A Clinical Investigation of the Concepts of Differential and Optimal Force in Canine Retraction

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Introduction

It is, perhaps, safe to assume that all orthodontic "philosophies" advocate the application of force. Beyond this, there is, or at least should be, considerable interest in characterizing the nature of the relationship between, on one hand, the magnitude of the applied force and, on the other, both the rate of tooth movement and the extent of anchorage loss.

Based on the classic studies of Storey and Smith [14,16] and Reitan,[9,10,11] the use of "light" forces has become increasingly popular, the assumption being that a so-called "differential" movement of teeth can generally be achieved. Moreover, it is generally thought that light forces are somewhat more efficient and somehow more "biologic" and, hence, less painful. Recently, however, Hixon and associates[6,7] have reported so great a variation in individual response as to cast doubt on the concept of differential forces, at least as it is generally enunciated. With respect to canine retraction they found that higher forces were generally more efficient.

Obviously, if light forces confer no consistent advantage vis-à-vis anchorage preservation and are less efficient with respect to tooth movement, per se, then heavier forces might once again be accorded a measure of overt respectability.

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The crux of the problem would seem to be the need for an analysis of the response to various force-magnitudes both *within* and *among* individuals. An obvious approach is an investigation cast in the form of a randomized-block analysis of variance.

It will be the purpose of this paper to examine clinically the following questions using canine retraction as the model system:

1) Is there a magnitude of force which can be regarded as "optimal" for a significant percentage of orthodontic patients?

2) Is there a generalized differential response to "differential" forces?

3) Do lighter forces produce significantly less discomfort?

Methods

Seven males and three females, twelve to sixteen years of age, who required the removal of four first premolar teeth and distal retraction of the canines were drawn from one hundred patients who presented for treatment at Case Western Reserve University Department of Orthodontics. Other than consent, the only criteria established for selection were: 1) the complete eruption of all teeth anterior to the first permanent molars, and 2) the necessity of first premolar extraction as determined by standard diagnostic procedures.

Experimental Design

In statistical terms each subject constituted a "block" of four quadrants. Accordingly, four forces could conveni-

TABLE I
EXPERIMENTAL DESIGN: FORCE ASSIGNMENT
(ounces)

Patient	Quadrant			
	Left		Right	
	Upper	Lower	Upper	Lower
1	2	11	8	5
2	11	8	2	5
3	5	2	11	8
4	5	11	8	2
5	11	5	2	8
6	2	8	5	11
7	8	11	5	2
8	8	5	2	11
9	8	2	11	5
10	11	2	5	8

ently be examined. In one quadrant a force of two ounces (about 55 gm) was employed (Paulson,[8] Reitan,[9] Stoner,[15]). In two quadrants, forces representative of Storey and Smith's "optimal forces," five ounces (about 140 gm) and eight ounces (about 225 gm), were used. In the remaining quadrant a force somewhat above Storey and Smith's "optimal" level but within the range used by Hixon and associates was used.[6] The magnitude of this force was eleven ounces (approximately 310 gm). The various treatment combinations were assigned randomly to the ten subjects as summarized in Table I.

Clinical Procedure

To maximize the rate of canine retraction, the first premolars were extracted one month prior to the onset of the study.[3] As shown in Figure 1, retraction was effected by Ricketts .016 x .016 sectional retraction springs.

This type of appliance was employed for a variety of reasons:

1) Presumably a treatment applied to one quadrant will have little effect on the other three.

2) With appropriate modification (vide infra), a considerable range of forces can be obtained from a fixed activation distance.

3) There is sufficient wire to ensure a relatively constant force.

4) The appliance is frictionless and thus simplifies interpretation of the data.

Fig. 1 Sectionals employed in canine retraction.

The active elements of the retraction springs were reduced electrolytically until the desired amount of force (2, 5, or 8 ounces) could be achieved with a deflection equal to that of the eleven-ounce spring. After insertion, each sectional was activated to the predetermined force-level (as judged by a standard 16 ounce tension gauge) and crimped distal to the buccal tube. The appliances were reactivated weekly at the buccal tube; if necessary, additional adjustments were also made mesial to the cuspid bracket.

