* effects of both the ortho*dontic* and the ortho*pedic* types, but even for this group total extrusion was on average no more than 1 mm. as compared to the control group.

Key words: Maxillary retraction, Class II treatment, ortho*dontic* effects, ortho*pedic* effects

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Orthodontic tooth movement is customarily defined as displacement of teeth *within* the bony matrix while "orthopedic tooth movement" is defined as displacement of teeth which occurs as a secondary consequence of the displacement of the bony matrix itself. The distinction between these two types of "movement" is of importance in treatment planning, since each is considered to be desirable in some circumstances and undesirable in others. For example, when distal translation of canines into premolar extraction

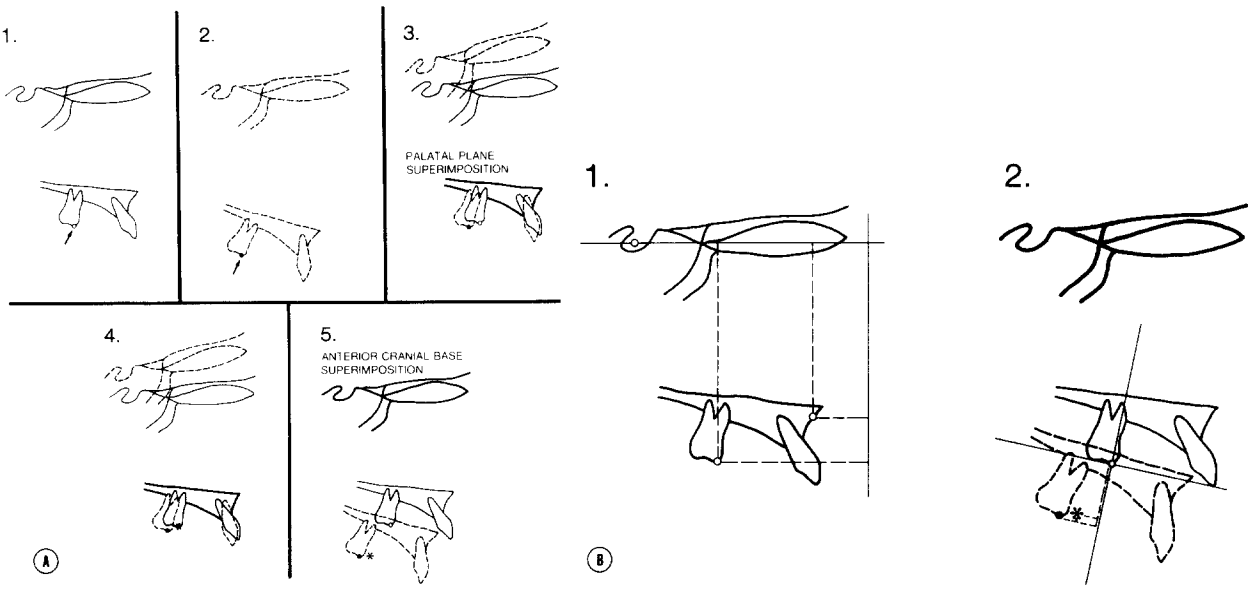

Fig. 1. A, The rationale for differentiating between ortho*dontic* and ortho*pedic* displacement. *A1,* Timepoint 1 tracing. White dot (○) indicates observed position of upper molar cusp. *A2,* Timepoint 2 tracing. Black dot (●) indicates observed position of upper molar cusp. *A3,* Superimposition of timepoint 2 tracing upon timepoint 1 tracing based upon the biologically defined "best fit" of palatal structures. The timepoint 1 and timepoint 2 positions of the upper molar cusp can both be seen in the superimposed tracings. *A4,* The timepoint 1 location of upper molar cusp is now transferred to the timepoint 2 tracing (*). *A5,* The two tracings are now shifted to superimposition upon the biologically defined "best fit" upon anterior cranial base. In this figure, the white dot (○) represents the original (timepoint 1) position of the upper molar cusp, the black dot (●) represents the observed position of the point on the timepoint 2 tracing and the asterisk (*) represents the transferred intermediate position of the upper molar cusp. The distance between the white dot and the asterisk represents ortho*pedic* displacement, while the distance between the asterisk and the black dot represents ortho*dontic* displacement. The vector sum of these two values (the distance between the white dot and the black dot) represents total displacement. **B,** Frames of reference employed. *A1,* Frame of reference used for the computation of the initial landmark coordinates of Table I. The X axis is the SN reference line of the timepoint 1 film and the origin is at nasion. *B2,* Frame of reference used for calculating between-film landmark displacements in Tables II and III. The X axis of this coordinate system is the occlusal plane (Downs) of the first film, and the origin is at the midpoint between the upper and lower molar cusps. Using this frame of reference, Table II and III report, in quantitative terms, displacements of the types demonstrated earlier in *A5.*

spaces is a treatment goal, movement of the canine *within* the bony matrix is usually desired. On the other hand, when clinicians attempt to correct mixed-dentition maxillary protrusion through the use of extraoral traction, they frequently wish to achieve distal displacement of the entire bony palate.

Although some disagree, most orthodontists believe that "light" forces are optimal for moving teeth *within* the bone (that is, for the achievement of "orthodontic movement"),[1-9] while "heavy" forces are optimal for moving teeth and investing structures as a unit (that is, in "orthopedic movement"). Thus, in the clinical situations cited, it would be conventional wisdom to use "light" forces for the retraction of canines but "heavy" forces for orthopedic retraction of the maxilla.

Underlying the use of different force levels to produce different treatment effects is the belief that different biologic mechanisms are involved in the two types of tooth movement. Classic orthodontic theory holds that if "light" forces ($\simeq$20 gm./cm.^{2} of root surface) are delivered, a tooth will displace "within" the periodontal space in what is said to be a physiologically normal manner.[10] Within the periodontal ligament, a "pressure" side and a "tension" side are said to be produced. The difference in physical state in these two regions purportedly triggers bone resorption and deposition in some yet undiscovered fashion and the tooth migrates through the bone. On the other hand, "heavy" forces are believed to impact the tooth against the cortical plate on the pressure side of the alveolus,

TABLE I: Pretreatment Comparability Among the Samples: Means and Standard Deviations

	TREATMENT TYPE				
	A CONTROL n=50	B CERVICAL n=74	C HIGH PULL n=53	D INTRAORAL n=61	*Significant Differences**
A. Sample Demographics					
Age at First Film	8.43 ± 0.97	10.29 ± 1.67	8.86 ± 1.33	9.96 ± 1.14	A,C < D,B
Sex (number and proportion of males)	30 (.60)	33(.45)	19(.36)	30 (.49)	
Class II Severity (mm)	−0.93 ± 1.87	−1.07 ± 1.48	−1.34 ± 1.61	−1.15 ± 1.76	
B. Relevant Physical Measurements					
1. Initial Angular Relationships (Degrees)					
Occlusal Plane (Downs)	17.02 ± 3.30	16.01 ± 3.73	18.37 ± 3.55	16.29 ± 3.86	B,D < C
MPA (Downs)	25.48 ± 5.41	25.22 ± 4.58	27.14 ± 5.45	26.64 ± 5.00	
SNA	80.71 ± 2.83	80.96 ± 3.17	80.84 ± 3.45	80.24 ± 3.20	
2. Initial Landmark Coordinates (mm)†					
Anterior Nasal Spine**					
x	−6.07 ± 2.60	−6.15 ± 2.99	−6.25 ± 3.21	−7.05 ± 3.33	
y	−50.07 ± 2.93	−50.74 ± 2.71	−50.33 ± 2.90	−52.82 ± 3.13	D < B,C,A
Upper Molar Cusp					
x	−41.42 ± 3.37	−40.63 ± 3.89	−42.26 ± 3.80	−43.46 ± 3.99	D < A,B
y	−62.57 ± 3.21	−64.47 ± 3.71	−63.59 ± 3.58	−67.03 ± 3.72	D < B,C,A; B < A
Upper Molar Apex					
x	−34.56 ± 3.24	−33.96 ± 3.29	−34.18 ± 3.23	−36.09 ± 3.55	D < C,B
y	−44.16 ± 2.44	−46.38 ± 3.57	−45.17 ± 3.09	−47.55 ± 3.38	D,B < A; D < C

† Expressed in terms of the SN coordinate system, registered on Nasion.
* $p < .05$ adjusted for the effects of multiple comparison after Bonferroni (20).
** According to Harvold's definition as illustrated in AJO, 75: 632, 1979.

producing ischemic conditions which prevent bone resorption.[11, 12] Since the forces delivered to the bone by the appliance have not been dissipated by tooth movement within the bone in the "heavy" forces situation, they are, according to theory, transmitted without alteration to the investing bone, causing displacement of the entire osseous matrix.

