CASE WESTERN RESERVE UNIVERSITY

GRADUATE STUDIES

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AN INVESTIGATION OF THE CONCEPTS OF DIFFERENTIAL AND OPTIMAL FORCE IN CANINE RETRACTION

by

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Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

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June, 1972

AN INVESTIGATION OF THE CONCEPTS OF DIFFERENTIAL AND OPTIMAL FORCE IN CANINE RETRACTION

Abstract

by

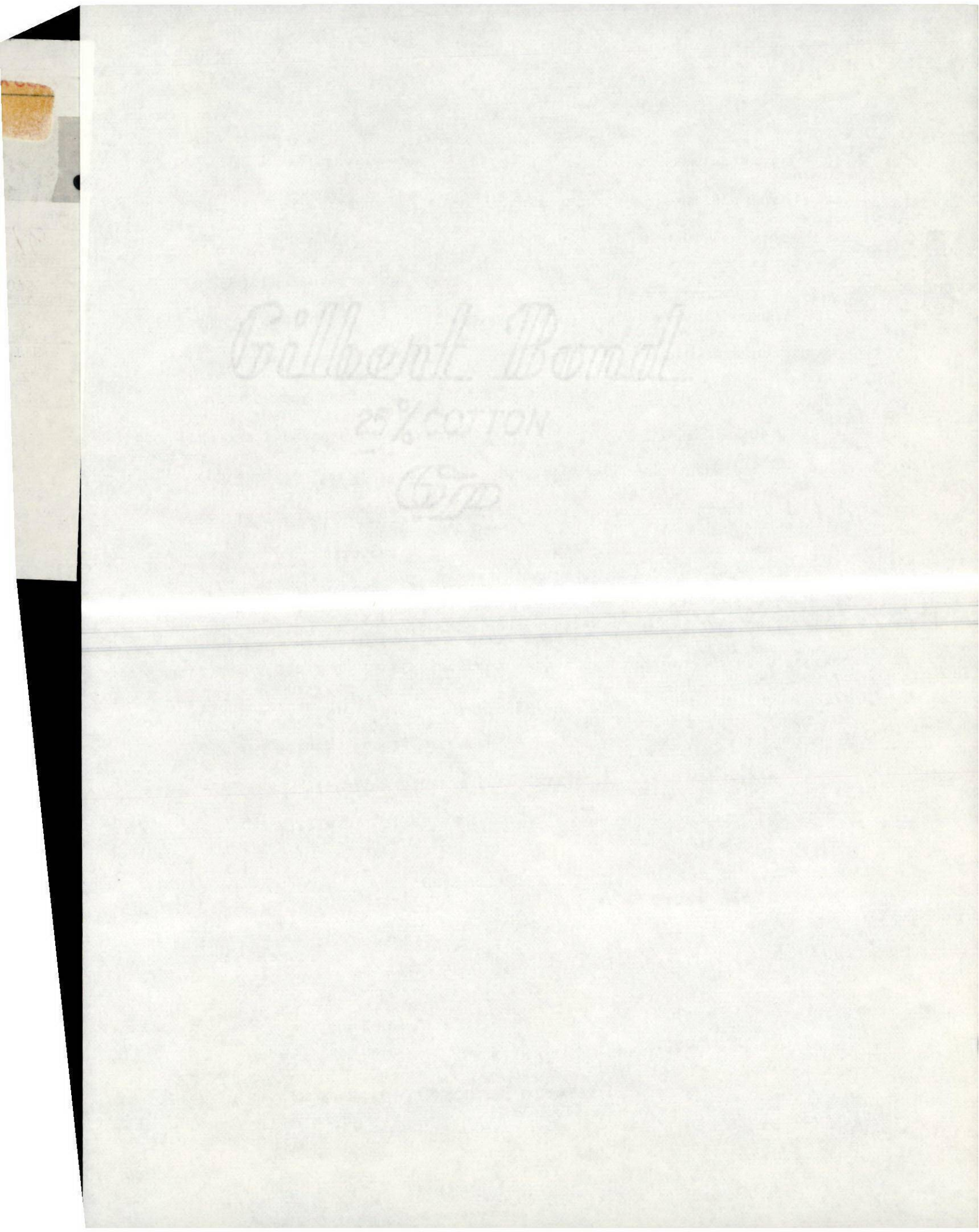
CHARLES HENRY BOESTER

A clinical investigation was conducted to compare the rate of orthodontic space closure into extraction sites when four different force levels are used. Ten patients who required extraction of four first bicuspids consented to participate in the study.

The four first bicuspids were extracted, and after a four-week healing period, all four quadrants were fitted with calibrated, commercially available, .016 x .016" preformed sectional cuspid-retracting appliances. In each patient, four different force levels (2 oz., approx. 55 grams; 5 oz., approx. 140 grams; 8 oz., approx. 225 grams; 11 oz., approx. 310 grams) were used in randomly-selected quadrants. Study models and 22.5° radiographic cephalograms were taken at this time. Each appliance was activated weekly, and direct intra-oral measurements were obtained. At the conclusion of the ten-week period, final radiographic cephalograms and study models were taken.

The data were analyzed graphically, by randomized block analysis of variance with ten blocks, with Tukey's method for multiple comparisons, and with Friedman's two-way analysis of

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variance for ranked data.

The results of the study showed the following:

1) The two ounce force level produced significantly less tooth movement than the five, eight, and eleven ounce force levels.

2) There was no significant difference among the five, eight, and eleven ounce force levels with regard to tooth movement.

3) No statistically significant evidence could be shown in support of the concept of differential force.

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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DEDICATED

To my Father

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INTRODUCTION AND REVIEW OF THE LITERATURE

All orthodontic techniques require the application of force to the dental structures in order to effect a correction of the malocclusion. There has been much discussion among orthodontists concerning the proper amount of force to be used in order to achieve the optimal orthodontic result in the most efficient manner.

Our forefathers in the orthodontic profession realized the importance of force application and its implications in regard to anchorage preservation. Pullen reported in 1911 that anchorage resistance should be selected with all due accord to the requirements of force to be used in the tooth movement. In 1920, Hellman made the following statement:

> Anchorage in its true sense does not exist in orthodontia. There is no point in the mouth to which an appliance may be attached that can resist force without being affected by it. The force necessary for inducing cell changes in the tissue constituting the alveolar process is so small that no device, however skillfully executed, will succeed in avoiding it.

Rhode (1948) stated that anchorage had for too long been considered a strict mechanical entity to the exclusion of its biologic aspects, which in reality were its fundamentals. He maintained that physical laws which operate on inanimate material behaved quite differently when applied to living tissue. His definition of anchorage was the resistance which is the result of the response of tissue changes which may be favorable or

unfavorable. He further stated that since we cannot control the reaction of tissue to any force, there is no general routine whereby the amount of force or the extent of movement within certain time limits can be applied to all cases. Rhode concluded that true anchorage was not available in the mouth.

When the necessity of extraction of teeth became an accepted adjunct to orthodontic treatment, the problem of anchorage maintenance during cuspid retraction became a prime consideration. Tweed (1966) developed a purely mechanical, "tent-stake" concept of anchorage. The anchor teeth were tipped back like tent stakes in order to resist forward displacement. In a recent work, Hixon, Atikian, Callow, McDonald, and Tacy (1969) concluded that the maintenance of molars in an upright position was relatively effective in resisting the canine retraction by distributing the force over larger root areas. They also maintained that angulated posterior brackets or tip-back bends help prevent mesial tipping by compensating for bracket position inaccuracies and flexion of the arch wire.

While the preservation of anchorage is of utmost importance in some cases, the use of the proper force values is applicable in all cases. Sandstedt realized in 1904 that excessive pressure slowed tooth movement. Schwarz (1932) was more specific. His work showed that, biologically, the most favorable treatment was that which worked with forces no greater in magnitude than the pressure in blood capillaries, this being approximately twenty

to twenty-six grams/cm.^{2}.

Stuteville (1937) pointed out that the distance over which the force was acting was equally important with regard to obliteration of blood vessels of the periodontal membrane.

Cary (1944) characterized the proper force in the following manner:

> Forces used in treatment of malocclusion should be controlled and directed in such a manner that it will be possible to move the dental tissues with a minimum of discomfort and destruction to their most aesthetic and most favorable mechanically functioning positions . . . . The mechanism should be selected so that the force may be exerted and controlled in any direction and intelligently managed so that the motion proceeds wherever possible in a direction which offers the least mechanical resistance. It should embody a relatively fixed stationary anchorage unit from which to obtain the required power to accelerate the objective unit without serious loss of stability to the emanating force or anchorage body . . . . Proper application of these principles will enable us to produce a more nearly perfect result with greater ease and efficiency, less discomfort to the patient, and to reduce the treatment time, and insure a more favorable retention.

The above quotation is, unfortunately, noticeably lacking in specifics.

Johns (1953) stated that the application of twenty to twenty-six grams/cm.^{2} was practically a clinical impossibility. However, he did feel that the further the appliance deviated from these ideal conditions, the more likely the tooth movement would be accompanied by pathosis.

Burstone (1961) noted that knowledge of the application of force at the coronal portion of the tooth was not sufficient. Statements concerning total force application must be tempered by

the realization that the force is distributed throughout the membrane according to the form of the roots (length, diameter, and contour), the nature of the periodontal membrane, and the site of force application.

From a histologic point of view, the works of Burstone (1962) and Reitan (1956, 1957, 1958) are of note. Burstone showed that when a relatively constant force was placed on a tooth, three phases of tooth movement could be differentiated: a) initial phase, b) lag phase, c) post-lag phase. The initial phase was characterized by a period of very rapid tooth movement which normally lasted a few days. He attributed this rapid tooth movement to the displacement of the tooth in the periodontal membrane space. The lag phase followed the initial phase immediately and was attributed to the de-vitalization of the periodontal membrane in areas of maximum stress. No tooth movement occurred until the area of de-vitalization was removed by osteoclasts. The lag phase was followed by a post-lag phase during which movement of the tooth proceeded again. Also, Burstone concluded that at lower force magnitudes, an increase in force enhanced the rate of tooth movement. However, at higher force magnitudes, an increase in force led to increased lag period. This lag period was followed by rapid tooth movement.

DaPrano (1971) has verified these phases of cuspid retraction as described by Burstone. Cuspids were retracted into both healed and recent extraction sites by means of sectional

arches; in each situation, the pattern was similar.

Reitan (1956, 1957, 1958) advised initial light forces for several reasons. First of all, after the application of force a few days must pass before osteoclasts can proliferate. Light forces do not inhibit osteoclastic proliferation. Second, light forces are advantageous during the initial period of elimination of compact bone lining the inner alveolar surface, in that fewer cell-free areas are formed. And third, in cases where the second premolars and first and second molars serve as anchorage for distal movement of the canines, a strong initial force would not move the canine distally because of formation of cell-free areas. In Reitan's experiments, however, the anchor teeth moved mesially. Reitan explained this anchorage loss in the following manner: the applied force, divided among three teeth, was only enough per tooth to cause direct bone resorption. He concluded that if it was desirable to move the canine and not the molars, the initial force must be kept light. Even then, however, there would be some mesial movement of molars.

These findings seem to support the classic report of Storey and Smith (1952). In their study, eight patients twelve to fifteen years of age were observed. Cuspid retraction was studied, with one exception, in the lower arch only. The upper arch was used as a point of reference to determine the amount of distal movement of the cuspid and mesial movement of the bicuspid and first molar (anchorage loss). Sectional arch wires were placed.

A light spring (175-300 grams) was used to retract the cuspid on one side, and a heavy spring (400-600 grams) was used on the opposite side. Uninhibited by friction, the cuspid was free to move distally; whereas, the molar and bicuspid, in order to move mesially, had to do so along the arch wire. No statistical analysis of the data was presented.

They reported that the use of light springs for cuspid retraction resulted in a marked movement (one mm.) during the first week. Movement of the cuspid occurred rapidly when the force was in the range value of 150-250 grams (5-9 ounces). When the force decreased to 130-180 grams (4.6-6.3 ounces), movement either ceased or continued at a slow rate. Also, there was very little movement of the anchor unit. On the other hand, when heavy retracting springs were used, there was no movement of the cuspid during the first week, but the anchor unit moved one millimeter. This movement continued until the force decreased below the value of 250 grams, when the response changed to that obtained with light springs. Also, they noted that where the forces had been accurately controlled, the response of all patients was very similar.

It appears from the above findings that the range of force between 150-250 grams is perhaps "ideal." If this be granted, the concept of anchorage maintenance is no longer of concern as long as the force values are maintained in this ideal range. This concept, that of "differential force," is fundamental in the Begg

technique of orthodontic therapy. As Begg has stated (1956): "Failure to move anterior teeth back and inability to prevent posterior teeth from moving forward into premolar extraction spaces are not due to the use of insufficient anchorage, as suggested by Strang, but to the use of excessive force."

A recent report by Hixon, Atikian, Callow, McDonald, and Tacy (1969), however, does not support Storey and Smith's findings. In this study, eight patients were observed for a period of eight weeks. A "Strang" loop appliance was used to retract cuspids in both the upper and lower arches. A continuous force of 300 grams was applied to the right maxillary and mandibular cuspids. Differing forces from 64-1515 grams were applied to the left maxillary and mandibular cuspids. Biweekly measurements and activation of springs were made. In three patients the initial activations on the left side were allowed to decay. Fixed landmarks were provided by means of tantalum implants, and twenty-five degree cephalograms were taken at the beginning and end of the study. Casts were also obtained biweekly on each patient.

With the appliance used in this study, both the distal movement of the cuspid and the mesial movement of the bicuspid and molar occurred along an arch wire. Model inspection revealed a distal rotation of the cuspids so that the vertical pins fitted to the bands for intra-oral measurements were not satisfactory for measuring tooth movement. The radiographic material was analyzed by measuring from lines scribed through the pupal canals to

compensate for the tooth rotations, as well as through the metallic implants. No correction was made for distortion between the before and after X-ray.

They found that the higher the force per unit area, the more rapid the tooth movement until a total of 300 grams had been applied to the tooth. The rapid movement obtained with light forces was explained as a result of tipping movement, in which the force was initially absorbed by a small area of the periodontal ligament primarily at the alveolar crest.

In a later study (1970), Hixon, Aasen, Arango, Clark, Klosterman, Miller, and Odom observed six patients, twelve to fifteen years of age. The cuspids, second bicuspids, and first molars were banded. The bicuspid and molar bands were soldered together. Tubes (.045") were soldered to the buccal and lingual surfaces of the posterior segment. Wires (.045") were placed through the tubes and soldered to the cuspid band. Elastic traction was used to retract the cuspids. This appliance was designed to try to eliminate tipping of all teeth. Only nineteen teeth (nine maxillary canines, seven mandibular canines, three mandibular molars) met the criterion.

The force delivered by the elastics was measured each time they were removed (three times per week). The average of the force that the elastic delivered at the time of removal was used to represent the force applied to the tooth.

Tantalum implants and twenty-five degree cephalograms

were used to establish the following criteria for bodily movement:

1) Clear initial and final X-rays of the crown and apex of the tooth under study.