Data Collection

To determine the amount of space closure, direct intraoral measurements (to the nearest .05 mm) of the distance between a notch cut into the molar buccal tube and the distal surface of the distal canine bracket were taken weekly for up to ten consecutive weeks.

Study casts were obtained immediately before placement of the appliances and at the end of the ten-week experimental period, immediately after the removal of the appliances. In those patients whose progress dictated that the investigation be terminated before the ten-week period, study casts were taken at the time of removal of the appliances. Measurements were made from cusp-tip of the canine to buccal cusp-tip of the second premolar.

To estimate the amount of canine retraction, as well as that of anchorage loss, 22.5° lateral cephalograms were taken just before appliance placement and immediately prior to appliance removal. An "intraoral grid",[4] a flexible polystyrene rod with ball bearings centered at four millimeter intervals, was used to correct for distortion and magnification. The grid was shaped to the form of the dental arch and embedded in a wax bite. Both cephalograms were traced and superimposed by way of individual landmarks in the region of the extraction site. An arbitrary vertical reference line was drawn at the extraction site and transferred to the other tracing in the series. The horizontal distance from the center of the canine and molar crown was measured and, with the aid of the grid, corrected by means of simple proportions. The difference between the corrected "before" and "after" dimensions was taken as the amount of anchorage loss or canine retraction.

Each patient was asked weekly if he had experienced tooth discomfort from the appliances. If discomfort had been experienced, he was asked to indicate the areas where it occurred. The number of complaints along with the quadrant in which each occurred were recorded for each patient.

Calculations were carried out on an electronic calculator and its accompanying software. The statistical design was a randomized-block analysis of variance, each patient constituting a block. In patient number two the data for the five ounce force level had to be estimated due to very early space closure. The method used was that outlined by Cochran and Cox.[2] Tukey's method for multiple comparisons as described by Guenther[5] was used to make individual contrasts suggested by the data.

In addition, a contingency test was employed to test the hypothesis that anchorage loss is independent of the force employed. Friedman's two-way analysis of variance by ranks was used to analyze the tooth discomfort data.[13]

Results

All patients showed the same general pattern of tooth movement. The relationship between average movement and time is depicted in Figure 2. As may be seen, there was an initial phase of very rapid tooth movement followed by a lag phase which, in turn, was superseded by an asymptotic post-lag phase. The pattern was the same for both arches and for each of the four forces.

Results for the several classes of measurements are summarized in Table II and variance ratios in Table III. There was a significant treatment effect for both the intraoral and model data, but not for cephalograms. With respect to this latter finding it is perhaps significant to compare the magnitude of the various "residual" terms.

Application of Tukey's "omega procedure" to the two significant analyses revealed the following:

1) For intraoral determinations the two ounce force level differed significantly ($p<.05$) from each of the other forces, as well as from their average.

2) For the model data the two ounce force level produced significantly less closure than eleven ounces; the other contrasts were not significant at the 5%