The belief of clinicians that one type of tooth movement can be "turned on" while the other is "turned off" if force values are chosen and delivered with sufficient subtlety is a logical outgrowth of this general theory. However, to our knowledge, no empirical test has yet established that different *types* of tooth movement occur during clinical treatment as a function of differences in force magnitude. The present article represents an attempt to identify and quantitate such differences by examining the orthodontic and orthopedic components of the displacement of the upper first molar and of ANS associated with the use of different appliance systems in the treatment of mixed-dentition Class II malocclusion.

MATERIALS AND METHODS

This article continues our analysis of stored data from a sample of 303 subjects with treated and untreated Class II malocclusions. The treated subjects in the sample were patients in the practices of well-known clinicians, each of whom is consensually accepted as an expert by the orthodontic community. Each patient was treated during the mixed-dentition stage to correct the anteroposterior dysplasia with one of five intraoral or extraoral appliances. All the patients of each clinician were treated by the single method and appliance which that clinician used for all of his or her cases at the time these patients were treated. The effects of full-banded appliances, of extraction therapy, and of Class II elastics are not considered in this study.

The five types of appliances studied have previously been described in some detail.[13] In the present article, we restrict our attention to the same subsample of 238 subjects that was reported in our last two articles.[14, 15] Two types of extraoral treatment (combination headgear and straight-pull headgear) have been

excluded from consideration because the sample sizes for these treatments are at present too small to permit statistically significant inferences to be drawn. For the remaining treatment types, all subjects with elapsed treatment time in excess of 42 months have been omitted because there is evidence that the relationship between elapsed time and treatment effect may not be linear beyond that point.[14] The data reported in this article are therefore drawn from the examination of pre- and posttreatment norma lateralis head films of fifty untreated Class II control subjects and of 188 subjects who underwent therapy to correct Class II malocclusions with either cervical traction, high-pull headgear to the upper first molar, or a modified activator.

The data being examined in this study were generated by the UCSF combined head film analysis, a computer-aided method for data acquisition from head films which has previously been reported.[16] Each film was traced independently by four judges. After digitization with a computer-linked electronic digitizer, the tracing values of the four judges were compared as a computer operation and outlying values were identified and cast out automatically. In those cases in which more than one estimate for the same landmark on a given film was characterized as an outlier, a final value was arrived at either by retracing or by assignment.

METHOD OF ANALYSIS

The task of differentiating between "ortho*dontic*" and "ortho*pedic*" effects on norma lateralis head films has been hampered by the lack of a rigorous operational rule for differentiating the two. We propose the following recipe (Fig. 1) which, we believe, is both mathematically and biologically sound.[17] Separate tracings of the timepoint 1 film and the timepoint 2 film are made, and the anatomic landmarks of interest are located upon them (Fig. 1, *A1* and *A2*). For the purposes of this article, the anatomic landmarks of interest are ANS, upper molar cusp, and upper molar apex, but, in order to simplify Fig. 1, only upper molar cusp is represented. The timepoint 1 positions of these two points are marked by white dots (○), while their timepoint 2 positions are marked by black dots (●).

The two tracings are superimposed on the best fit of palatal structures, using the biologic definition of choice (Fig. 1, *A3*). The landmarks of interest are then physically or mathematically transferred from the tracing of the pretreatment film onto the overlying tracing of the posttreatment film (Fig. 1, *A4*) upon which their timepoint 2 positions are marked by asterisks (*). Relative to the outline of the maxilla and within the limits of measurement error, the transferred points on the timepoint 2 tracing (*) now occupy precisely the positions at which the landmarks they represent would be imaged had the structures not undergone displacement within the maxilla in the period between the taking of the two films. Therefore, in terms of the definition in the first sentence of this article, the distance between the transferred point identifying any landmark on the timepoint 2 tracing (*) and its actual observed position on that tracing (●) is a valid measure of the ortho*dontic* displacement of the landmark between timepoints.

Next the posttreatment tracing is rotated and translated upon the pretreatment tracing until the two are superimposed upon the biologically defined best fit of anterior cranial base (Fig. 1, *A5*). Relative to the outline of anterior cranial base, and within the limits of measurement error, the transferred points (*) now occupy precisely the positions at which the landmarks they represent would be imaged if no intramaxillary (which is to say, ortho*dontic*) displacement had occurred between timepoints. Therefore, in terms of this superimposition, the distance between the observed position of any landmark on the timepoint 1 tracing (○) and the transferred point identifying that landmark on the timepoint 2 tracing (*) is a valid measure of ortho*pedic* displacement as defined in the first sentence of this article.

Total displacement is defined as the vector sum of ortho*dontic* displacement and ortho*pedic* displacement and may be measured as the distance between the observed locations of a landmark on the timepoint 1 tracing (○) and the timepoint 2 tracing (●) when the tracings are superimposed on anterior cranial base as shown in Fig. 1, *A5*.

This method of transferring points between superimposed tracings is the precise analog of that long used for *physically* transferring Frankfort plane in the Downs analysis[18] and more recently used by Isaacson[19] in calculating mandibular centers of rotation. In the present case, the point transfers are performed *mathematically* as a computer operation.[16]

RESULTS

In this section, we will report data bearing upon three issues: (1) pretreatment comparability of the samples for the different treatment groups; (2) between-treatment comparisons of *observed displacement* of ANS, upper molar cusp, and upper molar apex; and (3) between-treatment comparisons of the *treatment effect* upon ANS, upper molar cusp, and upper molar apex.

The first issue, the question of comparability of

TABLE II: Between Sample Comparisons of **Observed Displacement:** Parts A and B Means, Standard Deviations & Standard Errors†

	TREATMENT TYPE				
	A CONTROL n = 50	B CERVICAL n = 74	C HIGH PULL n = 53	D INTRAORAL n = 61	*Significant Differences**
A. CHANGES in Conventional Measures					
1. Occlusal Plane Angle (Downs)	−0.46 ± 1.97	0.37 ± 2.76	3.57 ± 2.75	1.15 ± 2.18	A,B,D < C; A < D
2. Mandibular Plane Angle (Downs)	−0.37 ± 1.30	0.50 ± 1.78	0.06 ± 1.39	−0.23 ± 1.38	A,D < B
3. SNA Angle	−0.05 ± 1.40	−1.85 ± 2.10	−2.06 ± 1.12	−0.29 ± 1.35	C,B < D,A
4. Class II Severity	−0.15 ± 1.86	3.35 ± 1.96	4.68 ± 3.08	2.53 ± 2.14	A < D,B < C
5. Cant of Palatal Plane	0.08 ± 1.46	1.73 ± 1.75	1.89 ± 1.21	0.61 ± 1.27	A,D < B,C
6. EYEARS**	2.17 ± 0.41	2.31 ± 0.60	1.33 ± 0.64	1.98 ± 0.13	C < D < A,B
B. Rotations of the Upper First Molar					
1. Orthopedic Rotion	0.08 ± 1.46	1.73 ± 1.75	1.89 ± 1.21	0.61 ± 1.27	A,D < B,C
2. Orthodontic Rotation	−0.93 ± 3.80	−2.06 ± 6.22	2.60 ± 7.72	−0.39 ± 5.33	B,A < C
3. Total Rotation	−0.85 ± 3.65	−0.32 ± 6.20	4.49 ± 7.50	0.21 ± 5.14	A,B,D < C

†Means and Standard **Errors** for the "Hyp" and "Angle of Displacement" variables.
Means and Standard **Deviations** for all other variables.
*$p < .05$ adjusted for the effects of multiple comparisons after Bonferroni (20).
**Elapsed time between films in years.

samples, is relatively independent of the other two, so that if the reader desires it may be passed over on first reading and perhaps returned to later. In discussing between-treatment comparisons of observed displacement, we will consider the combined effects of treatment and of intercurrent growth and development without attempting to distinguish between them. In our discussion of between-treatment comparisons of treatment effect, we will attempt to factor out an estimate of growth and developmental changes for each treated subject in order to produce estimates of the effects of treatment itself, separated from the effects of intercurrent developmental processes.