2) The three implants coincided within 0.2 mm. when initial and final tooth films were superimposed.

3) The lines scribed through the teeth before and after tooth movement were within 0.2 mm. of parallel.

4) The space closure as measured on the film and on the casts agreed within 0.5 mm.

Casts were also taken three times per week.

In collecting their data, whenever one of the molars (in one case a canine) moved less than 0.2 mm. in relation to the metallic implants during the eight-week period, space closure was attributed to the movement of the other tooth. The space closure as measured on the casts was then plotted against time. The amount of force varied on those teeth studied, as determined by their bodily movement criteria, from 60 grams to 1037 grams.

In this study, both distal cuspid movement and mesial molar and bicuspid movement was along the arch wire. Intra-oral measurements were not made. The average force applied by the elastics was less than the initial force being applied. The sample size was considerably reduced by the strict criteria for determining bodily movement.

The following conclusions were drawn from this study:

1) A wide variation in response was found among individuals. Within a given person there was an observable tendency for the higher forces to move teeth further in eight weeks than could the lighter forces.

2) Maxillary canines moved somewhat faster than mandibular.

3) The large variation between patients precludes formulation of simple theories regarding forces and anchorage.

4) Tipping of the tooth results in deformation of the alveolar crestal bone and thus introduces great variation in the physical load per unit area in different parts of the root.

5) The major source of variation is probably not the magnitude of force, but variation in metabolic response.

6) The data tend to confirm earlier works which state that there is no evidence to support the theory of differential force.

There appears to be a discrepancy among various groups of investigators with regard to the proper force, differential force, and anchorage. It will be the purpose of this paper to investigate these areas specifically, with respect to the following questions:

1) Is there an optimal force for cuspid retraction within and among patients?

2) Does differential force during canine retraction significantly occur within and among patients?

METHODS

Sample

Seven males and three females, twelve to sixteen years of age, who required the removal of four first bicuspid teeth and distal retraction of the canines were selected randomly from one hundred patients who presented themselves for orthodontic treatment at Case Western Reserve University Department of Orthodontics. The nature of the study, its significance, requirements, and potential problems were explained to each subject and his or her parents. Permission to conduct the investigation, in each case, was obtained in writing (Appendix I).

The only criteria, other than consent, established for selection were: 1) the complete eruption of all teeth anterior to the first permanent molars, and 2) the necessity of first bicuspid extraction as determined by standard diagnostic procedures.

Experimental Design

A table of random numbers was used to assign treatments to the various patients. In one quadrant a force of 2 ounces (about 55 grams) was applied (Paulson, 1970; Reitan, 1956; Stoner, 1961). In two quadrants forces representative of Storey and Smith's "optimal forces" were used. Specifically, forces of 5 ounces (about 140 grams) and 8 ounces (about 225 grams) were

applied. In the last area, a force somewhat above Storey and Smith's "optimal forces" but within the range of forces used by Hixon and associates (1969) was used. The magnitude of this force was 11 ounces (about 310 grams). Table 1 illustrates the experimental design.

Clinical Procedure

The first permanent molar, second bicuspid and cuspid were banded in each quadrant (Lancer Pacific, Carlsbad, Calif., bicuspid and molar; Ormco, Glendora, Calif., cuspid). Siamese edgewise brackets (.022 x .028") were prewelded on the cuspid and bicuspid bands, and a buccal tube (.022") was prewelded on the molar band. Lingual cleats were welded on the molar and bicuspid bands to facilitate ligation on both the buccal and lingual to gain anchorage potential and to reduce the amount of rotation (DaPrano, 1971). All four first permanent bicuspids were extracted one month prior to the onset of the study for maximum cuspid movement (DaPrano, 1971). Ricketts (.016 x .016") sectional retracting springs (No. A518-A520 Rocky Mountain, Denver, Colorado) were the appliance of choice (Plates I-V). This appliance was chosen for the following reasons:

1) It is a sectional appliance; therefore, the effects of treatment in one quadrant will have little or no effect on the other three quadrants.

2) A large range of force could be obtained with this appliance over equal activation distances.

3) The force would be relatively continuous between weekly activations.

TABLE 1

EXPERIMENTAL DESIGN: FORCE ASSIGNMENT

(ounces)

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

PLATE I

FRONTAL VIEW - TEETH IN OCCLUSION



PLATE II

OCCLUSAL VIEW - MAXILLARY ARCH



PLATE III

OCCLUSAL VIEW - MANDIBULAR ARCH



PLATE IV

LEFT SIDE - TEETH IN OCCLUSION



PLATE V

RIGHT SIDE - TEETH IN OCCLUSION

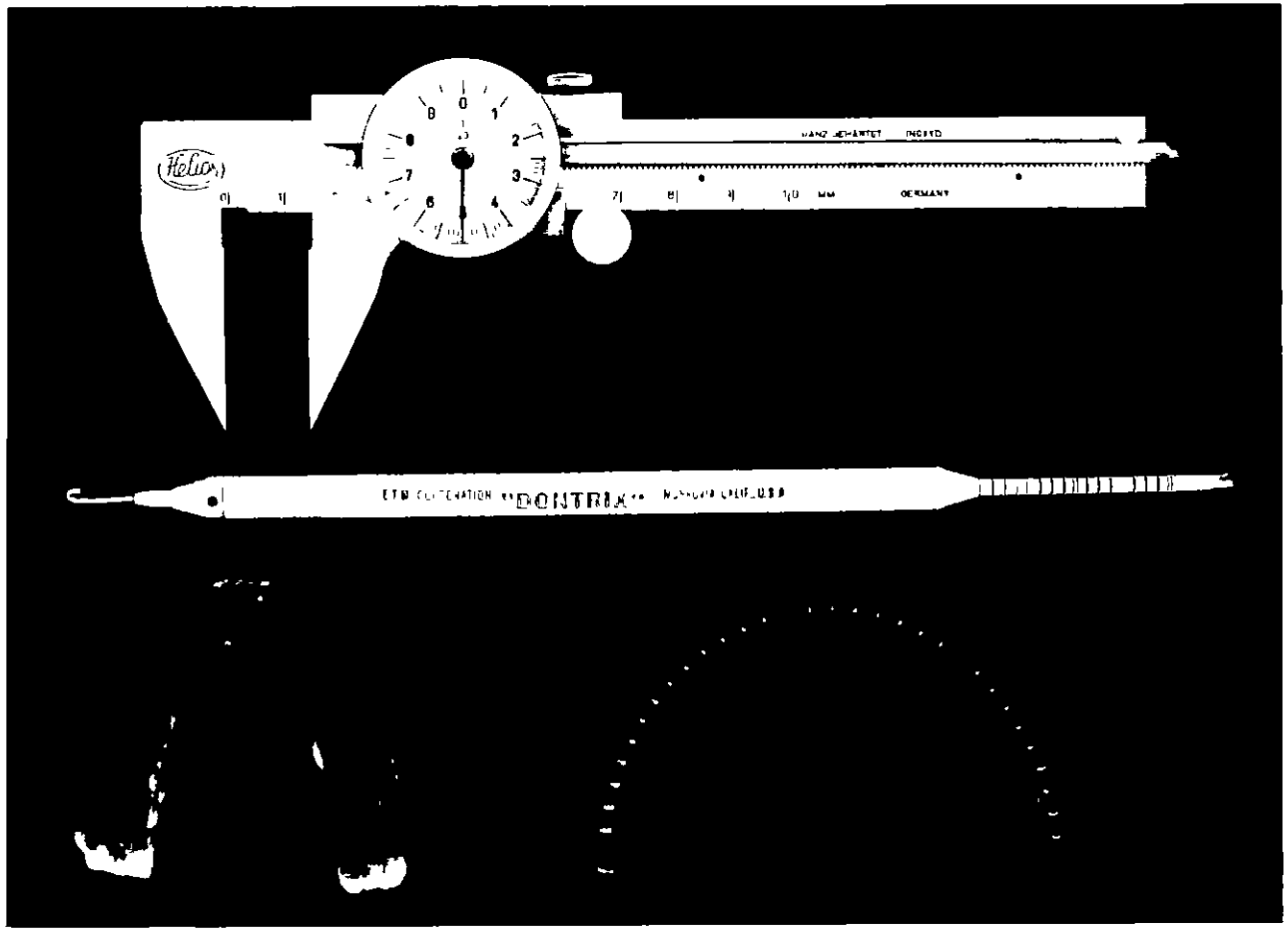


4) The sectional arch appliance constitutes a frictionless system, and thus simplifies interpretation of the data.

Prior to insertion, these retraction springs were calibrated to provide different force values over equal activation distances. This was accomplished by coating those portions of the wire engaging the brackets and molar tubes with clear lacquer. The remainder of the appliance, the looped portion not engaged by the brackets or tube, was not coated. The springs to be used for the two, five, and eight ounce force values were reduced in an acid reducer (Rocky Mountain 700, Denver, Colorado) until the desired amount of force was achieved with a deflection equal to that of the eleven ounce spring. The four springs for each patient were prepared in this manner. These calibrated appliances were then placed into the appropriate quadrant in each patient. The wire was bent over the distal of the molar tube. With the aid of a tension gauge (Dontrix-Richmond Orthodontic Stress and Tension Gauge, Unitek), each appliance was activated to its proper force level (Plate 6). The cuspid was tied on both bracket arms with .010" steel ligature wire. The appliances were reactivated weekly by adjusting the amount of wire bent over the distal of the buccal tube until the desired force was obtained as measured by the tension gauge. Additional adjustments were also made in a similar manner mesial to the cuspid bracket.

PLATE VI

VERNIER CALIPER, "DONTRIX" GAUGE, WAX-BITE, INTRA-ORAL GRID


Helios
GERMANY

Data Collection

Intra-Oral Measurements

In order to determine the amount of space closure, direct intra-oral measurements were taken weekly for ten consecutive weeks. Measurements were taken on only four of the ten patients for the entire ten-week period. The study was discontinued before the ten-week period had passed in those cases where the experimental procedures were starting to jeopardize the total orthodontic treatment of the patient. The distance measured was the distance between a notch cut into the molar buccal tube and the distal surface of the distal cuspid bracket (Figure 1). Readings were obtained to the nearest .01 mm. with the aid of a pointed vernier caliper (Dental Corporation of America, Washington, D.C.) (Plate 6). The measurements obtained represent total space closure.

Study Casts

Study casts were made at the beginning, 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 completed before the ten-week period, study casts were taken at the time of removal of the appliances. Measurements were made from the cusp tip of the cuspid to the cusp tip of the second bicuspid (Figure 2). These anatomical reference points were used to minimize rotational effects. The measurement obtained represented total space closure.

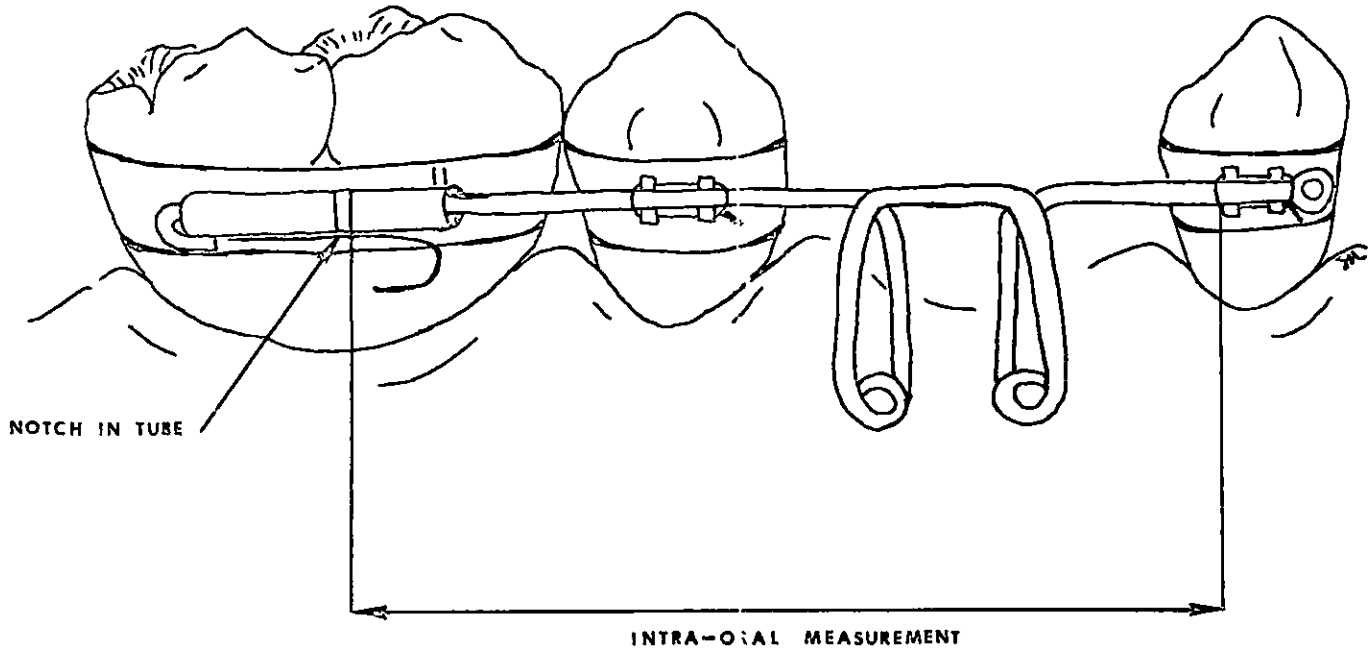


Figure 1. Intra-Oral Recording Landmarks

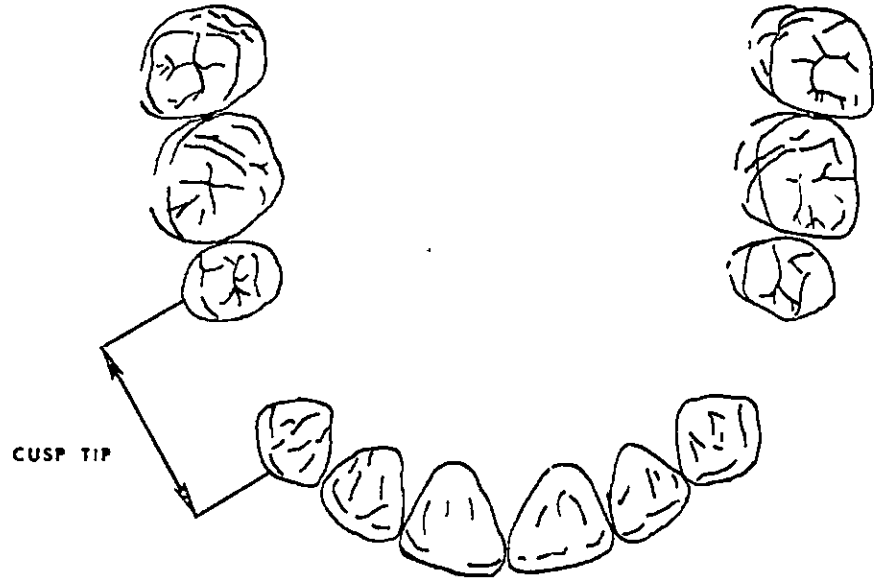


Figure 2. Model Measurements

Cephalometric Radiographs

An Ortho X-ray cephalometer (Ortho X-ray Division, Ottawa, Illinois) was used to take cephalograms with the head rotated 22.5 degrees toward the film. An "intra-oral grid" (Digiulio, 1970) was used to quantitate distortions and magnifications. The grid was placed in a wax bite constructed for each patient. This facilitated a uniform opening of the patient's mouth, and a uniform placement of the grid along the occlusal surfaces of the teeth (Plate 6).