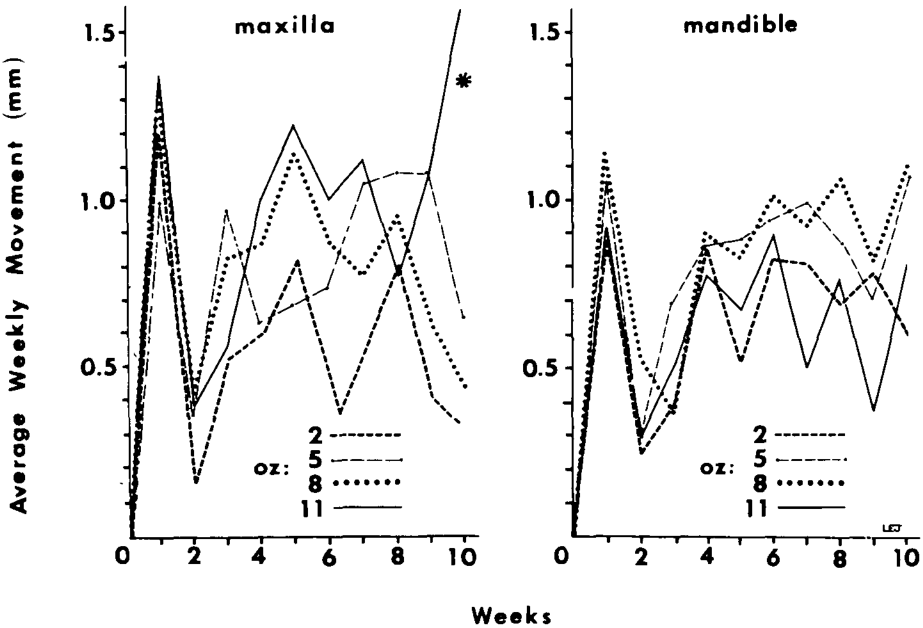

Fig. 2 Total space-closure expressed as a function of time. There was only one data point (*) for 11 oz. at 10 weeks in the maxilla.

level (.05<p<.10). On the average, *all* forces produced more canine retraction than anchorage loss. Moreover, as may be seen in Table IV, there appears to be little if any relationship between relative anchorage loss and such rubrics as "ideal" or "heavy." Indeed, it would be hard to find a less significant result: after correction for continuity, $\chi^2=0$.

The relationship seen between force and discomfort is summarized in Table V.

Analysis of these data leads to two conclusions:

1) There appears to be great variability within and among patients with regard to the relationship, if any, between discomfort and amount of force applied to the teeth.

2) Although the two ounce force level elicited the fewest complaints, Friedman's two-way analysis of variance for ranked data revealed no significant among-treatment differences ($p \simeq .50$).

Discussion

The present study supports the findings of previous investigators with re-

	Intra-Oral				Model				Cephalogram											
									Total				Cuspid				Molar			
Ounces	2	5	8	11	2	5	8	11	2	5	8	11	2	5	8	11	2	5	8	11
Maxillary	5.08	7.74	6.83	8.01	4.25	6.02	5.12	6.10	3.17	4.49	3.90	4.59	2.08	3.24	2.09	2.68	1.09	1.25	1.81	1.91
Mandibular	5.65	6.33	7.86	5.77	4.24	4.52	5.61	4.82	3.63	3.65	4.48	3.38	2.07	2.05	2.90	2.45	1.57	1.49	1.58	0.73
Total	5.36	7.04	7.34	6.89	4.24	5.27	5.36	5.46	3.40	4.07	4.19	3.98	2.08	2.64	2.50	2.56	1.33	1.37	1.70	1.32

TABLE II
Average Space-closure (mm).

Source	df	Intra-Oral		Model		Cephalogram					
						Total		Canine		Molar	
		SSQ	MSQ	SSQ	MSQ	SSQ	MSQ	SSQ	MSQ	SSQ	MSQ
Forces	3	23.345	7.782	9.654	3.218	15.452	5.151	7.904	2.634	3.551	1.184
Patients	9	42.696	. .	20.035	. .	84.524	. .	76.704	. .	17.176	. .
Residual	26[a]	35.577	1.368	21.993	0.846	104.596	4.023	101.382	3.899	71.613	2.754
Total	38[a]	101.618	. .	51.686	. .	204.572	. .	185.990	. .	92.340	. .
Variance ratios[b]		5.687**		3.804*		1.280		0.676		0.430	

[a]One degree of freedom lost estimating a missing value.

[b]$F^{*}_{(3,26).95} = 2.98$; $F^{**}_{(3,26).99} = 4.64$

TABLE III
Analysis of Variance.

gard to the temporal sequence of tooth movement.[1,3,12] It is perhaps significant that all forces produced essentially an identical pattern. With respect to the lag phase, even a force as light as two ounces produced a delay in resorption, perhaps due to hyalinization of the periodontal membrane.