Pretreatment comparability of the samples for the different treatment groups

Table I summarizes information on the state of each of the sample groups at the time of the first film. We would desire that the initial states of the several samples be as well matched as possible. As the table shows, comparability between the samples is good but far from perfect. Among the demographic data (Table IA), the several group samples are seen to be rather large and rather well matched for size. Observed differences in Class II severity prior to treatment are small and are not statistically significant. (It should be noted in passing that we measure Class II severity along the occlusal plane of Downs, using the midpoint between the upper and lower mesiobuccal cusps as the origin. This means that our zero value is at what would be described clinically as a "cusp-to-cusp" relationship. Hence, in terms of conventional clinical standards, the listed values for Class II severity are systematically understated by one half the width of a molar cusp.)

Some differences in sex distribution do exist between samples. We consider these to be of no great concern here, since a study of residuals using methods we have discussed previously[14] indicates that sex difference does not effect treatment outcome for the variables currently under consideration.

There are consequential and statistically significant differences between samples with regard to age at first film, but these differences are primarily a result of the fact that clinicians who employ different treatment modalities *choose* to begin treatment at different ages. Since differences in age at start of treatment result from clinician choice, the observed differences in age at first film may legitimately be considered properties of the treatments themselves (just as, for example, differences in force magnitude and direction are properties of the different treatments). Hence, it would be inappropriate to match cases between samples for this variable.

Table IB lists relevant physical measurements for the several samples. Here one would wish either a high degree of matching between samples or, in the absence of such matching, some assurance that the measured differences in antecedent state have no effect upon treatment outcome. The angular measures listed exhibit

TABLE II: Between Sample Comparisons of **Observed Displacement:** Part C
Means, Standard Deviations & Standard Errors†

		TREATMENT TYPE				
		A CONTROL n = 50	B CERVICAL n = 74	C HIGH PULL n = 53	D INTRAORAL n = 61	*Significant Differences**
C. Displacements of Landmarks						
Anterior Nasal Spine						
Orthopedic Displacement						
Variable # 1	x	1.91 ±1.73	0.46 ±1.64	−0.32 ±1.24	1.23 ±1.04	C < B < D,A
2	y	−2.16 ±1.19	−3.68 ±1.95	−1.98 ±1.05	−2.25 ±1.10	B < D,A,C
3	Hyp	2.88 ±0.19	3.71 ±0.22	2.00 ±0.14	2.56 ±0.13	
4	Angle	48.47 ±4.56	82.91 ±3.02	80.67 ±5.04	61.34 ±3.25	
Orthodontic Displacement						
Variable # 5	x	−0.03 ±0.72	0.27 ±0.84	0.35 ±0.85	0.04 ±0.75	
6	y	0.02 ±0.63	0.24 ±1.06	0.15 ±0.81	0.17 ±0.68	
7	Hyp	0.04 ±0.11	0.37 ±0.11	0.38 ±0.13	0.18 ±0.09	
8	Angle					
Total Displacement						
Variable # 9	x	1.88 ±1.82	0.73 ±2.04	0.02 ±1.47	1.27 ±1.26	C,B < A; C < D
10	y	−2.14 ±1.07	−3.44 ±2.04	−1.82 ±1.17	−2.08 ±1.18	B < A,C
11	Hyp	2.85 ±0.18	3.51 ±0.24	1.82 ±0.16	2.43 ±0.13	
12	Angle	48.60 ±4.72	77.97 ±3.87	89.30 ±6.35	58.59 ±4.15	
Upper Molar Cusp						
Orthopedic Displacement						
Variable #13	x	1.88 ±1.92	−0.19 ±2.01	−1.08 ±1.26	0.99 ±1.14	C < B < D < A
14	y	−2.10 ±0.97	−2.77 ±1.43	−0.98 ±0.98	−1.91 ±0.78	B < A,D < C
15	Hyp	2.82 ±0.21	2.77 ±0.17	1.46 ±0.13	2.16 ±0.09	
16	Angle	48.13 ±4.47	85.98 ±4.80	42.34 ±6.83	62.51 ±4.03	
Orthodontic Displacement						
Variable #17	x	0.84 ±1.19	0.04 ±2.10	−2.51 ±2.69	−0.01 ±1.75	C < D,B < A
18	y	−1.68 ±1.41	−2.22 ±1.32	0.85 ±1.83	−0.86 ±1.15	B,A < D < C
19	Hyp	1.88 ±0.18	2.22 ±0.15	2.66 ±0.40	0.86 ±0.15	
20	Angle	63.59 ±5.73	89.03 ±6.32	18.78 ±4.49	89.57 ±14.92	
Total Displacement						
Variable #21	x	2.72 ±1.69	−0.16 ±2.70	−3.59 ±3.34	0.99 ±1.81	C < B < D < A
22	y	−3.78 ±1.64	−4.99 ±2.22	−0.13 ±2.44	−2.77 ±1.38	B < A < D < C
23	Hyp	4.66 ±0.22	4.99 ±0.26	3.60 ±0.45	2.94 ±0.20	
24	Angle	54.30 ±3.08	88.20 ±3.60	2.06 ±5.51	70.38 ±4.09	
Upper Molar Apex						
Orthopedic Displacement						
Variable #25	x	1.92 ±1.74	0.39 ±1.68	−0.43 ±1.24	1.20 ±1.03	C < B < D,A
26	y	−2.10 ±0.95	−2.83 ±1.47	−1.05 ±0.97	−1.93 ±0.78	B < A,D < C
27	Hyp	2.85 ±0.19	2.86 ±0.17	1.14 ±0.13	2.28 ±0.09	
28	Angle	47.58 ±4.08	82.13 ±3.89	67.95 ±8.86	58.08 ±3.46	
Orthodontic Displacement						
Variable #29	x	0.57 ±1.55	−0.61 ±2.11	−1.49 ±2.16	−0.10 ±1.56	C,B < A; C < D
30	y	=0.50 ±1.49	−1.37 ±1.43	0.99 ±1.71	−0.49 ±1.17	B < A,D < C
31	Hyp	0.76 ±0.22	1.50 ±0.19	1.79 ±0.32	0.50 ±0.16	
32	Angle	41.32 ±15.40	66.15 ±8.57	33.63 ±6.48	78.10 ±22.51	
Total Displacement						
Variable #33	x	2.50 ±1.95	−0.21 ±2.61	−1.92 ±2.49	1.10 ±1.57	C < B < D < A
34	y	−2.61 ±1.50	−4.21 ±2.14	−0.06 ±2.29	−2.42 ±1.34	B < A,D < C
35	Hyp	3.61 ±0.24	4.21 ±0.25	1.92 ±0.34	2.66 ±0.16	
36	Angle	46.27 ±3.93	87.07 ±4.09	1.91 ±9.61	65.55 ±4.54	

†Means and Standard **Errors** for the "Hyp" and "Angle Displacement" variables.
Means and Standard **Deviations** for all other variables.
*$p < .05$ adjusted for the effects of multiple comparisons after Bonferroni (20).
Statements of significant difference are not provided for "Hyp" and "Angle" values.

little evidence of between-group differences of such magnitude as might confound the interpretation of treatment results. The coordinate values which follow are perhaps more sensitive measures of small between-group physical differences and are in some ways more interesting. The coordinate data presented are oriented in the sella-nasion frame of reference but with the origin at nasion rather than at the more commonly used sella (Fig. 1, *B1*). When nasion is used as the origin, the X coordinate for any structure constitutes a very good estimate of the structure's relationship to the facial profile while the Y coordinate has the same value and meaning that it would have with the origin at sella.