The first two cephalograms (right and left sides) in each series were taken just before the placement of the appliances; the final two were taken after the ten-week period before the removal of the appliances. In those patients completed before the ten-week period had elapsed, the records were taken just prior to the removal of the appliances.

Superimposition of the cephalograms was made in the following manner. A tracing of the molar, canine, lower border of the mandible, mandibular symphysis, palatal border, and other individual landmarks in the general vicinity of the extraction site was made of both the initial and final cephalogram. Each tracing was corrected for magnification, specifically in the region of the extraction site by means of the intra-oral grid. The actual movement of the cuspid and molar was calculated by the use of simple proportions. The procedure is illustrated below for molars (Figure 3).

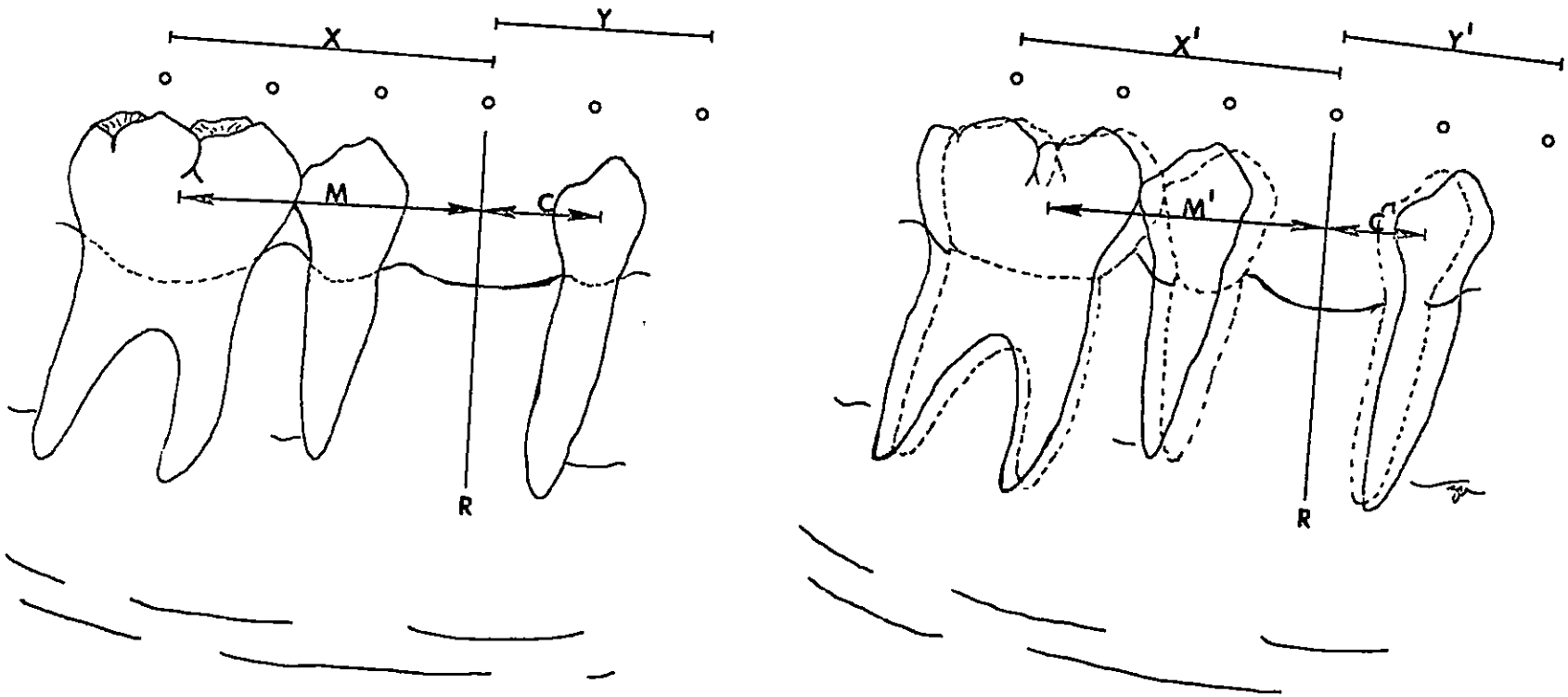


Figure 3. Radiographic Method Procedure

1) The actual distance from the center of the molar crown to an arbitrary reference line, R, was obtained by solving the equation, Actual distance = 4(N)M/X, where M and X are measurements obtained from the cephalometric radiographs, N = number of grid-intervals in dimension X, and 4 = the distance between intervals in millimeters.

2) Tracings of all previously described landmarks were made on the second radiograph (except the arbitrary line, R) and superimposed on the extraction site lamina dura; the arbitrary line was transferred to the second film. This line from the initial film was used as the base line from which measurements of the second radiograph were made. The second measurements were corrected with the aid of the intra-oral grid as previously described.

3) The movement was recorded as the difference between the "corrected" measurements of the second film (M-M'). Calculations for cuspids were executed in the same way (C-C'). The sum of the cuspid and molar movement was taken as the total space closure, (M-M') + (C-C').

Discomfort Index

Each patient was asked weekly if they had experienced any tooth discomfort from the appliances. If discomfort had been experienced, they were asked to describe the areas where it occurred. The total number of complaints of tooth discomfort, and the areas where the tooth discomfort occurred were recorded for each patient.

Data Reduction

Calculations were carried out on an electronic calculator (Model 9100A; Hewlett-Packard Co., Loveland, Colorado) and its accompanying software. The statistical design was a randomized block analysis of variance with ten blocks. The linear model for this design may be expressed as follows:

$$x_{ij} = \mu + \tau_i + \beta_j + \varepsilon_{ij} \text{ where,}$$

x_{ij} = any measurement for the ith treatment in the jth individual.

μ = the population mean

τ_i = the effect of the ith treatment

β_j = the effect of the jth block ($j = 1,2, \ldots 10$ patients)

ε_{ij} = the experimental error associated with the ith treatment in the jth individual

Any given measurement may be thought of as a linear combination of an overall mean plus a treatment effect (2 oz., 5 oz., 8 oz., 11 oz.), a block effect, and the "error" for that particular determination.

In patient number two, the data for the five ounce force level had to be estimated due to complete space closure within one week. The method used was that outlined by Cochran and Cox (1953, pp. 450-452).

Tukey's method for multiple comparisons as described by Guenther (1964, pp. 54-57) was used to make individual contrasts suggested by the data.

The Friedman two-way analysis of variance by ranks was used to analyze the percentage of molar and canine movement and the tooth discomfort data (Siegel, 1956, pp. 166-173).

RESULTS

The results of the present investigation will be presented under four headings: 1) intra-oral measurements, 2) model measurements, 3) determinations from cephalometric radiographs, and 4) discomfort index.

Intra-oral

General

All patients showed the same general pattern of tooth movement. The relationship between average movement and time is presented in Figures 4 and 5 and Tables 2 and 3. Individual totals and means are shown in Tables 4 and 5.

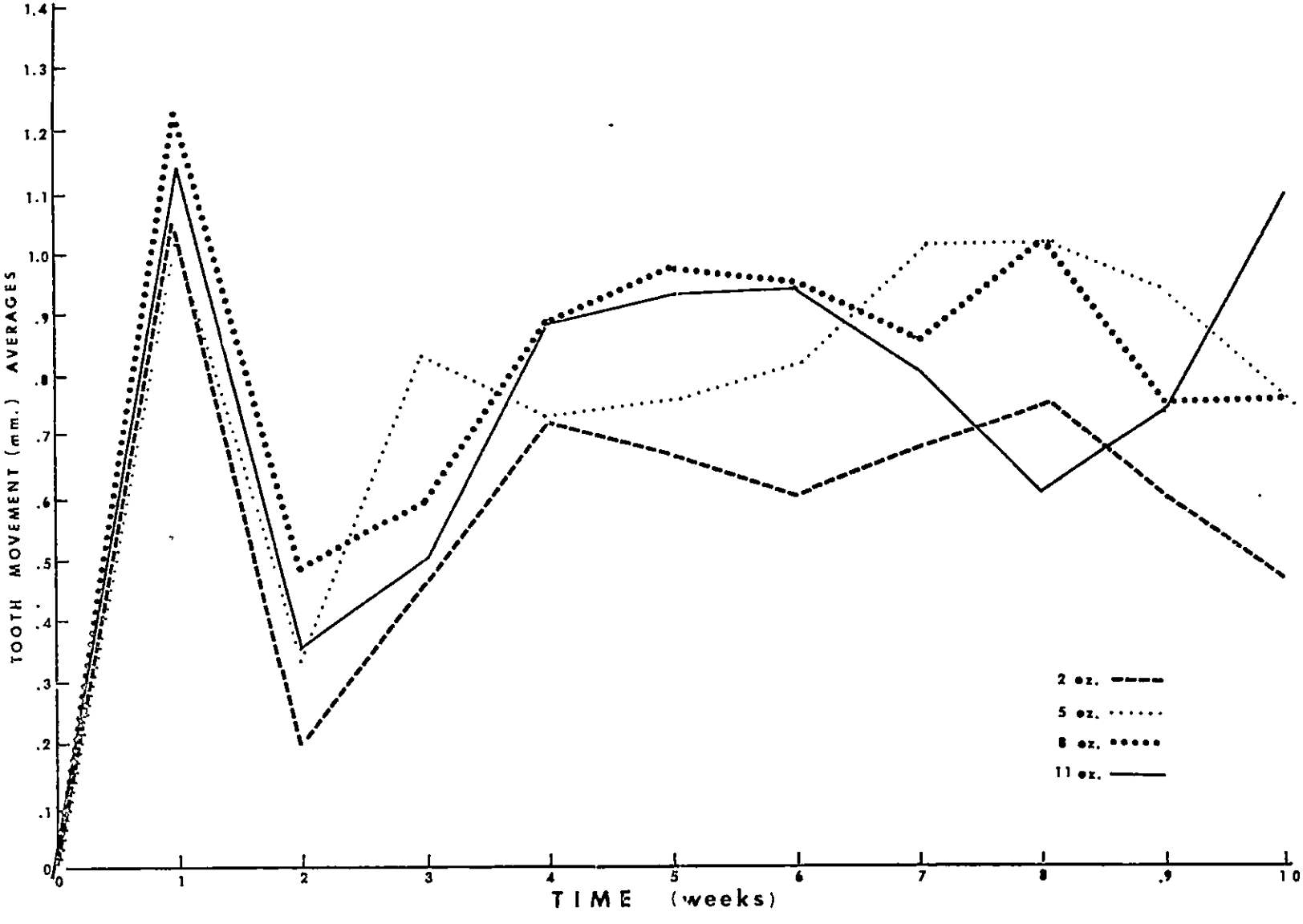


Figure 4. Average Weekly Tooth Movement - Total

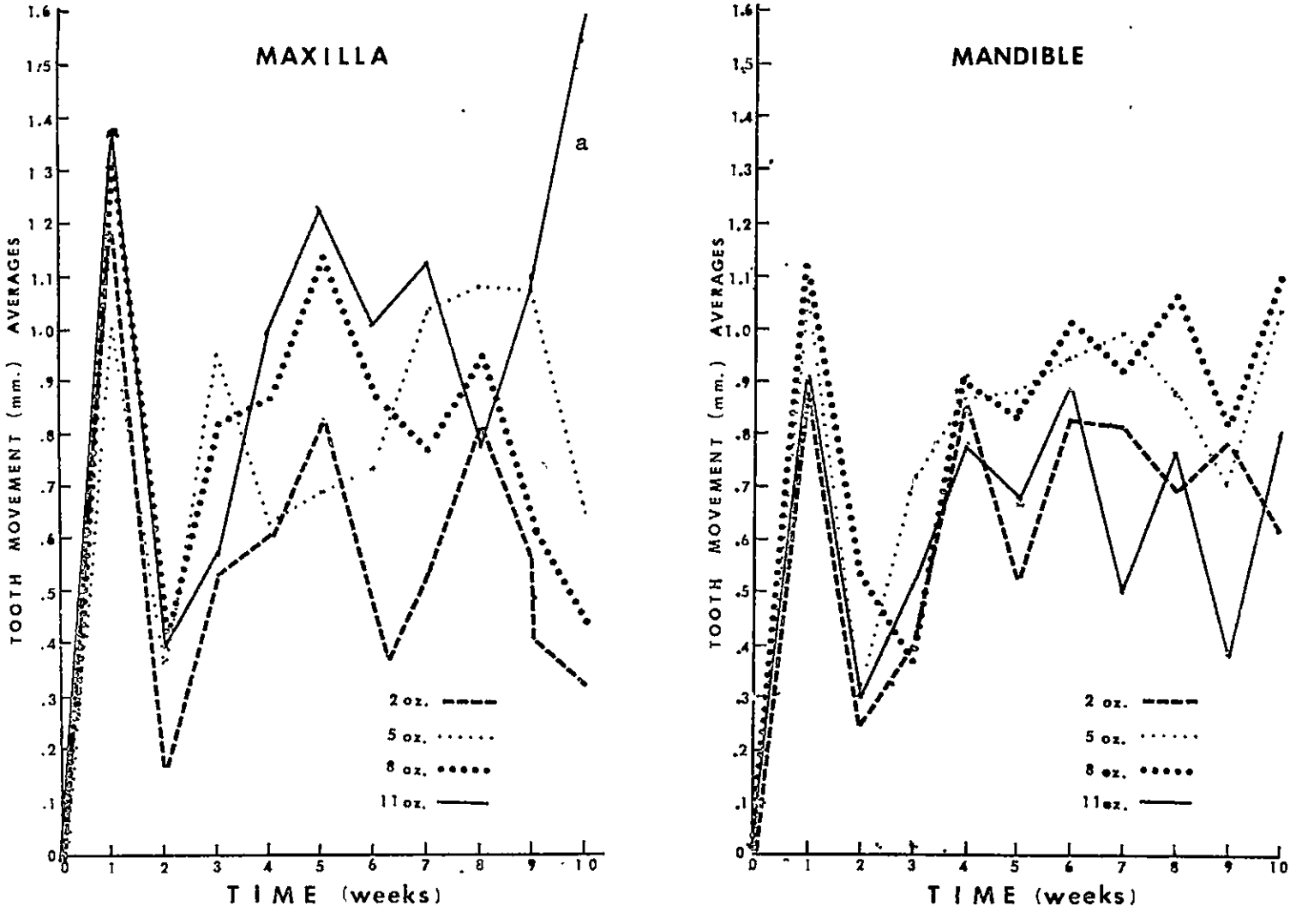


Figure 5. Average Weekly Tooth Movement - Maxilla and Mandible

[a] Tenth week - one patient only

TABLE 2

INTRA-ORAL MEASUREMENTS: AVERAGE SPACE CLOSURE
(millimeters/week)