The report of Hixon *et al.*[6] that tooth movement is a linear function of force up to about three hundred grams could not be supported in the present investigation. Rather, the data suggest that space closure proceeds equally rapidly at forces ranging from five (or probably less) to eleven ounces. In this range, bone resorption, per se, appears to be occurring at a maximal rate and, accordingly, may constitute the rate-limiting factor. Only at lower levels does force appear to be the rate-limiting variable.

Although relative anchorage loss appears independent of the class of force, it should be noted that the cephalometric data appear to be generally less reliable than that obtained from the mouth or from casts. Nonetheless, if "differential forces" yield a generalized

TABLE IV
DIFFERENTIAL RESPONSE RATIO: $\frac{\text{Canine retraction}}{\text{molar slippage}}$

Forces	Ratio		Totals
	>1	<1	
"Heavy" (11 oz.)	8	2	10
"Ideal" or less (2, 5, 8 oz.)	22	8	30
Totals	30	10	40

TABLE V
TOOTH DISCOMFORT
(frequency of complaint)

Patient	Force			
	2 oz.	5 oz.	8 oz.	11 oz.
1	..	1	..	..
2	3	2	8	6
3	4	5	3	3
4	1	5	3	4
5	7	6	8	6
6	1	1	1	1
7	2	2	2	2
8	2	3	2	3
9	5	5	5	5
10	3	7	5	4
Total	28	37	37	34

differential response of more than subtle magnitude, such an effect should have been resolved even by an experiment of minimal statistical power.

It should be noted that the methods of the present study (not to mention those of contemporary Begg therapy) do not really constitute a replication of Storey and Smith's work. In their original investigations the canines had no bracket engagement, whereas the buccal and anterior segments did and were connected via a sliding yoke arrangement. As a result, anchorage loss produced by a frictional system was compared with canine retraction achieved without friction.

Hixon and associates[7] have shown that an archwire similar to Storey and Smith's with a span of only seven millimeters will deflect one millimeter when two hundred grams of force are applied. Assuming a comparable deflection, binding in the sliding yoke could easily have bound the buccal segments to the anterior segment and, in conjunction with the additional anchorage provided by the lips and upper incisors, created a system in which anchorage loss was practically impossible at lower force values.

Furthermore, it should be noted that Storey and Smith's springs were allowed to decay for a number of weeks. Accordingly, after the first week of activation, "heavy" springs became "light" whereas the "light" springs maintained a more constant activation. Nor, as is usually assumed, did heavier forces "anchor" canines; the total retraction in eight patients was 21.25 millimeters as opposed to 25.75 millimeters for forces characterized as "light" (Smith and Storey, 1952, Table 3).[14] Also, there is some reason to question the accuracy of their measurements inasmuch as they were unable to detect the commonly reported "initial rapid phase" when "heavy" forces were employed (p. 301): "During the first week practically no movement of the cuspid teeth occurred."

Given the present data, a somewhat more prosaic interpretation may be attached to Storey and Smith's data. *Firstly,* one must assume that there is a linear relation between force and movement only at lower levels and that at a given level (two to five ounces in the present study) rate of movement becomes maximal and, hence, independent of force. *Secondly,* there is reason to assume that structures other than just molars and premolars contributed to the anchorage in Storey and Smith's study. And *thirdly,* "heavy" forces produced about the same canine retraction as did "light." Accordingly, it is obvious that if springs act on one tooth and react on a large number of anchor units, movement will occur first for the canine and only at much higher levels for the individual elements constituting the anchorage.

With regard to discomfort, considerable variability was seen, both within and among individual patients. Treatment differences were slight and nonsignificant.

Thus, of the three most common arguments favoring light forces, efficiency, anchorage preservation, and comfort, none could be substantiated in the exact sense of their original proposal or present belief. This is not to say that various techniques, per se, have been found wanting, but rather some of the "evidence" advanced in their behalf.