It will be seen that, even though the absolute differences between group means are not large for most coordinate measures, the observed differences are statistically significant for a number of measures. We should not be surprised to find *some* real between-group differences in coordinate values, given the previously mentioned differences in age at which the clinicians have chosen to initiate different types of treatment. The question is, rather, whether the observed differences in antecedent state are associated with corresponding differences in treatment outcome for the parameters under study. To answer this question, tests of residuals were made by plotting the antecedent X and Y values of the three landmarks under study against their observed orthodontic and orthopedic displacements.[14] It was concluded that there was no discernible association between the original anteroposterior position of the landmarks and their displacement during treatment. Hence, the observed differences in antecedent values are deemed to be of no consequence to the interpretation of treatment effects in this study.

Between-sample comparisons of observed displacement

Description of data available. Table IIA summarizes for each treatment the observed changes in the conventional measures listed in Sections A and B of Table I.

Table IIB reports the angular rotation (in degrees) of the upper first molar as a result of orthopedic movement, the angular rotation of the upper first molar as a result of orthodontic movement, and the total angular rotation of the upper first molar. It will be noted that the angular rotation of the upper first molar as an orthopedic effect is identical to the angular rotation of the palate (since for these purposes we have converted the palate cum molar into a single rigid body). For reader convenience, however, we have relisted the values.

Table IIC summarizes the *observed changes* in position for each of three landmarks in each of the four subsamples. Because the values reported in this table are from measurements of *total observed change*, they reflect in the three treatment groups the combined effects *both* of treatment *and* of intercurrent growth and development. The values reported for the control group are, however, entirely the product of growth and developmental changes, since no treatment of any sort has been delivered to the subjects in this group. Data are reported in terms of an orthogonal coordinate system in which the X axis is parallel to the Downs occlusal plane of the pretreatment film with the origin at the timepoint 1 location of the landmark under consideration (Fig. 1, *B2*). For each landmark for each subsample, we report descriptive statistics on ortho*pedic* displacement, ortho*dontic* displacement, and total displacement as defined under Methods of Analysis and illustrated in Fig. 1, *A*. Note again, however, that the terms "ortho*dontic*" and ortho*pedic*" as conventionally used and as defined in the introduction refer to *types of movement* rather than to treatment effects.

For each type of movement, we report X displacement, Y displacement, total linear displacement (termed "HYP"), and angle of displacement relative to the X axis (termed "ANG"). Statements of statistically significant difference between treatments at the 0.05 level, corrected after the method of Bonferroni[20] for the effects of conducting multiple statistical comparisons, are listed for all measures. (In this study, six comparisons have been conducted for each measure.)

Fig. 2 summarizes, in graphic form and to scale, the mean values for the several variables of Table II. The meaning of the findings is considerably easier to grasp in these graphic terms, so our written presentation will be keyed almost entirely to the figure. In describing changes, we will discuss the data mainly in terms of the mean values of the appropriate measures for each treatment group. Measures of variability within and between treatments are also available in Table II in the form of standard deviations and standard errors.

Expanded characterization of selected data on observed changes. In this portion of the text we will draw attention to a number of specific findings of particular interest which are abstracted from Table II and illustrated in Fig. 2. The four subsamples will be considered separately. In connection with each assertion in the text, we will attempt to specify the numerical statistic in Table II upon which that assertion is based. In order to keep the text from being lengthened unduly, these specifications will be the table section and the variable number. Thus, for example, the location of a reference

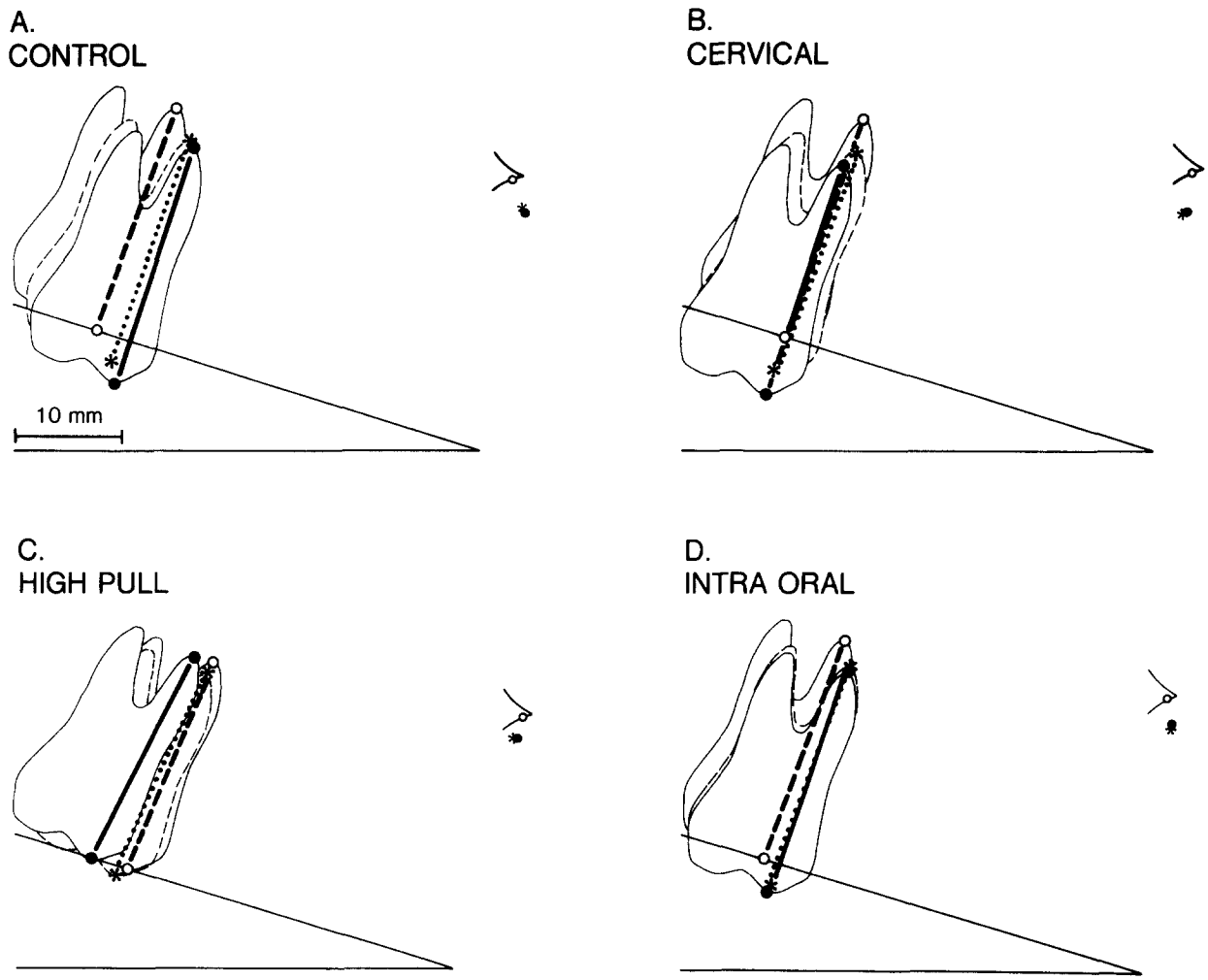

Fig. 2. Observed displacements for three landmarks (ANS, upper first molar cusp, and upper first molar apex). For each landmark, the white dot represents the starting location at the timepoint 1 film, the asterisk represents the landmark's theoretical intermediate position, and the black dot represents the landmark's position at timepoint 2. (All portions of this figure are drawn to the same scale, and the relative locations of the landmarks are accurately depicted. However, tooth contours are interpolated and are only approximate.)

to "ortho*dontic* rotation of the upper first molar" will be indicated as "B2."