Week	Force			
	2 oz.	5 oz.	8 oz.	11 oz.
1	1.03	1.02	1.22	1.13
2	.20	.34	.48	.35
3	.46	.84	59	.50
4	.72	.74	.89	.88
5	.67	.77	.98	.93
6	.60	.82	.95	.94
7	.68	1.02	.86	.81
8	.75	1.02	1.02	.61
9	.60	.95	.75	.74
10	.47	.76	.76	1.10

TABLE 3

INTRA-ORAL MEASUREMENTS: AVERAGE SPACE CLOSURE
(millimeters/week)

	Arch							
	Maxillary				Mandibular			
Week	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	1.19	1.00	1.31	1.35	.87	1.05	1.12	.90
2	.16	.37	.42	.39	.25	.30	.53	.31
3	.52	.95	.81	.57	.40	.70	.37	.51
4	.60	.63	.86	.99	.85	.87	.91	.77
5	.81	.69	1.13	1.22	.53	.88	.83	.68
6	.37	.73	.86	1.08	.83	.95	1.01	.89
7	.53	1.03	.76	1.12	.82	.99	.92	.50
8	.80	1.08	.94	.77	.70	.88	1.06	.76
9	.41	1.07	.61	1.09	.79	.71	.82	.38
10	.32	.66	.43	1.54	.62	1.04	1.10	.80

TABLE 4

INTRA-ORAL MEASUREMENTS: TOTAL SPACE CLOSURE

(millimeters)

	Arch							
	Maxilla				Mandible			
Patient	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	3.80	. .	5.16	. .	. .	6.24	. .	5.17
2	5.15	. .	. .	8.37	. .	6.68[a]	7.15	. .
3	. .	7.59	. .	9.69	7.60	. .	10.16	. .
4	. .	8.30	7.74	. .	4.34	. .	. .	4.17
5	4.44	. .	. .	5.18	. .	7.47	6.93	. .
6	5.38	5.92	. .	. .	. .	. .	7.36	6.94
7	. .	8.39	8.68	. .	5.03	. .	. .	5.89
8	6.64	. .	7.76	. .	. .	5.47	. .	6.69
9	. .	. .	4.79	7.06	5.06	5.77	. .	. .
10	. .	8.50	. .	9.74	6.22	. .	7.71	. .
Total	25.41	38.70	34.13	40.04	28.25	31.63	39.31	28.86

[a] Estimated datum

TABLE 5

MEANS: INTRA-ORAL
(millimeters)[b]

Arch	2 oz.	5 oz.	8 oz.	11 oz.	Mean
Maxillary	5.08	7.74	6.83	8.01	6.92
Mandibular	5.65	6.33	7.86	5.77	5.12
Mean	5.36	7.04	7.34	6.89	6.01

[b]Rounded where necessary to nearest hundredth

There was an initial phase of very rapid tooth movement, which lasted one week. A "lag" phase followed beginning the second week and continued until the beginning of the third week. The third through eighth weeks showed a general increase in tooth movement, although some variations are seen, especially with the eleven ounce force-level. The ninth and tenth weeks generally showed a decrease in tooth movement, again with the exception of the eleven ounce force-level in the maxillary arch.

The general pattern of tooth movement was the same for both the upper and lower arches. After the initial phase and lag phase there appeared to be considerable variability in tooth movement in both arches. Increases and decreases of movement alternated either weekly or every two weeks. In both arches, the two ounce force-level produced the least amount of initial movement and the least amount of movement during the lag phase. The eight ounce force-level produced the most movement during the lag phase in both arches, and also the most initial movement in the mandibular arch. The eleven ounce force-level produced the most movement during the initial phase in the maxillary arch.

The average weekly movement was greatest with the eleven ounce force-level in the maxillary arch every week except the second, third, and eighth. In the mandible, the average weekly movement was greatest with the eight ounce force-level during all weeks except the third, fifth, and seventh. The five ounce force-level had the greatest average weekly movement during those weeks.

Comparative Description

The total space closure for each patient is illustrated in Figures 6-15 and summarized in Tables 6-13.

In the maxillary arch, the total space closure did not vary directly with regard to force. The most total space closure was produced with the eleven ounce force level. The five ounce force level was next, followed by the eight and two ounce levels respectively.

In the mandibular arch, the most total space closure was produced with the eight ounce force level, followed closely by the five, eleven, and two ounce levels respectively.

Analysis of Variance

The results of the analysis of variance on the intra-oral data are presented in Table 14.

Tukey's method for multiple comparisons indicates that the two ounce force level is significantly different from the five, eight, and eleven ounce force levels, as well as the mean of these force levels. No significant difference was found between the five, eight, and eleven ounce force levels.