Summary and Conclusions

A clinical investigation was conducted to compare the rate of tooth movement at four different force-levels. Ten patients whose orthodontic therapy required the extraction of four first premolars consented to participate in the study.

Four weeks after extraction each quadrant was fitted with calibrated, commercially available, .016 x .016 sectional canine retracting appliances. In each patient four different force-levels (2 ounces, 5 ounces, 8 ounces, and 11 ounces) were assigned to randomly-selected quadrants. Study models and 22.5° radiographic cephalograms were taken at this time. Each appliance was activated weekly at which time direct intraoral measurements were obtained. At the conclusion of the ten-week period final cephalograms and study models were taken.

The data were analyzed graphically by randomized-block analysis of variance in conjunction with Tukey's method for multiple comparisons, by Friedman's two-way analysis of variance for ranked data, and by the χ^2 test for contingency.

The results of the study suggest that:

1) The two-ounce force-level produced significantly less movement than did five, eight and eleven ounces.

2) There was no significant difference among five, eight and eleven ounces; each produced about the same amount of space closure.

3) No statistically significant evidence could be shown in support of the differential force concept as presently constituted; relative anchorage loss was independent of the force employed.

4) No significant difference was seen among the two, five, eight and eleven ounce force levels with regard to tooth discomfort.

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References

1. Burstone, C. J.: The biomechanics of tooth movement. In *Vistas in Orthodontics*. Chapter 5, Edited by B. S. Kraus and R. A. Riedel. Lea and Febiger, Philadelphia, 1962.
2. Cochran, W. G. and Cox, G. M.: *Experimental Designs*. 2nd Edition. John Wiley and Sons, Inc., New York, 1957.
3. DaPrano, A. A.: Canine retraction in healed and recent extraction sites. Unpublished M. S. Thesis, Case Western Reserve University, 1971.
4. DiGiulio, J.: Quantitative measurements from panoramic radiograms. Unpublished M. S. Thesis, Case Western Reserve University, 1970.
5. Guenther, W. C.: *Analysis of Variance*. 2nd Edition. Prentice-Hall, Inc., New Jersey, 1964.
6. Hixon, E. H., Atikian, H., Callow, G., McDonald, H., and Tacy, R. J. Optimal force, differential force, and anchorage. *Am. J. Orthod.*, 55:437-457, 1969.
7. Hixon, E. H., Aasen, T. O., Aranzo, J., Clark, R. A., Klosterman, R., Miller, S. S., and Odom, W. M. On force and tooth movement. *Am. J. Orthod.*, 57:476-489, 1970.
8. Paulson, R. C., Speidel, T. M., and Isaacson, R. J.: Cuspid retraction versus molar anchorage. *Angle Orthod.*, 40:20-27, 1970.
9. Reitan, K.: Selecting forces in orthodontics. *Eur. Ortho. Soc. Trans.*, 32:108-125, 1956.
10. ————:Some factors determining the evaluation of forces in orthodontics. *Am. J. Orthod.*, 43:32-45, 1957.
11. ————: Retraction of upper canines after removal of first premolars. *Eur. Ortho. Soc. Trans.*, 34:172-176, 1958.
12. ————: "Bone formation and resorption during reversed tooth movement." In *Vistas in Orthodontics*. Edited by B. S. Kraus and R. A. Riedel. Lea and Febiger, Philadelphia, pp. 69-84, 1962.
13. Siegel, S.: *Nonparametric Statistics for the Behavioral Sciences*. McGraw-Hill Book Company, Inc., New York, 1956.
14. Smith, R. and Storey, E.: The importance of force in orthodontics. The design of cuspid retraction springs. *Aust. Dent. J.*, 56:291-304, 1952.
15. Stoner, M. M.: Force control in clinical practice. *Am. J. Orthod.*, 46:163-186, 1961.
16. Storey, E., and Smith, R.: Force in orthodontics and its relation to tooth movement. *Aust. Dent. J.*, 56:11-18, 1952.