CONTROL GROUP. Fig. 2, *A* and column A of Table II describe the *observed changes* in position of the upper first molar and of ANS for the control group. The molar cusp and the point ANS each displace downward and forward approximately 3 mm. (C15 and C3) at an angle of approximately 50 degrees (C16 and C4) to the occlusal plane purely as a result of the displacement of the maxilla with respect to the anterior cranial base. This movement is the analog of "ortho*pedic*" displacement. In addition, the molar cusp displaces downward and forward *within* the maxilla about 2 mm. (C19) at an angle of about 65 degrees to the occlusal plane (C20). This movement, the analog of ortho*dontic* displacement, represents *in the control group* a measure of the developmental mesial migration of the upper first molar. (The equivalent type of observed displacement at ANS would be a representation of bone remodeling.) The data also show that in the control group there is essentially no change in the cant of palatal plane (A5) and hence no equivalent "ortho*pedic*" rotation of the upper first molar (B1). On the other hand, the first molar uprights an average of about 1 degree (B2) as its crown comes forward more than does its root (compare C17 and C29) during the process of eruption. In terms of our definitions, this is the analog of an ortho*dontic* effect.

CERVICAL GROUP. In Fig. 2, *B* and in column B of Table II, the *observed changes* in position for the cervi-

cal sample are represented, and we see that they are quite different indeed. The total linear ortho*pedic* displacement of ANS is greater than that in the control group (C3), and the direction has been altered so that the angle of movement with respect to the occlusal plane is much more nearly vertical (C4). Anterior displacement of ANS is markedly reduced as compared to the control group (C1). In the region of the molar cusp, anterior ortho*dontic* displacement is virtually nil (C17), while the downward component of ortho*dontic* displacement is slightly greater than that observed in the control group (C18). So far as rotation of the palate is concerned, we observe that the ortho*pedic* effect is associated with a slightly greater downward movement at ANS (C2) than at the molar apex (C26), increasing the cant of palatal plane about 1.75 degrees (A5) and rotating the molar cusp distally to the same extent (B1). However, the ortho*dontic* rotation of the molar (B2) is in the opposite direction from that of the palatal cant, so that the final angulation of the tooth (B3) is not much different from its angulation at the first film.

HIGH-PULL GROUP. Fig. 2, *C* and column C of Table II show the analogous *observed changes* in the "high-pull" group. In this group, the patients were instructed to use forces of greater magnitude than those used in the two other treatment groups. The observed displacements are strikingly different from those in the other samples in terms of both the magnitude and the character of the displacements observed. The observed ortho*pedic* displacement includes a small but real absolute reversal of the mesial movement of ANS which was seen in the control group and the other two treatment groups (compare values of C1), as well as a reduction in the downward displacement of the posterior bony palate (compare values of C26). These effects combine to produce an increase of about 2 degrees in the cant of the palatal plane (A5) and in distal crown tip of the molar (B1). The magnitude of these rotational changes is very similar to those observed in the cervical group, even though in this case the total downward movement of ANS is smaller (compare values for C2). The molar cusp in the high-pull group also has an observed downward displacement averaging 1 mm. as an ortho*pedic* effect (C13).

The observed ortho*dontic* displacements for the high-pull group are entirely different from those in the other groups. On average, the molar cusp is displaced upward and backward approximately 2.5 mm. (C19) at an angle of about 20 degrees to the occlusal plane (C20). In the process, the tooth tips distally another 2.5 degrees (B2), ending with its apex roughly 2 mm. distal to its starting position (C33) and with an increase in distal crown tip totaling about 4.5 degrees (B3). The mean location of the molar cusp at the end of treatment is about 3.5 mm. distal to its original position (C21), while its vertical orientation is essentially unchanged with respect to the pretreatment occlusal plane (C22). Note that, contrary to our expectations from theory, by far the larger component of tooth movement in the high-pull group is an ortho*dontic* displacement—not an ortho*pedic* displacement (compare C17 with C13).

INTRAORAL GROUP. Fig. 2, *D* and column D of Table II represent the *observed changes* associated with modified activator treatment. The change in cant of the palatal plane (A5) and the equivalent ortho*pedic* rotation of the first molar (B1) are less than for either of the other treated groups—only about 0.6 degree. The ortho*dontic* rotation of the molar (B2) is also less than that for either of the other treatment groups.

As concerns ortho*pedic* displacement of the maxilla as seen from ANS, forward movement is impeded slightly as compared to the control group but not as much as in either of the other treatment groups (compare values of C1). Downward ortho*pedic* displacement of the maxilla is similar to that observed in the control group, both in the region of the molar cusp (C14) and in the region of ANS (C2).

The ortho*dontic* displacement of the molar cusp is reduced in both the forward direction (C17) and the downward direction (C18) as compared to the untreated control group, and the total displacement of the tooth from combined orthodontic and orthopedic effects (C23) is smaller than that in any other sample.

Between-sample comparisons of treatment effect

Description of data available. The findings of Table II and Fig. 2 which have just been summarized contain information on the *combined effects* of treatment *and* of the processes of growth and development which took place during the treatment period. It would be desirable to be able to gain at least an approximate idea of the effects of treatment per se by factoring out the effects of intercurrent growth and development for the treated subjects. Certainly, no perfect assessment is currently possible, but we may at least attempt an approximation.

Our best estimate of the effects of intercurrent growth and development upon any treated patient during a given interval of treatment is the mean change observed over a similar time interval in a control group of untreated subjects with the same type of malocclusion. This self-evident principle provides a basis for estimating the "pure treatment effect" in our treated samples by factoring out of the total observed changes