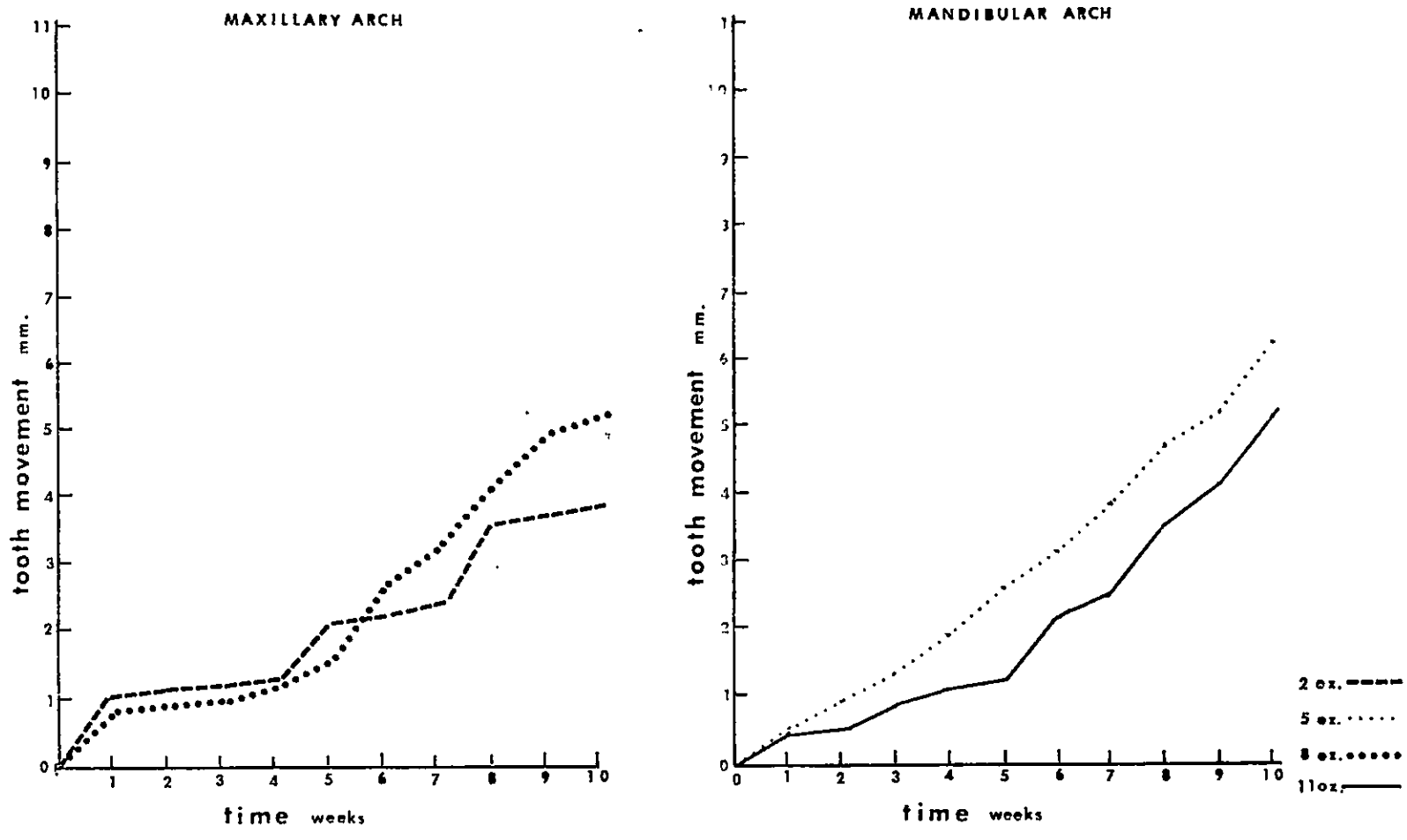


Figure 6. Weekly Cumulative Space Closure - Patient 1

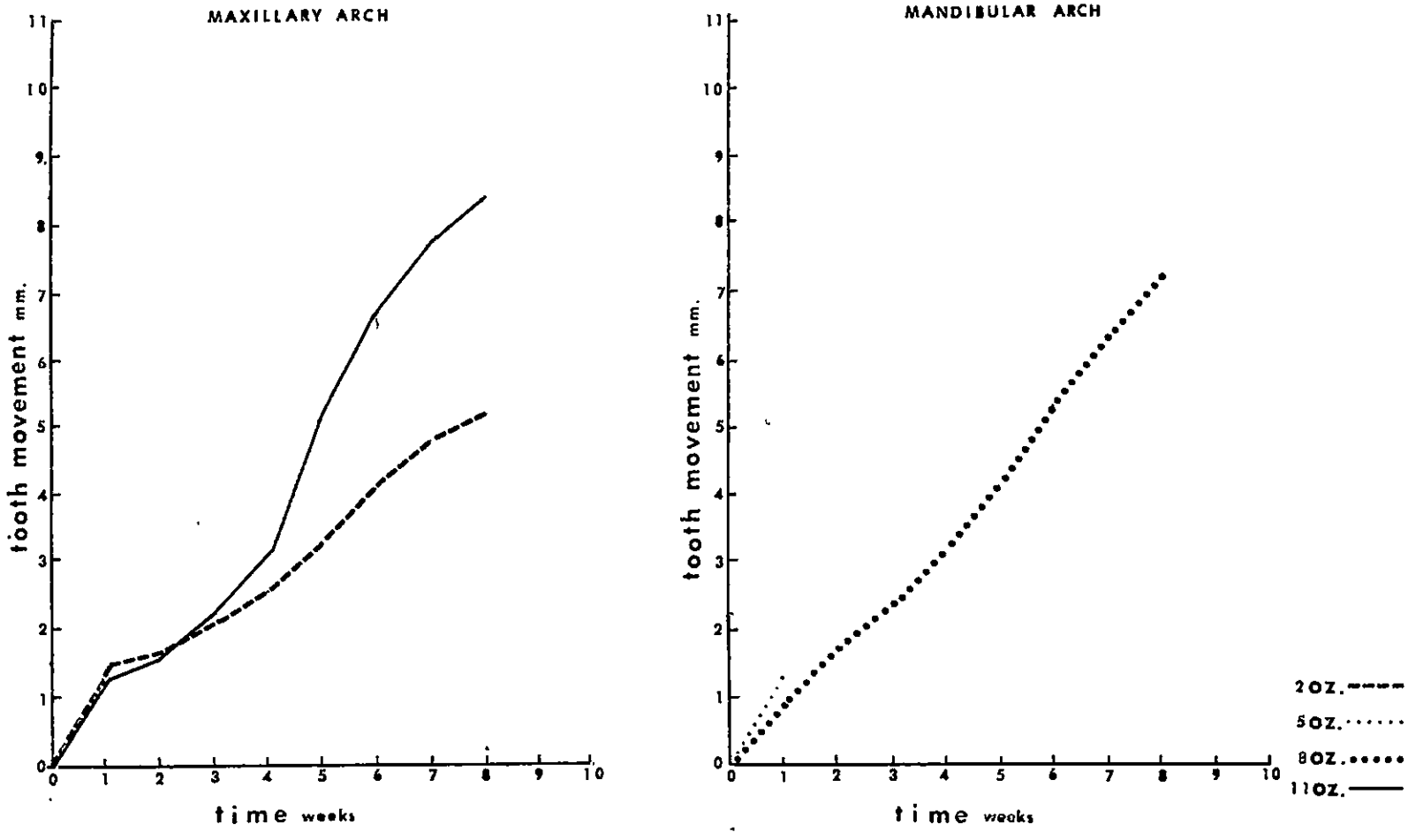


Figure 7. Weekly Cumulative Space Closure - Patient 2

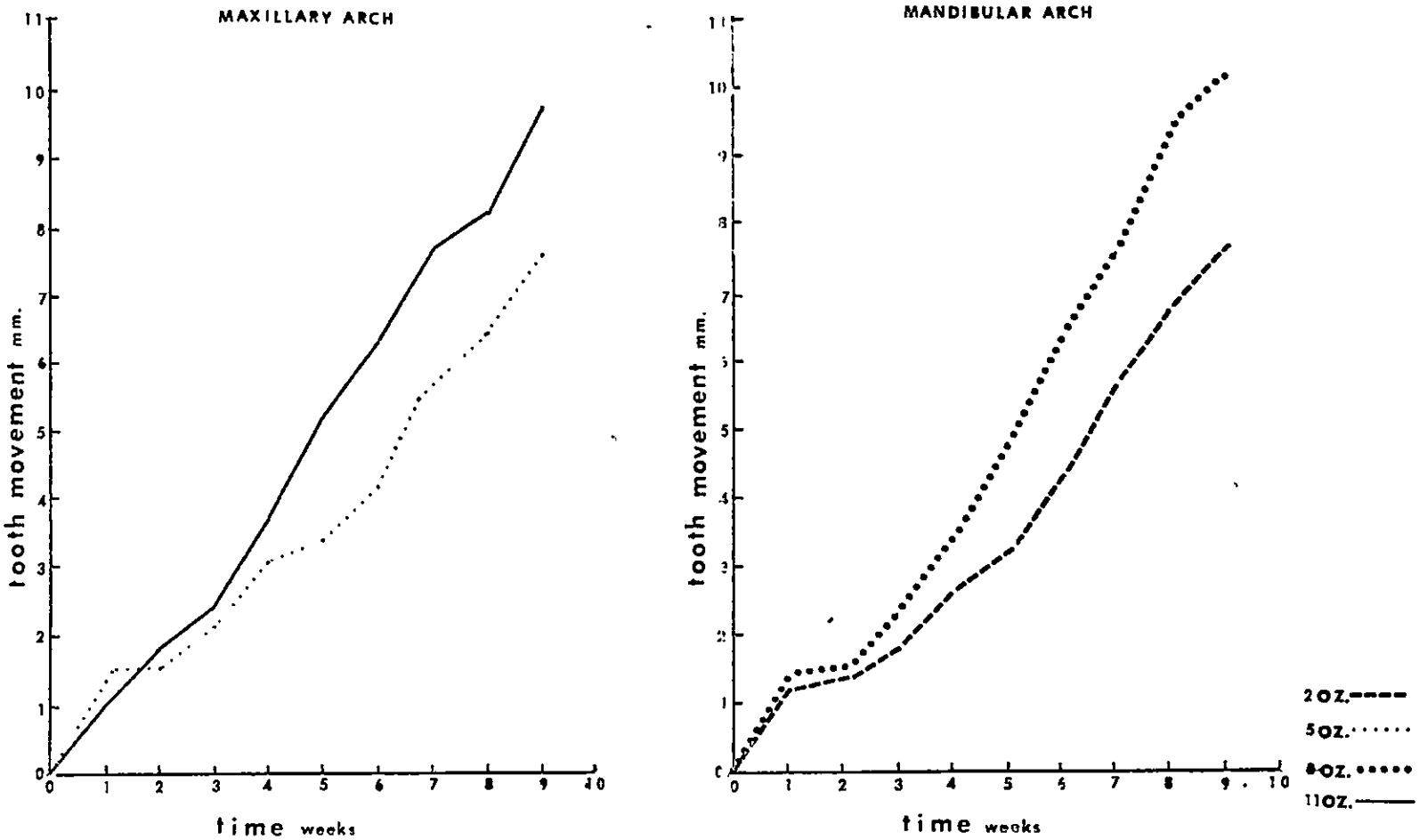


Figure 8. Weekly Cumulative Space Closure - Patient 3

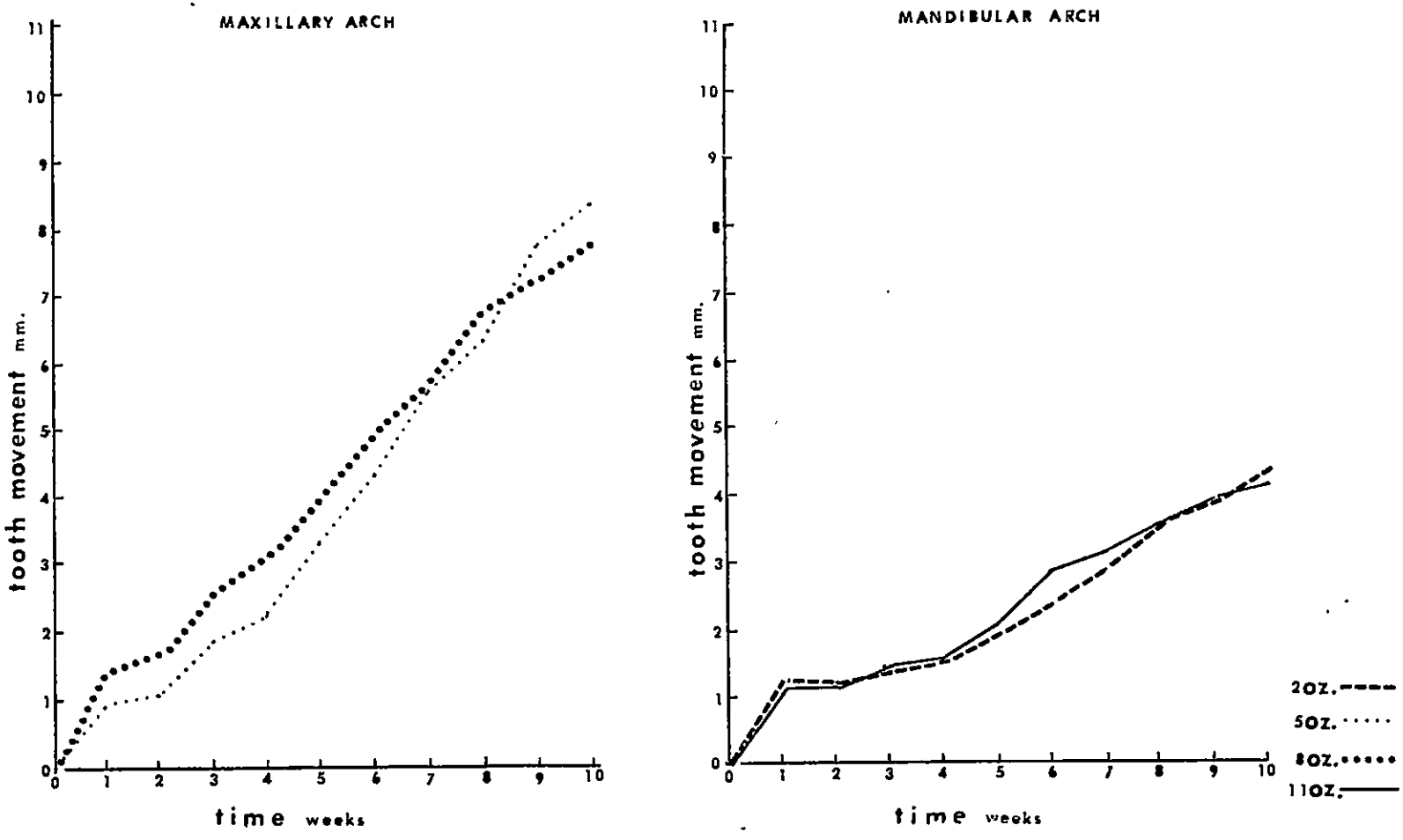


Figure 9. Weekly Cumulative Space Closure - Patient 4

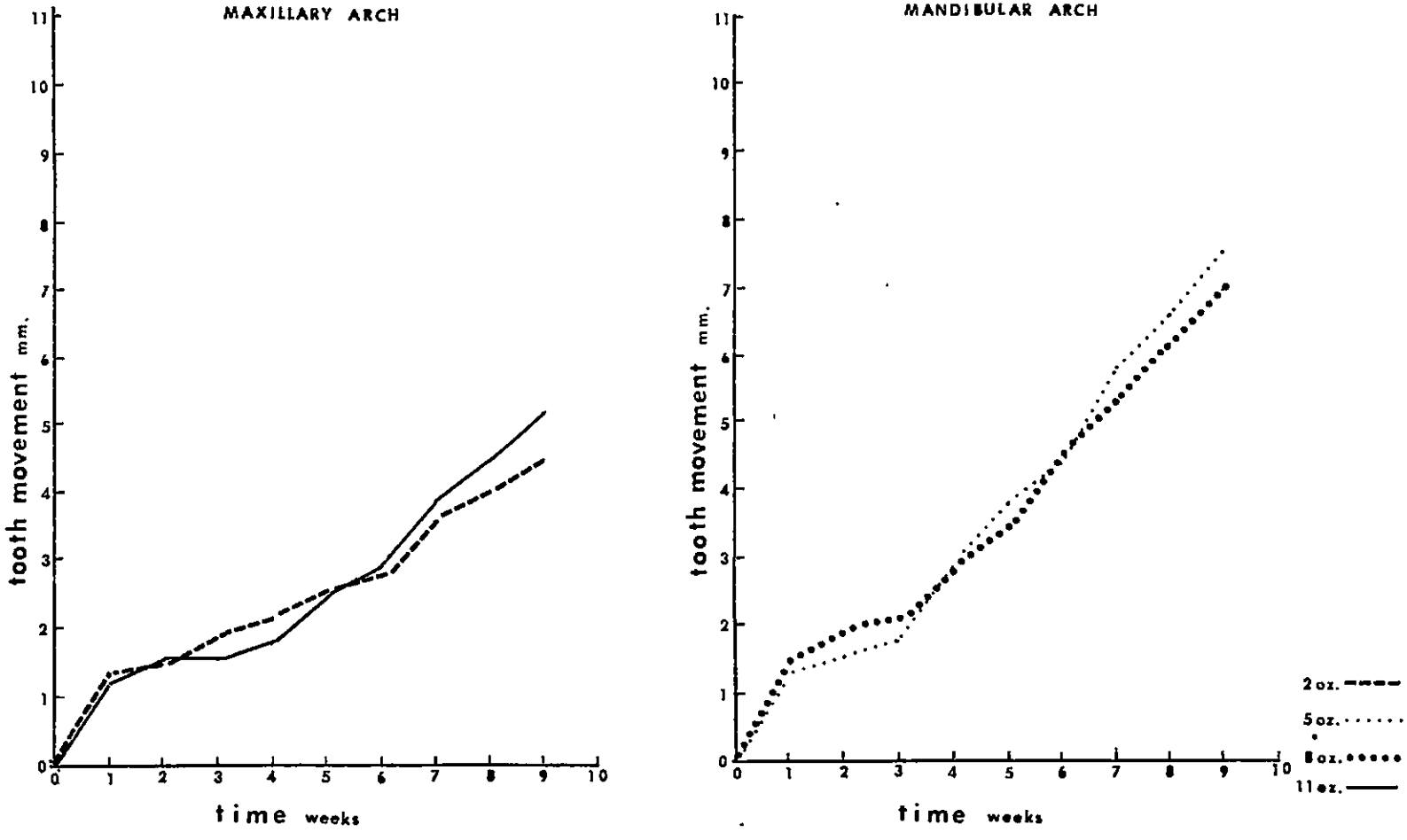


Figure 10. Weekly Cumulative Space Closure - Patient 5

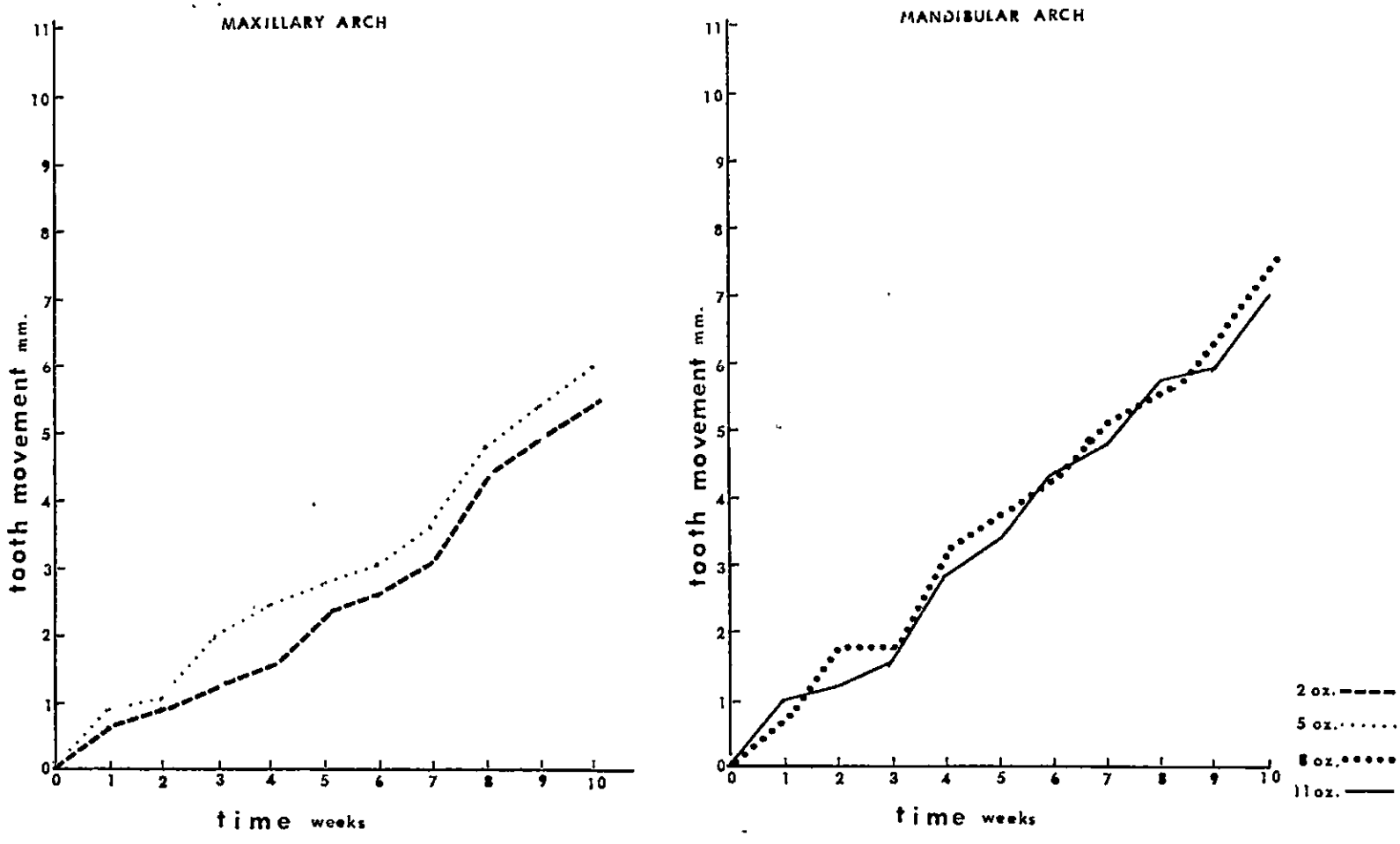


Figure 11. Weekly Cumulative Space Closure - Patient 6

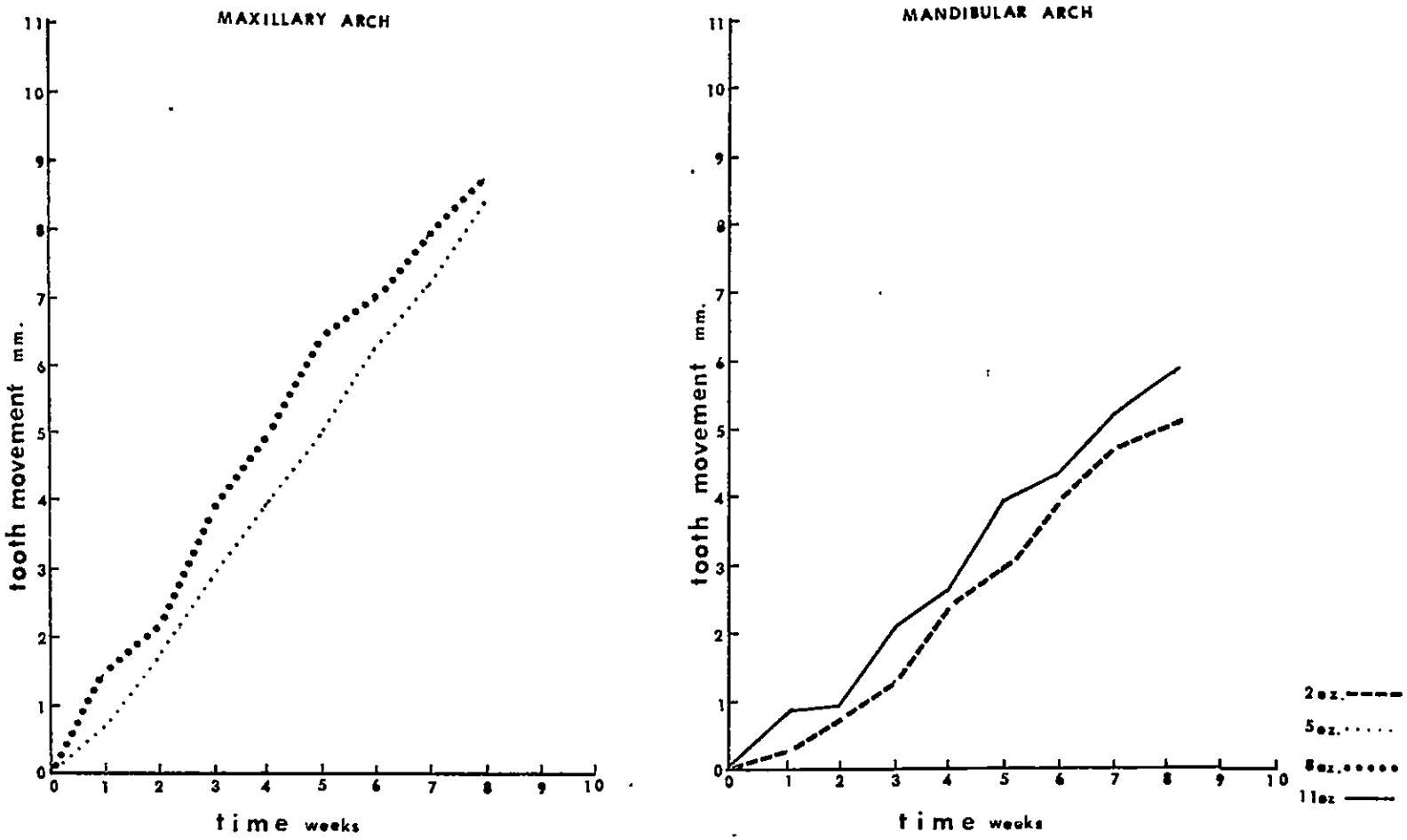


Figure 12. Weekly Cumulative Space Closure - Patient 7

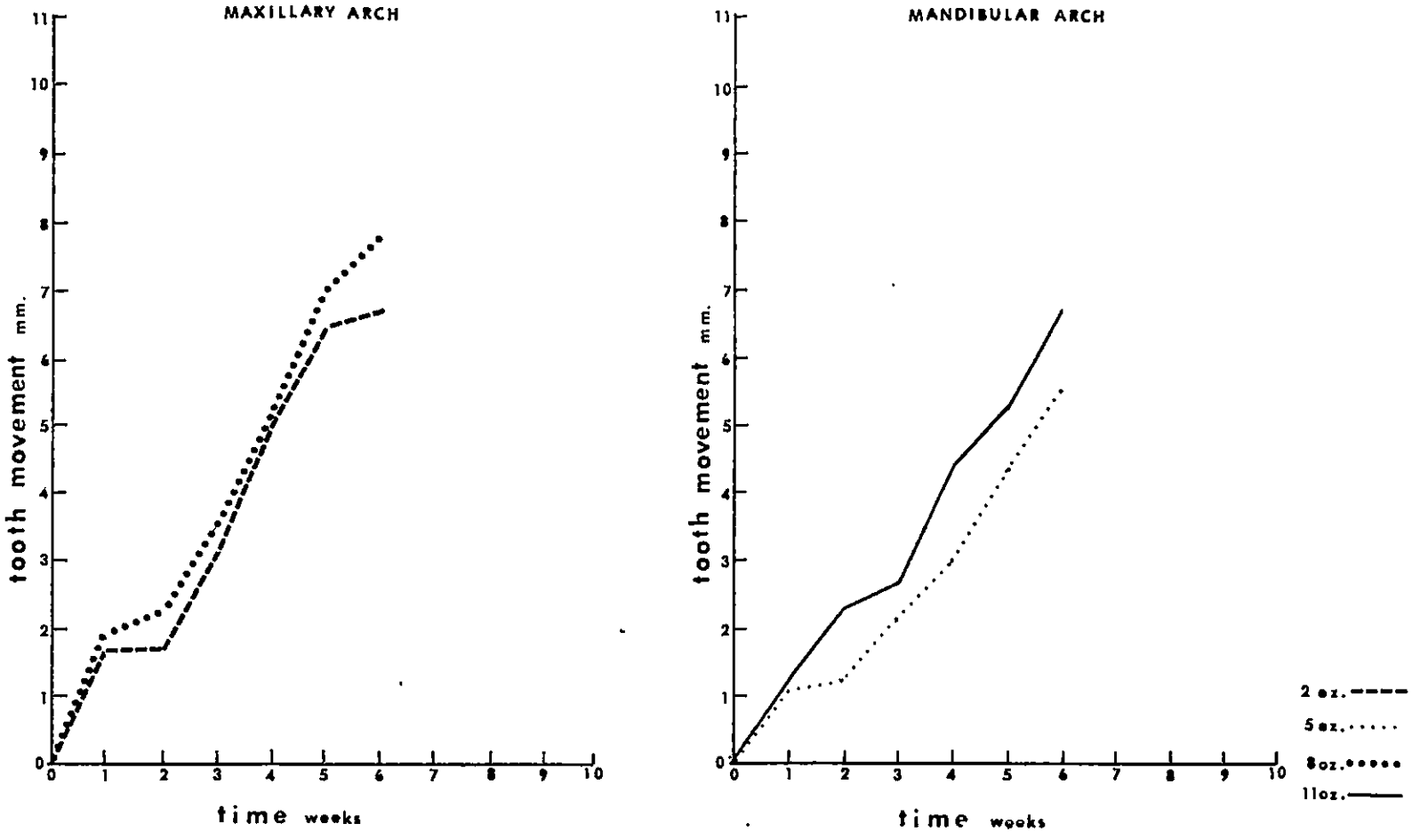


Figure 13. Weekly Cumulative Space Closure - Patient 8

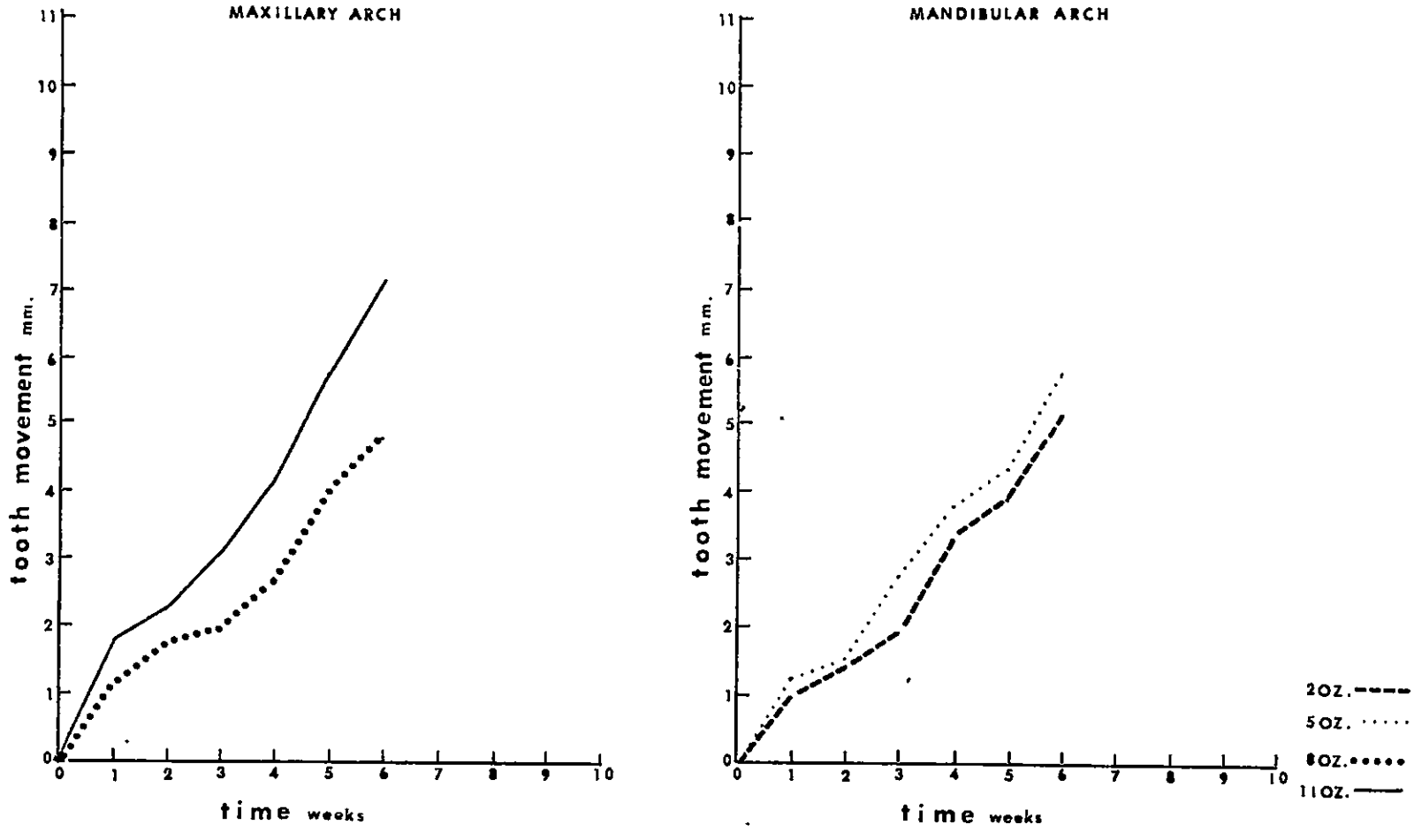


Figure 14. Weekly Cumulative Space Closure - Patient 9

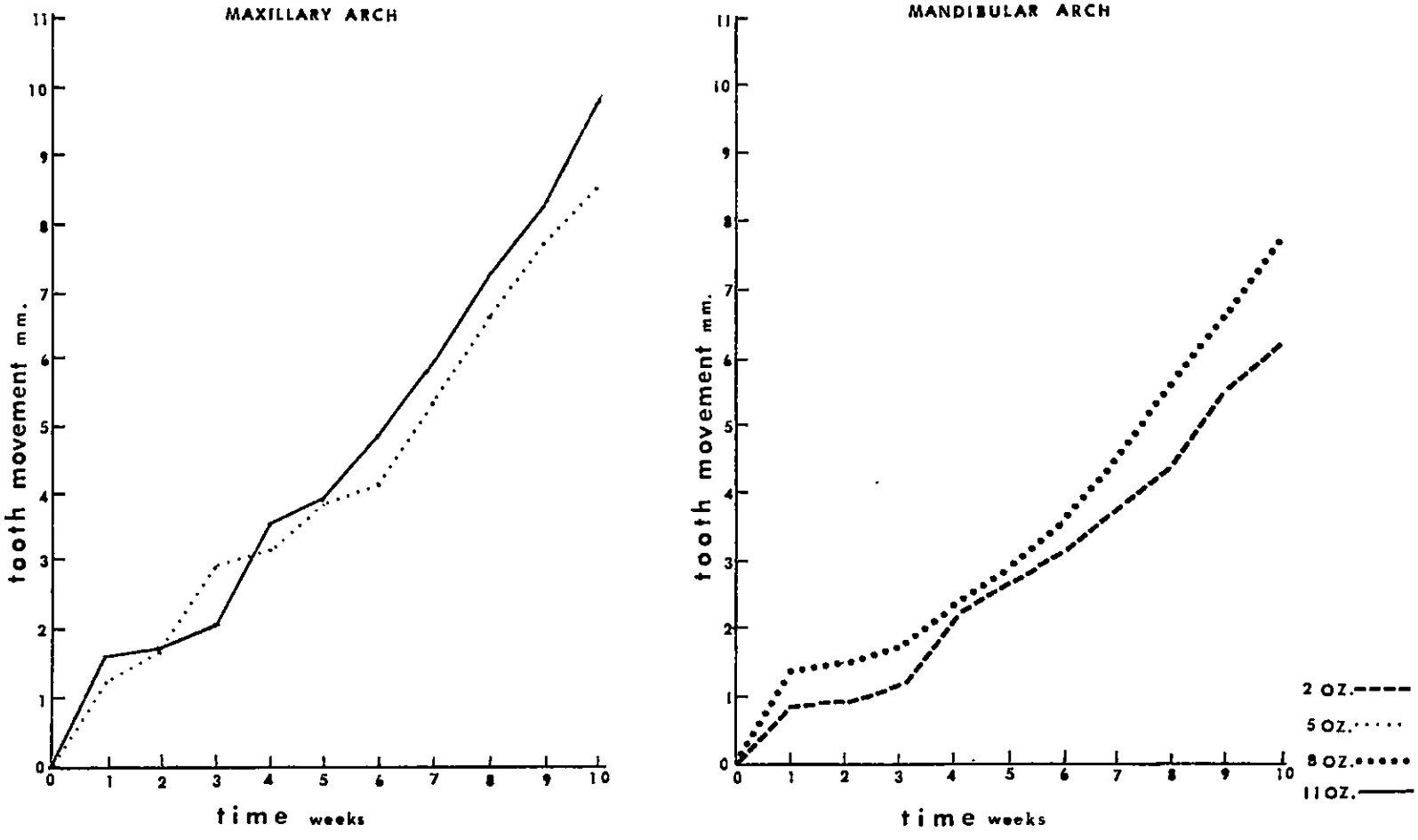


Figure 15. Weekly Cumulative Space Closure - Patient 10

TABLE 6

SPACE CLOSURE: TWO OUNCES MAXILLARY ARCH

(millimeters)

Week	Patient				