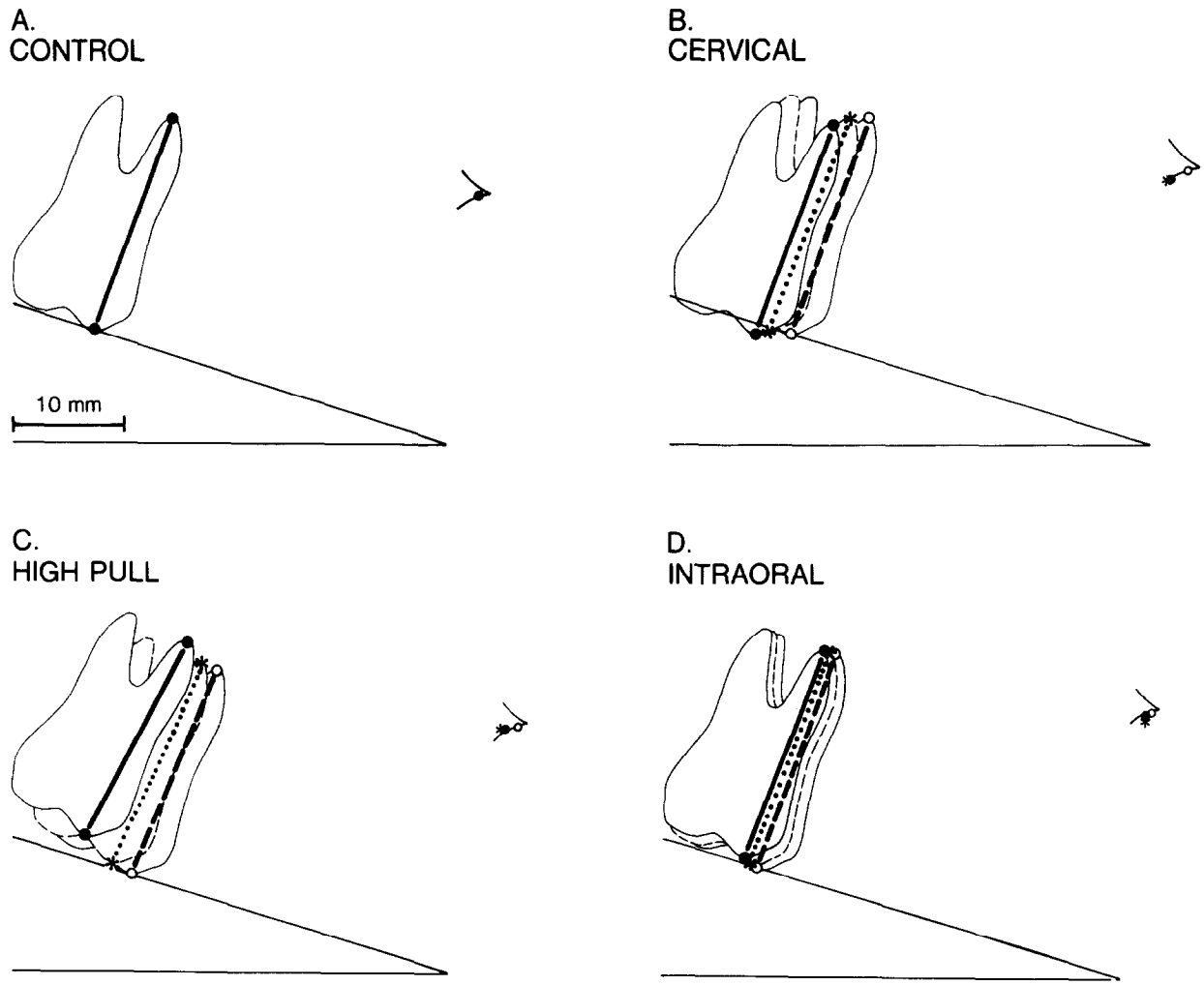

Fig. 3. Treatment effects (as defined in the text) for three landmarks (ANS, upper first molar cusp, and upper first molar apex). For each landmark, the white dot represents the starting location at the timepoint 1 film, the asterisk represents the landmark's theoretical intermediate position, and the black dot represents the landmark's position at timepoint 2. (All portions of this figure are drawn to the same scale, and the relative locations of the landmarks are accurately depicted. However, tooth contours are interpolated and are only approximate.)

reported in Table II an estimate of the changes that would have occurred solely as a result of growth and development had the persons in question not been treated.

In order to conduct such a factoring-out operation, we compute the annual rate of displacement for each member of the control group for each of the parameters that we are interested in measuring. The mean annual rate for the entire control group is then computed by taking the average of the individual rates (which we designate $\overline{X}_c$).

Once we have calculated $\overline{X}_c$, the method of factoring out the estimated growth effect for any patient in any treatment group is as follows:

$$E_i = O_i - (\overline{X}_c \cdot EYEARS_i)$$

where O_i = observed change for the patient, $EYEARS_i$ = the between-films time interval for that patient in years, and E_i = treatment effect for the patient. The best estimate of the treatment effect for any treatment group is then taken to be the mean among the E_i's of that group.

We believe that this scheme for factoring out the growth effect is consistent with current biologic concepts and that, although it is clearly imperfect, it is the best device currently available. Its main weakness is that it assumes rates of change within persons to be constant during the treatment period. Such an assumption is clearly not completely valid but, as we have

TABLE III: Between Sample Comparisons of **Treatment Effect:** Parts A and B Means, Standard Deviations & Standard Errors†

	TREATMENT TYPE				
	A CONTROL n = 50	B CERVICAL n = 74	C HIGH PULL n = 53	D INTRAORAL n = 61	*Significant Differences**
A. CHANGES in Conventional Measures					
1. Occlusal Plane Angle (Downs)	0.07 ± 1.98	0.93 ± 2.79	3.89 ± 2.73	1.63 ± 2.18	A,B,D < C; A < D
2. Mandibular Plane Angle (Downs)	−0.04 ± 1.29	0.85 ± 1.79	0.26 ± 1.38	0.07 ± 1.38	A,D < B
3. SNA Angle	0.04 ± 1.40	−1.75 ± 2.10	−2.01 ± 1.11	−0.21 ± 1.35	C,B < D,A
4. Class II Severity	0.09 ± 1.88	3.61 ± 1.96	4.83 ± 3.07	2.75 ± 2.13	A < D,B,C; D < C
5. Cant of Palatal Plane	0.04 ± 1.46	1.69 ± 1.75	1.86 ± 1.21	0.57 ± 1.27	A,D < B,C
B. Rotations of the Upper First Molar					
1. Orthopedic Rotion	0.04 ± 1.46	1.69 ± 1.75	1.86 ± 1.21	0.57 ± 1.27	A,D < B,C
2. Orthodontic Rotation	−0.01 ± 3.79	−1.08 ± 6.18	3.16 ± 7.68	0.44 ± 5.32	B,A < C
3. Total Rotation	0.03 ± 3.65	0.61 ± 6.17	5.02 ± 7.46	1.02 ± 5.13	A,B,D < C

†Means and Standard **Errors** for the "Hyp" and "Angle of Displacement" variables.
Means and Standard **Deviations** for all other variables.
*$p < .05$ adjusted for the effects of multiple comparisons after Bonferroni (20).

demonstrated from studies of residuals, it seems, on average, to be acceptable for groups of persons over the relatively short treatment periods considered here.

To illustrate the method, we demonstrate the actual calculations for a pair of representative but hypothetical patients. Let us assume that we wish to compute the orthopedic component of treatment effect for horizontal displacement at ANS. Our first patient has an elapsed time between head films of 2.5 years and an *observed* (which is to say, directly measured) *change* in the mesial or positive direction of 0.5 mm. relative to superimposition on the anterior cranial base. The second hypothetical patient required only 1.5 years of Phase 1 clinical intervention and had an *observed change* of ANS in the *distal* direction of 0.4 mm.

We wish to assess the actual effect of treatment itself upon ANS location for each of these patients. In order to do so, we must estimate what would have happened to each patient between timepoints had no treatment taken place. For each individual patient, the best estimate of what would have happened between timepoints had the patient not been treated is the mean *observed change* for the given variable which occurs during an equal period of time for a group of similar persons for whom no treatment is performed. Such an estimate may be obtained by multiplying the mean annual rate of change in the control group by the amount of time for which the individual patient was treated.

At Table II, column A, variable C1, we see that the mean value for X displacement at ANS in the control group was 1.91 mm. (In biologic terms, this value represents the mesial or anterior displacement of ANS measured relative to superimposition on the anterior cranial base which occurs as a result of the spontaneous growth and development of the head.) At Table II, column A, variable A6, we observe that the mean elapsed time between films in the control group is 2.17 years. Dividing 1.91 by 2.17, we calculate an estimate of the average annual rate to be +0.88 mm. per year. This value corresponds to $\overline{X}_c$ in our formula, and we now have all the information we need in order to derive the E_i or treatment effect values for each of our hypothetical patients as follows:

Recall that

$$E_i = O_i - (\overline{X}_c \cdot \text{EYEARS}).$$

Then for the first patient,

$$E_1 = +0.50 - (0.88 \cdot 2.5)$$
$$= +0.50 - (2.2)$$
$$= -1.70$$

For the second patient,

$$E_2 = -0.40 - (0.88 \cdot 1.5)$$
$$= -0.40 - (1.32)$$
$$= -1.72$$

Since each of these E_i values is adjusted for the effect of individual differences in treatment time, we have accomplished the task of adjusting the directly observed displacements for the differences in spontaneous development that would have occurred in the

TABLE III: Between Sample Comparisons of **Treatment Effect:** Part C
Means, Standard Deviations & Standard Errors†

		TREATMENT TYPE				
		A CONTROL n = 50	B CERVICAL n = 74	C HIGH PULL n = 53	D INTRAORAL n = 61	*Significant Differences**
C. Displacements of Landmarks						
Anterior Nasal Spine						
Orthopedic Displacement						
Variable # 1	x	0.07 ± 1.60	−1.51 ± 1.70	−1.45 ± 1.19	−0.45 ± 1.03	B,C < D,A
2	y	−0.03 ± 1.05	−1.41 ± 1.93	−0.68 ± 0.80	−0.31 ± 1.09	B < C < A; B < D
3	Hyp	0.07 ± 0.19	2.07 ± 0.22	1.60 ± 0.15	0.55 ± 0.15	
4	Angle		43.22 ± 5.50	24.95 ± 4.58	34.35 ± 12.92	
Orthodontic Displacement						
Variable # 5	x	−0.02 ± 0.72	0.29 ± 0.84	0.35 ± 0.85	0.05 ± 0.75	
6	y	0.00 ± 0.63	0.22 ± 1.06	0.14 ± 0.81	0.15 ± 0.68	
7	Hyp	0.02 ± 0.10	0.36 ± 0.11	0.38 ± 0.13	0.16 ± 0.09	
8	Angle					
Total Displacement						
Variable # 9	x	0.05 ± 1.72	−1.22 ± 2.09	−1.10 ± 1.46	−0.40 ± 1.27	B,C < D,A
10	y	−0.03 ± 0.93	−1.19 ± 2.00	−0.53 ± 0.96	−0.15 ± 1.18	B,C < A; B < D
11	Hyp	0.06 ± 0.19	1.70 ± 0.24	1.22 ± 0.21	0.43 ± 0.17	
12	Angle		44.39 ± 8.01	25.99 ± 5.79		
Upper Molar Cusp						
Orthopedic Displacement						
Variable #13	x	0.05 ± 1.83	−2.15 ± 2.07	−2.20 ± 1.20	−0.68 ± 1.15	C,B < D,A
14	y	−0.01 ± 0.86	−0.55 ± 1.43	0.29 ± 0.71	−0.01 ± 0.79	B < D,C
15	Hyp	0.05 ± 0.25	2.21 ± 0.24	2.22 ± 0.17	0.68 ± 0.15	
16	Angle		14.27 ± 4.41	7.56 ± 2.51	0.73 ± 8.51	
Orthodontic Displacement						
Variable #17	x	−0.02 ± 1.20	−0.87 ± 2.09	−3.04 ± 2.61	−0.79 ± 1.74	C < B,D < A
18	y	0.01 ± 1.38	−0.42 ± 1.30	1.89 ± 1.66	0.68 ± 1.14	B,A < D < C
19	Hyp	0.02 ± 0.16	0.97 ± 0.23	3.58 ± 0.37	1.04 ± 0.21	
20	Angle		25.61 ± 10.37	31.86 ± 3.31	40.85 ± 8.82	
Total Displacement						
Variable #21	x	0.03 ± 1.56	−3.02 ± 2.73	−5.24 ± 3.10	−1.46 ± 1.78	C < B < D < A
22	y	−0.00 ± 1.47	−0.96 ± 2.19	2.18 ± 1.96	0.67 ± 1.36	B < A,D < C
23	Hyp	0.03 ± 0.21	3.17 ± 0.32	5.67 ± 0.45	1.61 ± 0.23	
24	Angle		17.71 ± 4.63	22.60 ± 2.20	24.66 ± 5.84	
Upper Molar Apex						
Orthopedic Displacement						
Variable #25	x	0.06 ± 1.61	−1.58 ± 1.74	−1.56 ± 1.18	−0.49 ± 1.03	B,C < D,A
26	y	−0.01 ± 0.84	−0.61 ± 1.46	0.22 ± 0.69	−0.03 ± 0.79	B < D,A,C
27	Hyp	0.06 ± 0.22	1.70 ± 0.20	1.58 ± 0.16	0.49 ± 0.13	
28	Angle		20.95 ± 5.97	8.16 ± 3.53		
Orthodontic Displacement						
Variable #29	x	−0.03 ± 1.56	−1.25 ± 2.13	−1.86 ± 2.12	−0.65 ± 1.56	B,C < A; C < D
30	y	0.01 ± 1.49	−0.83 ± 1.42	1.30 ± 1.65	−0.02 ± 1.17	B < D,A < C
31	Hyp	0.03 ± 0.23	1.50 ± 0.24	2.27 ± 0.31	0.65 ± 0.20	
32	Angle		33.49 ± 6.82	35.04 ± 5.11	1.97 ± 13.11	
Total Displacement						
Variable #33	x	0.03 ± 1.85	−2.84 ± 2.71	−3.42 ± 2.31	−1.14 ± 1.57	C,B < D < A
34	y	0.00 ± 1.41	−1.43 ± 2.08	1.53 ± 1.91	−0.05 ± 1.34	B < D,A < C
35	Hyp	0.03 ± 0.26	3.18 ± 0.32	3.75 ± 0.36	1.14 ± 0.20	
36	Angle		26.83 ± 4.27	24.06 ± 3.16	2.45 ± 8.53	

†Means and Standard **Errors** for the "Hyp" and "Angle of Displacement" variables.
Means and Standard **Deviations** for all other variables.
*$p < .05$ adjusted for the effects of multiple comparisons after Bonferroni (20).
Statements of significant difference are not provided for "Hyp" and "Angle" values.

two patients as a result of differences in treatment duration. The final values represent reasonable estimates of pure treatment effect. (For the mathematically rigorous reader, we note in passing that the value actually used as $\overline{X}_c$ in Table III is the mean among the rates of the individual cases in the control group rather than the ratio between the mean displacement and the mean elapsed time. While we believe that the mean among rates is the conceptually superior statistic, the actual numerical differences between the output variable values when the two methods are used occur only at the second decimal place and hence have no substantive bearing on the thrust of this study.)

Applying this method to all the variables of Table II, we derive and present in Table III and Fig. 3 a set of estimates of treatment effect adjusted to remove contributions from intercurrent growth and developmental changes. Of course, the set of statistics that results could never exist in nature since treatment takes time and developmental changes occur inevitably with the passage of time. Rather, the statistics presented are a reasonable representation of a set of natural occurrences with some of its components factored out. Examination of this table and figure (like examination of a lateral skull film) allows us to perceive with greater clarity some aspects of the system under observation which, in the original, were obscured by intercurrent processes that are not the present focus of interest.

Expanded characterization of selected data on treatment effects. The remainder of this section on results consists of comments concerning the data on *treatment effects* contained in Table III and Fig. 3. In making these comments, we have used the same convention previously observed with respect to Table II by supporting each text assertion with a variable designation. For example, data dealing with the horizontal displacement of the upper molar cusp as a result of migration of the tooth *within* the maxilla would be labeled "C17."

CONTROL GROUP. Fig. 3, *A* and column A of Table III represent the effects of conducting the mathematical operations just described upon the untreated control sample. We see that there is, on average, essentially zero displacement of ANS or of the upper molar cusp or apex. This is to be expected, since what we have factored out is precisely the displacements of the untreated control sample. The residual deviations from zero are computational "noise" resulting from the fact that not all persons in the control group grew at the same rate.

CERVICAL GROUP. Fig. 3, *B* and column B of Table III represent the similarly derived values for the cervical treatment group. At ANS, the mean ortho*pedic* effect of treatment (which is to say, the difference as compared to the control group) is a mean downward and backward displacement of about 2 mm. (C3) at an angle of about 40 degrees (C4) to the occlusal plane of the first film. Ortho*dontic* displacement measured at ANS totals, on average, about 0.3 mm. (C7) as compared to the analogous change measured in the control group.