	1	2	5	6	8
1	1.00	1.39	1.30	.62	1.62
2	.13	.21	.14	.28	.05
3	.05	.44	.39	.31	1.41
4	.09	.49	.31	.32	1.79
5	.79	.71	.36	.68	1.51
6	.14	.81	.26	.38	.26
7	.19	.73	.79	.42	. .
8	1.15	.37	.44	1.22	. .
9	.15	. .	.45	.62	. .
10	.11	. .	. .	.53	. .
Total	3.80	5.15	4.44	5.38	6.64

TABLE 7

SPACE CLOSURE: FIVE OUNCES MAXILLARY ARCH

(millimeters)

Weeks	Patient				
	3	4	6	7	10
1	1.36	.88	.88	.67	1.22
2	.13	.16	.13	1.02	.43
3	.62	.82	.93	1.15	1.25
4	.93	.38	.46	1.09	.28
5	.35	1.09	.30	1.05	.67
6	.77	.99	.30	1.26	.31
7	1.28	1.25	.57	.88	1.19
8	.96	.72	1.20	1.27	1.26
9	1.19	1.41	.60	. .	1.06
10	. .	.60	.55	. .	.83
Total	7.59	8.30	5.92	8.39	8.50

TABLE 8

SPACE CLOSURE: EIGHT OUNCES MAXILLARY ARCH

(millimeters)

Week	Patient				
	1	4	7	8	9
1	.77	1.39	1.44	1.86	1.09
2	.10	.30	.73	.38	.60
3	.08	.86	1.63	1.22	.27
4	.20	.58	1.17	1.67	.68
5	.32	.86	1.38	1.75	1.34
6	1.12	.90	.60	.88	.81
7	.60	.74	.93	. .	. .
8	.86	1.16	.80	. .	. .
9	.78	.43	. .	. .	. .
10	.33	.52	. .	. .	. .
Total	5.16	7.74	8.68	7.76	4.79

TABLE 9

SPACE CLOSURE: ELEVEN OUNCES MAXILLARY ARCH

(millimeters)