The *treatment effects* observed in the region of the upper molar cusp are of somewhat different character. Here the mean ortho*pedic* effect has a larger distal component (compare C13 with C1) and a smaller downward component (compare C14 with C2) than is the case at ANS, so that, on average, the cusp moves downward and backward about 2.3 mm. (C15) at an angle of only about 15 degrees (C16) to the occlusal plane of the first film. The ortho*dontic* contribution typically adds an additional 0.9 mm. of distal displacement (C17) plus about 0.4 mm. of downward displacement (C18). The total effect is a mean distal displacement of about 3 mm. (C23) (just sufficient, on average, to correct the Class II molar relationship in this sample) with a relative extrusion of just under 1 mm. (C22) as compared with the control group. This value for extrusion is much smaller in absolute terms than many practitioners would have anticipated for this treatment modality. However, it should be noted that the cervical treatment is the only one of three treatments in which *any* extrusion of the first molar is observed as a treatment effect.

HIGH-PULL-TO-MOLAR GROUP. The treatment effects in the high-pull group, which are shown in Fig. 3, *C* and column C of Table III, are different in character. Total *treatment effects* at the molar are substantially greater than for either of the other treatment groups and are accompanied by the largest mean value for treatment-associated distal crown tipping (B3). This tipping is primarily ortho*dontic* in character (B2). At ANS, the mean ortho*pedic* displacement in the horizontal direction (C1) is similar to that seen in the cervical group, but the downward displacement observed (C2) is much smaller. Remodeling at ACB (the osseous analog to ortho*dontic* displacement) is not markedly dissimilar from that in the cervical group in either magnitude or direction (compare C5 through C8). In the region of the molar cusp, the most striking findings are the total magnitude of the ortho*dontic* displacement—a mean value of more than 3.5 mm. from this component alone (C19)—plus the fact that the tooth *intrudes* both as an ortho*pedic* (C14) and as an ortho*dontic* (C18) effect. Total repositioning of the molar cusp (as compared to what might have been expected

had the case remained untreated) involves a mean distal displacement of about 5.2 mm. (C21) and a mean intrusion of about 2.2 mm. (C22).

INTRAORAL GROUP. The treatment effects in the intraoral group are smaller in magnitude than those observed for either of the extraoral appliances, as may be seen in Fig. 3, *D* and column D of Table III. At ANS, total displacement from combined ortho*pedic* displacement and remodeling differs, on average, by less than 0.5 mm. from the analogous mean value for the control group (C11). At the molar cusp the treatment effects are somewhat more consequential. There, total displacement averages about 1.5 mm. (C21) as compared to the control group, stemming about equally from ortho*dontic* (C17) and ortho*pedic* (C13) contributions. In the vertical direction, there is a mean intrusion of about 0.7 mm. as compared to the untreated controls, all of it being of ortho*dontic* origin (C18). This finding is a quantitative representation of the success of this appliance in retarding the eruption of the upper molar. (Harvold[21] has characterized this retarding of upper molar eruption as a major mechanism by means of which the modified activator corrects Class II molar relationships.)

DISCUSSION

On the basis of these findings, some important general conclusions seem appropriate. First, the use of forces to retract the maxilla does produce substantial effects in the maxilla of both the ortho*pedic* and ortho*dontic* types. Second, the character and magnitudes of the effects observed are different when different appliance systems are used. The high-pull appliance, which was also the device with which the largest nominal force values were used, produced the largest changes of *both* the orthopedic *and* the orthodontic types in the region of the upper first molar and did so over the shortest mean treatment time. Contrary to our expectations from classic orthodontic theory, distally directed tooth displacement in the molar region with this relatively high force system was more ortho*dontic* than ortho*pedic* in character, as may be seen in Table III. (Ortho*dontic* treatment effect, $\overline{X} = -3.04$ mm., variable C17; ortho*pedic* treatment effect $\overline{X} = -2.20$ mm., variable C13). On the other hand, the analogous values for the cervical appliance, a relatively low force system as used here, show a *smaller* ortho*dontic* effect than ortho*pedic* effect. (Ortho*dontic* treatment effect, $\overline{X} = -0.87$ mm., variable C17; ortho*pedic* treatment effect, $\overline{X} = -2.15$ mm., variable C13). These observations are contrary to the expectations from conventional theory but consistent with recent observations by Weislander[21] and others. The intraoral apparatus, which may reasonably be characterized as the lightest force system of the three, produced smaller magnitudes of tooth displacement than did either of the other two devices. Its total impact was about equally divided between ortho*dontic* and ortho*pedic* effects. (Ortho*dontic* treatment effect, $\overline{X} = -0.79$ mm., variable C17; ortho*pedic* effect, $\overline{X} = -0.68$ mm., variable C13).

These data might be taken to support the conclusion that heavier forces tend to displace the teeth within the bone while lighter forces tend to displace the bony matrix in toto. If the causal relationship were this straightforward, we might expect to find high within-treatment associations between elapsed time required for Class II correction and the within-case ratio of orthopedic displacement to orthodontic displacement. In order to test for the strength of this association, within-treatment Pearson correlations were computed, relating elapsed time of treatment and the ratio between orthodontic and orthopedic displacement of the molar cusp. These correlations proved to be quite weak, implying that the ratio between orthodontic and orthopedic displacement which we observe within individual cases depends mainly on factors other than force magnitude. We conclude, therefore, that the precise relationship between force magnitude and type of displacement in the clinical situation is still incompletely defined. It does seem clear, however, that the data of Tables II and III do *not* support the hypothesis that heavy forces produce ortho*pedic* displacement while light forces produce ortho*dontic* displacement.

Viewed from the perspective of ANS, it was also manifest that all appliance systems produced changes. As compared to the untreated control group, the total treatment effect in the cervical sample may be seen to have involved a downward and backward displacement of ANS approximating 1.7 mm. (C11) at an angle of about 45 degrees (C12). The analogous effect in the high-pull group involved a somewhat smaller linear displacement, the main difference being in the vertical component (compare C9 and C10). As was the case in the molar cusp region, the mean treatment effects at ANS were smaller in the intraoral group than for either of the extraoral appliances. Here mean total linear displacement differed by less than 0.5 mm. from the control group base line value (C11), being about one third that of the high-pull group and one fourth that of the cervical group.

So far as changes in the orientation of the palate are concerned, all appliance systems tended to increase the cant of the palatal plane which, in the untreated control group, remained remarkably constant on average. This

increase in the cant of the palatal plane was similar in magnitude in the two extraoral samples, measuring 1.73 degrees in the cervical group and 1.89 degrees in the high-pull group. (These values are from Table II, variable A5). However, as has already been indicated, the *mechanism* of change in the two groups appeared to be different. By this, we mean that in the cervical group the change appeared to involve relatively greater downward displacement in the anterior region of the palate while in the high-pull group it appeared to be associated with relative upward movement in the posterior part of the palate. The increase in the cant of the palatal plane in the intraoral group was only about one third that in the extraoral groups.

We have also been concerned with the estimation of the longer-range effects of the displacements of the maxilla and the upper molar under investigation here. In the course of the present study, we have become more sharply aware of the clinical importance of the fact that treatment modalities such as the high-pull headgear, which achieve treatment goals over relatively brief periods of intensive treatment, leave the patient with a longer residual posttreatment period in which spontaneous growth and developmental changes can continue to occur. We believe that the question of whether the processes of treatment accelerate, decelerate, or leave unaltered the magnitude of posttreatment developmental changes is still unresolved. We have attempted to generate projections of the anticipated posttreatment state for each of our samples based on the assumption that posttreatment development within each sample would proceed at the same rate as in the untreated control group. However, since we currently lack appropriate long-range follow-up films for most of the cases reported here, we have no way at present of testing empirically the validity of those projections. Hence, we defer reporting conclusions about long-range perturbations in growth pattern until more appropriate long-range data are available to us.

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