Week	Patient				
	2	3	5	9	10
1	1.39	.93	1.19	1.68	1.58
2	.15	.84	.32	.56	.09
3	.65	.61	.01	.81	.42
4	.82	1.28	.26	1.11	1.47
5	2.03	1.49	.63	1.58	.35
6	1.56	1.11	.46	1.32	.97
7	1.03	1.35	.98	. .	1.11
8	.74	.54	.58	. .	1.22
9	. .	1.54	.75	. .	.99
10	. .	. .	. .	. .	1.54
Total	8.37	9.69	5.18	7.06	9.74

TABLE 10

SPACE CLOSURE: TWO OUNCES MANDIBULAR ARCH

(millimeters)

Week	Patient				
	3	4	7	9	10
1	1.10	1.19	.27	.93	.85
2	.23	.01	.47	.47	.05
3	.46	.18	.55	.50	.29
4	.78	.12	1.05	1.38	.91
5	.60	.36	.54	.58	.55
6	1.05	.51	.93	1.20	.47
7	1.37	.48	.82	. .	.61
8	1.12	.62	.40	. .	.66
9	.89	.38	. .	. .	1.09
10	. .	.49	. .	. .	.74
Total	7.60	4.34	5.03	5.06	6.22

TABLE 11

SPACE CLOSURE: FIVE OUNCES MANDIBULAR ARCH
(millimeters)

Week	Patient				
	1	2	5	8	9
1	.51	. .	1.25	1.06	1.21
2	.42	. .	.27	.20	.29
3	.44	. .	.25	.86	1.23
4	.53	. .	1.03	.88	1.05
5	.69	. .	.97	1.32	.53
6	.57	. .	.60	1.15	1.46
7	.67	. .	1.31	. .	. .
8	.84	. .	.91	. .	. .
9	.53	. .	.88	. .	. .
10	1.04	. .	. .	. .	. .
Total	6.24	6.68[a]	7.47	5.47	5.77

[a]Estimated datum

TABLE 12

SPACE CLOSURE: EIGHT OUNCES MANDIBULAR ARCH
(millimeters)

Week	Patient				
	2	3	5	6	10
1	.85	1.33	1.41	.66	1.38
2	.84	.18	.46	1.05	.11
3	.58	.77	.21	.01	.26
4	.81	1.11	.70	1.37	.56
5	1.00	1.36	.64	61	.54
6	1.17	1.56	1.15	.54	.74
7	1.00	1.22	.66	.84	.87
8	.90	1.75	.95	.50	1.20
9	. .	.88	.75	.69	.94
10	. .	. .	. .	1.09	1.11
Total	7.15	10.16	6.93	7.36	7.71

TABLE 13

SPACE CLOSURE: ELEVEN OUNCES MANDIBULAR ARCH
(millimeters)

Week	Patient				
	1	4	6	7	8
1	.46	1.03	.95	.82	1.25
2	.05	.14	.23	.09	1.03
3	.36	.29	.36	1.16	.37
4	.24	.10	1.27	.55	1.69
5	.14	.52	.53	1.30	.92
6	.93	.78	.92	.37	1.43
7	.36	.28	.50	.87	. .
8	1.01	.43	.88	.73	. .
9	.59	.31	.23	. .	. .
10	1.03	.29	1.07	. .	. .
Total	5.17	4.17	6.94	5.89	6.69

TABLE 14

ANALYSIS OF VARIANCE: INTRA-ORAL DATA

Source	df	SSQ	MSQ
Treatments	3	23.345	7.782
Blocks	9	42.696	. .
Errors	26	35.577	1.368
Total	38	101.618	. .

$F(3,26) = 5.687$

$F(3,26).95 = 2.98$

Model Measurements

The data for the model measurements are given in Figure 16 and Tables 15 and 16.

TABLE 15

MODEL MEASUREMENTS
(millimeters)

	Arch							
	Maxilla				Mandible			
Patient	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	2.75		3.64	. .	. .	3.23	. .	4.16
2	5.38	. .	. .	6.42	. .	4.65[a]	4.46	. .
3	. .	5.31	. .	6.66	5.66	. .	7.69	. .
4	. .	7.51	5.95	. .	3.55	. .	. .	4.83
5	4.64	. .	. .	5.71	. .	5.87	4.68	. .
6	2.96	5.29	. .	. .	. .	. .	5.17	4.60
7	. .	6.31	5.81	. .	2.62	. .	. .	5.36
8	5.50	. .	5.14	. .	. .	4.56	. .	5.13
9	. .	. .	5.07	6.04	4.61	4.31	. .	. .
10	. .	5.70	. .	5.77	4.79	. .	6.05	. .
Total	21.25	30.12	25.61	30.60	21.23	22.62	28.05	24.08

[a] Estimated datum

TABLE 16

MEANS: MODELS
(millimeters)[b]

Arch	2 oz.	5 oz.	8 oz.	11 oz.	Mean
Maxillary	4.25	6.02	5.12	6.10	5.37
Mandibular	4.24	4.52	5.61	4.82	4.80
Mean	4.24	5.27	5.36	5.46	5.08

[b] Rounded where necessary to nearest even hundredth

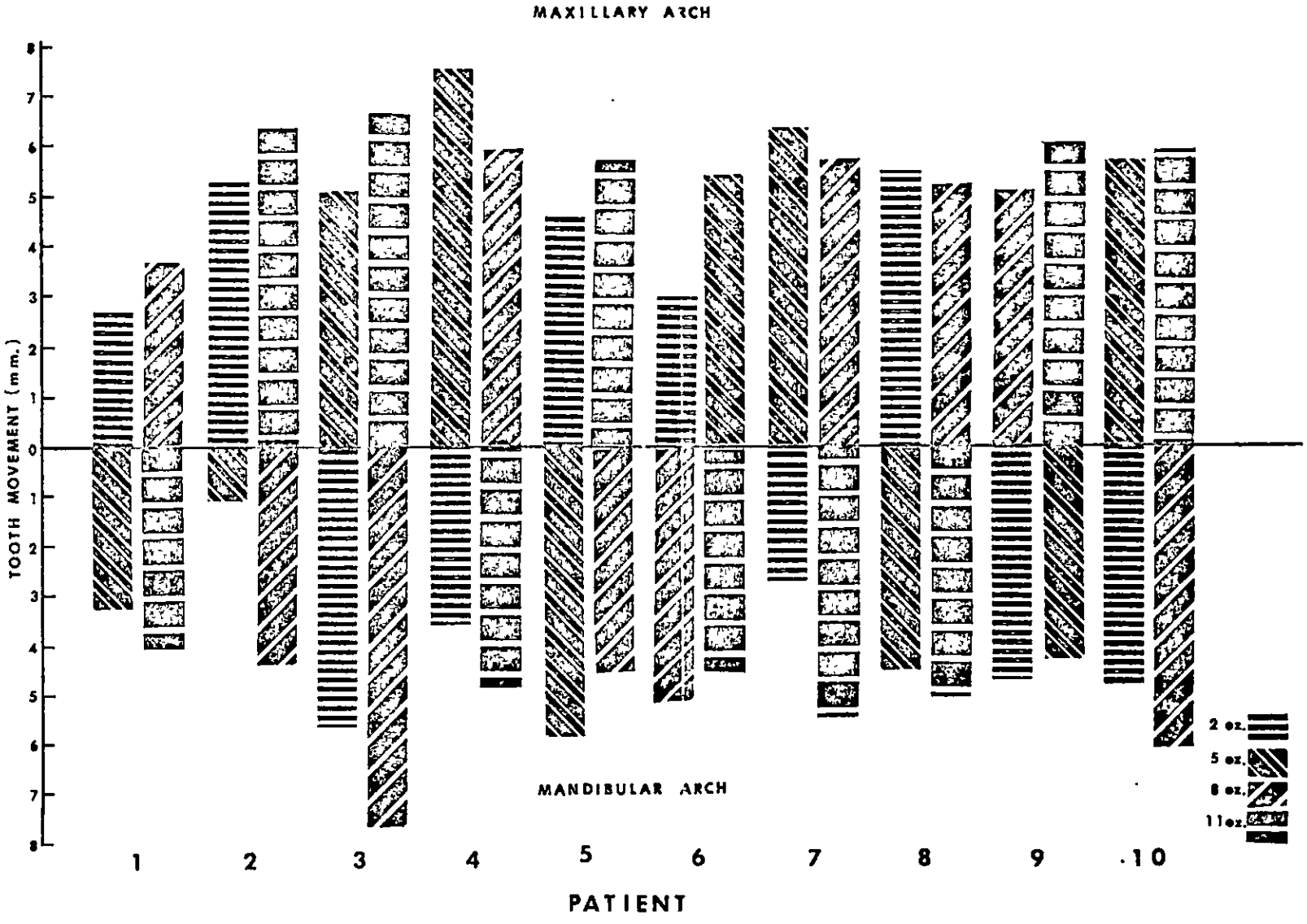


Figure 16. Total Movement: Models

In the maxillary arch, the pattern of tooth movement was identical to that found with the intra-oral measurements. On the average, the most closure occurred with the eleven ounce force level. This was followed by the five, eight, and two ounce force levels respectively.

In the mandibular arch, however, the most closure occurred with the eight ounce force level, followed by the eleven, five, and two ounce force levels respectively.

Analysis of Variance

The results of the analysis of variance on the model data are presented in Table 17.

Tukey's method for multiple comparisons indicates that the two ounce force level is significantly different from the eleven ounce force level. The eight ounce force level and the mean for the five, eight, and eleven ounce force levels were not significantly different from the two ounce force level at the 95 percent level of confidence. However, it should be noted that $.05 < p < .10$.

TABLE 17

ANALYSIS OF VARIANCE: MODEL DATA

Source	df	SSQ	MSQ
Treatments	3	9.654	3.218
Blocks	9	20.035	. .
Error	26	21.993	0.846
Total	38	51.682	. .

F(3,26) = 3.804

F(3,26).95 = 2.98

Cephalometric Radiograms

The total space closure as recorded on the cephalometric radiograms is given in Figure 17 and Tables 18 and 19.

TABLE 18

CEPHALOMETRIC RADIOGRAPHIC MEASUREMENTS: TOTAL CLOSURE
(millimeters)

	Arch							
	Maxilla				Mandible			
Patient	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	2.06	. .	3.02	. .	. .	3.50	. .	2.74
2	3.43	. .	. .	4.97	. .	3.72[a]	3.56	. .
3	. .	2.94	. .	5.73	4.90	. .	6.46	. .
4	. .	5.57	3.65	. .	2.36	. .	. .	2.93
5	3.06	. .	. .	4.30	. .	4.49	3.26	. .
6	3.48	2.04	. .	. .	. .	. .	4.97	3.24
7	. .	6.32	5.41	. .	4.20	. .	. .	4.72
8	3.84	. .	4.29	. .	. .	3.00	. .	3.27
9	. .	. .	3.12	3.60	3.09	3.25	. .	. .
10	. .	5.57	. .	4.37	3.61	. .	4.16	. .
Total	15.87	22.44	19.49	22.97	18.16	18.26	22.41	16.90

[a] Estimated datum

TABLE 19

MEANS: CEPHALOMETRIC RADIOGRAMS
(millimeters)[b]

Arch	2 oz.	5 oz.	8 oz.	11 oz.	Mean
Maxillary	3.17	4.49	3.90	4.59	4.04
Mandibular	3.63	3.65	4.48	3.38	3.78
Mean	3.40	4.07	4.19	3.98	3.91

[b] Rounded where necessary to nearest hundredth

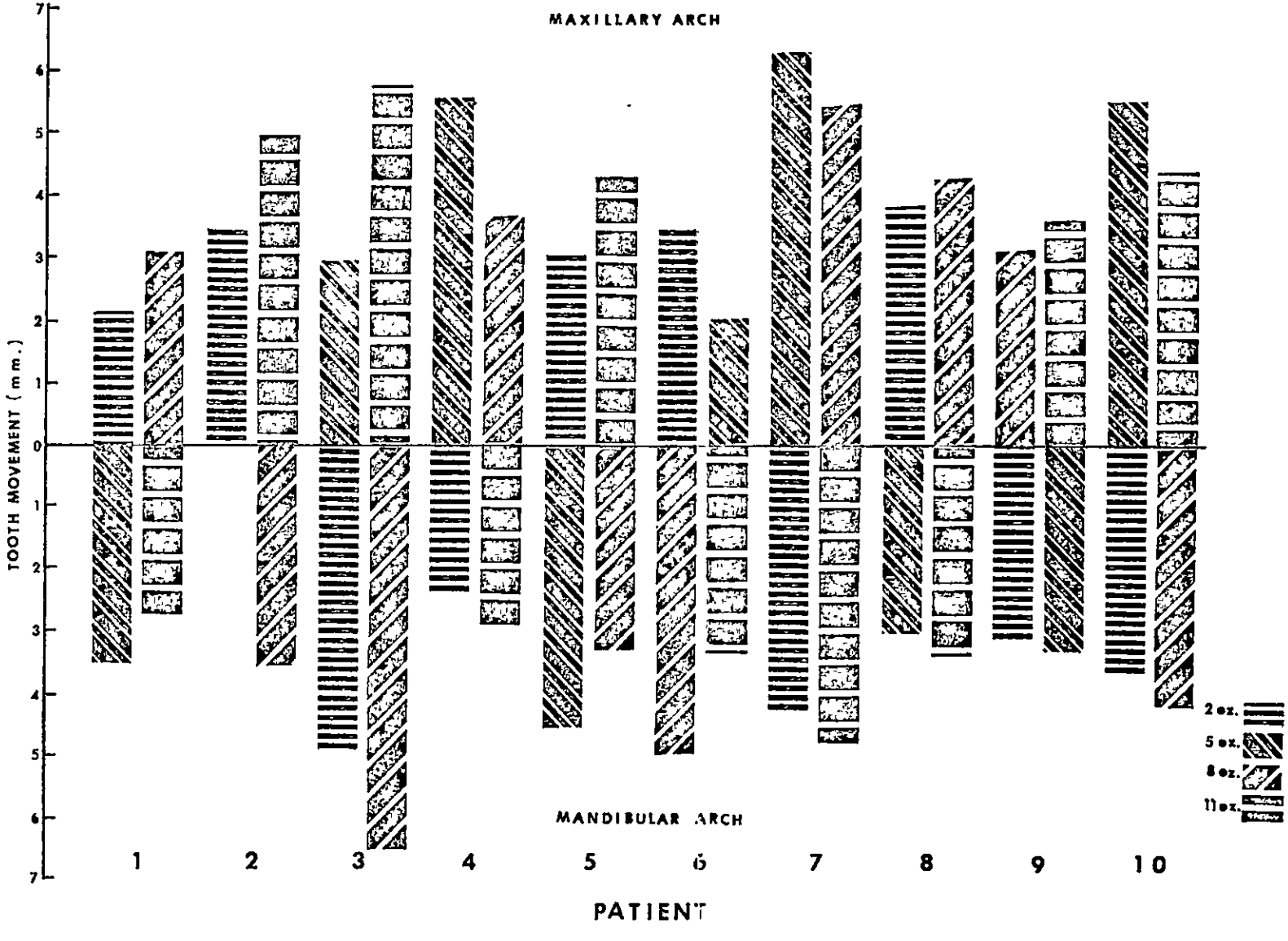


Figure 17. Total Movement: Cephalometric Radiograms

The data tend to indicate that in the maxillary arch, the pattern established with the intra-oral and model measurements was found again. On the average, the most space closure occurred at the eleven ounce force level, followed by five, eight, and two ounce force levels respectively.

In the mandibular arch, the movement appeared to vary directly with force through the eight ounce level. The eleven ounce force level produced more space closure than the two ounce level but less than the five ounce level.

Analysis of Variance

The results of the analysis of variance on the cephalometric radiograms are presented in Table 20. Inasmuch as the null hypothesis could not be rejected, no treatment comparisons were attempted.

TABLE 20

ANALYSIS OF VARIANCE: CEPHALOMETRIC RADIOGRAPHIC DATA

Source	df	SSQ	MSQ
Treatments	3	15.452	5.151
Blocks	9	84.524	. .
Error	26	104.596	4.023
Total	38	204.572	. .

$F(3,26) = 1.28$

$F(3,26).95 = 2.98$

Molar Movement

The amount of space closure attributable to mesial movement of the molar as determined from the cephalometric radiogram is presented in Figure 18 and Tables 21 and 22.

TABLE 21

CEPHALOMETRIC RADIOGRAMS: MOLAR MOVEMENT
(millimeters)

	Arch							
	Maxilla				Mandible			
Patient	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	.68	. .	1.09	. .	. .	.80	. .	1.32
2	1.99	. .	. .	1.15	. .	1.60[a]	1.68	. .
3	. .	1.12	. .	1.51	2.20	. .	1.54	. .
4	. .	1.72	2.11	. .	.64	. .	. .	.75
5	.42	. .	. .	2.04	. .	2.42	.44	. .
6	2.00	.34	. .	. .	. .	. .	3.11	.80
7	. .	2.66	1.48	. .	1.48	. .	. .	.58
8	.37	. .	2.10	. .	. .	.52	. .	.20
9	. .	. .	2.26	2.12	1.41	2.09	. .	. .
10	. .	.39	. .	2.74	2.13	. .	1.14	. .
Total	5.46	6.23	9.04	9.56	7.86	7.43	7.91	3.65

[a] Estimated datum

TABLE 22

MEANS: MOLAR MOVEMENT
(millimeters)[b]

Arch	2 oz.	5 oz.	8 oz.	11 oz.	Mean
Maxillary	1.09	1.25	1.81	1.91	1.52
Mandibular	1.57	1.49	1.58	.73	1.34
Mean	1.33	1.37	1.70	1.32	1.43

[b] Rounded where necessary to the nearest hundredth

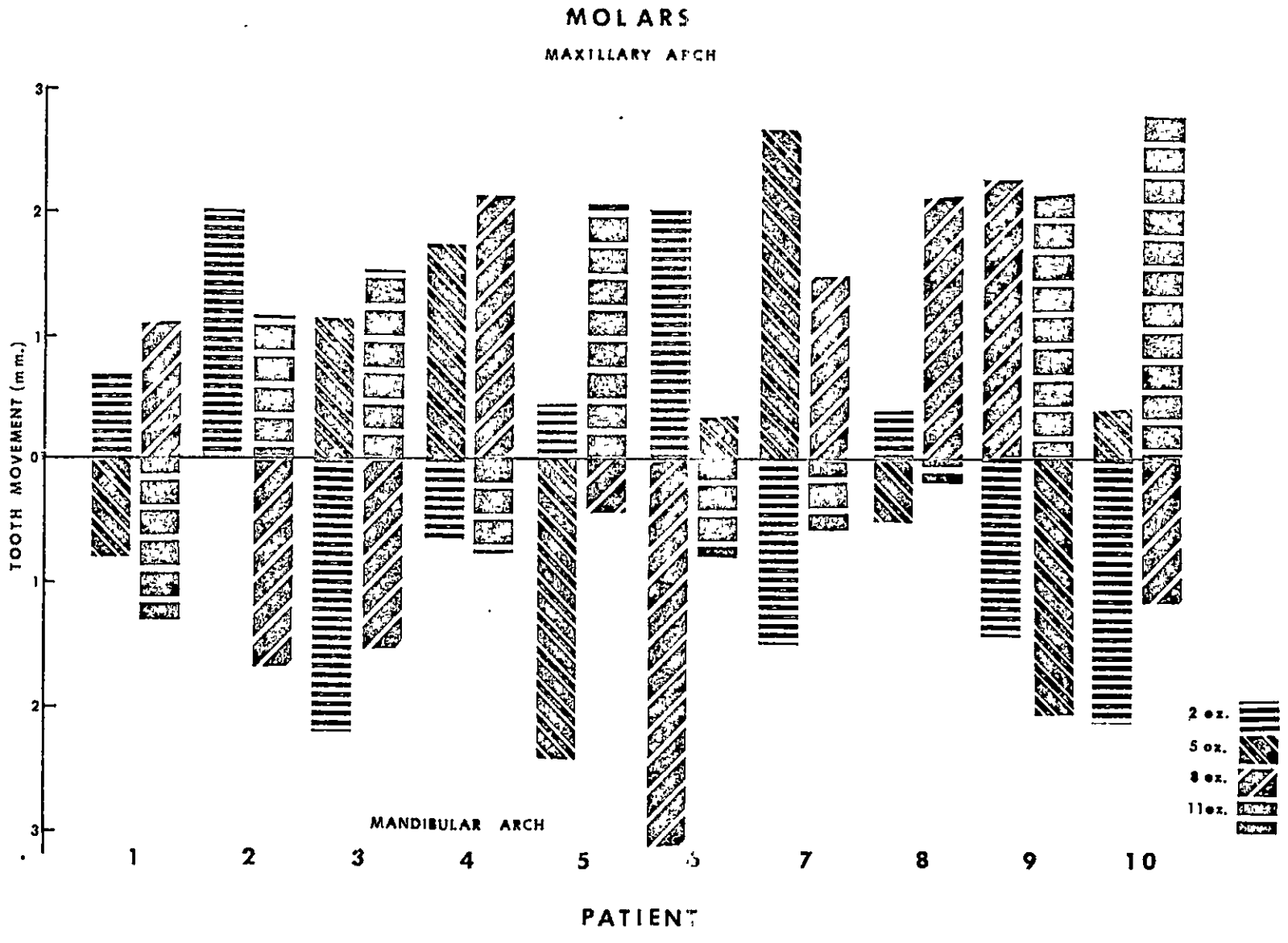


Figure 18. Total Movement: Molars

The apparent trend of the data can be summarized in the following manner: 1) more molar movement occurred in the maxilla than in the mandible; 2) in the maxilla, molar movement varied directly with the force applied; 3) in the mandible, the least amount of molar movement was seen with eleven ounces of force, and the most movement was seen with eight ounces of force.

Analysis of Variance

The results of the analysis of variance on the molar data are presented in Table 23. Inasmuch as the null hypothesis could not be rejected, no treatment comparisons were attempted.

TABLE 23

ANALYSIS OF VARIANCE: MOLAR DATA

Source	df	SSQ	MSQ
Treatments	3	3.551	1.184
Blocks	9	17.176	. .
Error	26	71.613	2.754
Total	38	92.340	. .

$F(3,26) = .430$

$F(3,26).95 = 2.98$

Canine Movement

The amount of space closure attributable to the distal movement of the canine as determined from the cephalometric radiograms is presented in Figure 19 and Tables 24 and 25.

TABLE 24

CEPHALOMETRIC RADIOGRAMS: CANINE MOVEMENT
(millimeters)

Patient	Arch							
	Maxilla				Mandible			
	2 oz.	5 oz.	8 oz.	11 oz.	2 oz.	5 oz.	8 oz.	11 oz.
1	1.38	. .	1.93	. .	.	2.70	. .	1.42
2	1.44	. .	. .	3.82	. .	1.86[a]	1.88	. .
3	. .	1.82	. .	4.22	2.70	. .	4.92	. .
4	. .	3.85	1.54	. .	1.72	. .	. .	1.18
5	2.64	. .	. .	2.26	. .	2.07	2.82	. .
6	1.48	1.70	. .	. .	. .	. .	1.86	2.44
7	. .	3.66	3.93	. .	2.78	. .	. .	4.14
8	3.47	. .	2.19	. .	. .	2.48	. .	3.07
9	. .	. .	.86	1.48	1.68	1.16	. .	. .
10	. .	5.18	. .	1.63	1.48	. .	3.02	. .
Total	10.41	16.21	10.45	13.41	10.36	10.27	14.50	12.25

[a] Estimated datum

TABLE 25

MEANS: CANINE MOVEMENT
(millimeters)[b]

Arch	2 oz.	5 oz.	8 oz.	11 oz.	Mean
Maxillary	2.08	3.24	2.09	2.68	2.52
Mandibular	2.07	2.05	2.90	2.45	2.37
Mean	2.08	2.64	2.50	2.56	2.44

[b] Rounded where necessary to the nearest hundredth

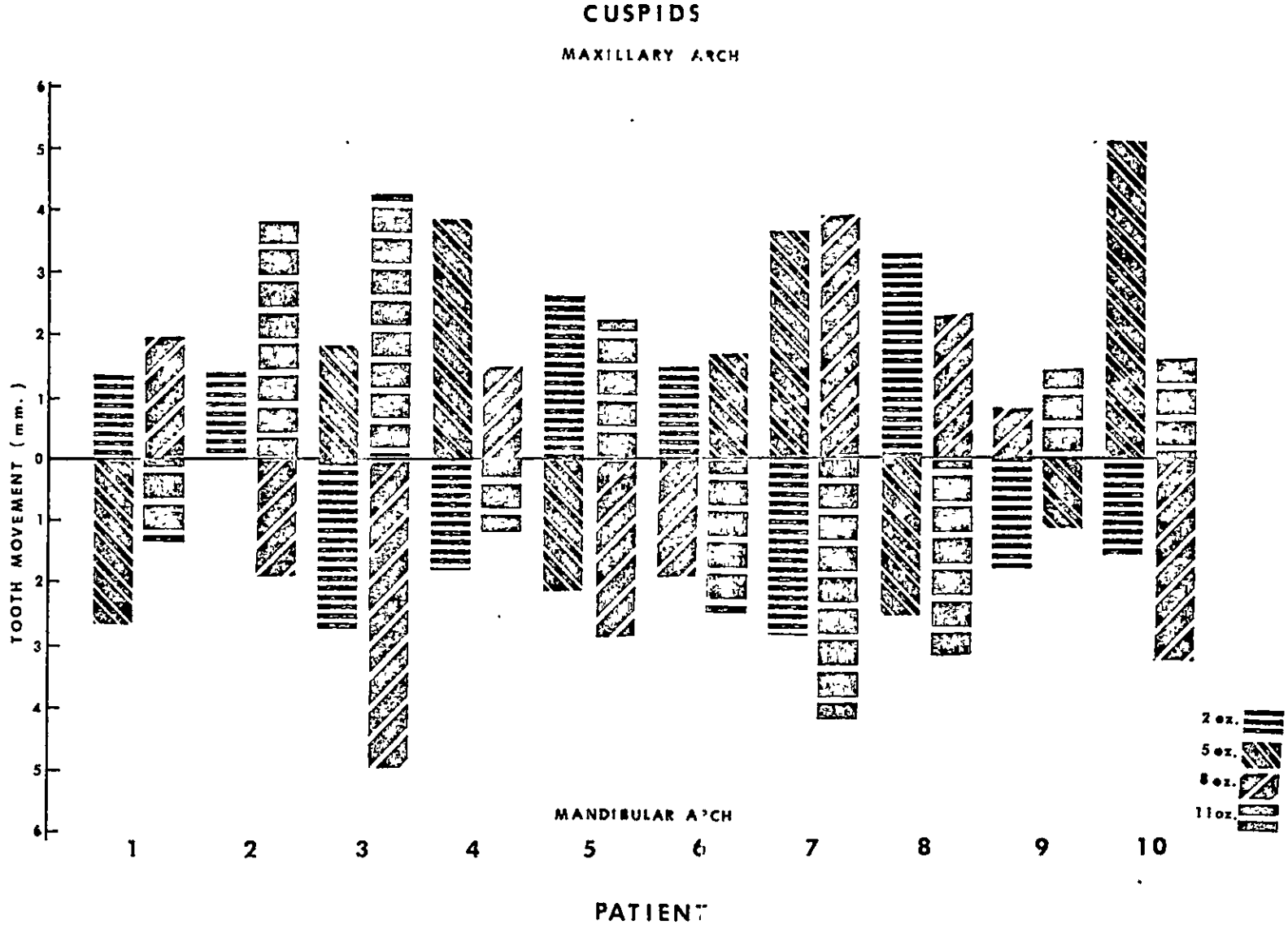


Figure 19. Total Movement: Cuspids

The apparent trend of the data can be summarized as follows: 1) more cuspid movement occurred in the maxilla than in the mandible; 2) in the maxilla, the most movement occurred with five ounces of force followed by eleven, eight, and two ounces respectively; 3) in the mandible, the most movement occurred with eight ounces of force, followed by eleven, two, and five ounces respectively.

Analysis of Variance

The results of the analysis of variance on the canine data are presented in Table 26. Again, in lieu of a significant F, no individual comparisons were performed.

TABLE 26

ANALYSIS OF VARIANCE: CANINE DATA

Source	df	SSQ	MSQ
Treatments	3	7.904	2.634
Blocks	9	76.704	. .
Error	26	101.382	3.899
Total	38	185.990	. .

$F(3,26) = .676$

$F(3,26).95 = 2.98$

Discomfort Index

The results for the amount of tooth discomfort for each patient are summarized in Table 27.

TABLE 27

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

The results can be summarized as follows: 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) the two ounce force level elicited the fewest number of responses concerning tooth discomfort; 3) Friedman's two-way analysis of variance for ranked data showed the data highly non-significant ($p = .50$). Therefore, there is no evidence that there is a difference in tooth discomfort when teeth are subjected to two, five, eight and eleven ounces of force.

DISCUSSION

Pattern of Tooth Movement

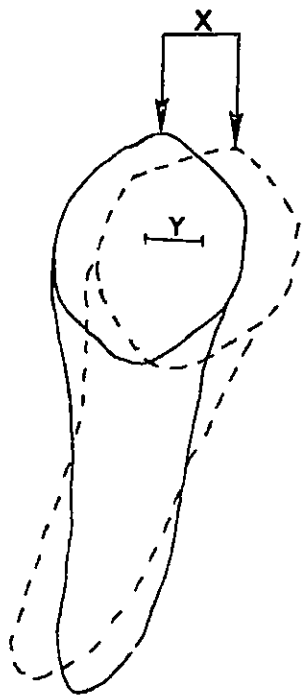
The present study supports the findings of previous investigators with regard to pattern of tooth movement (Burstone, 1961; Reitan, 1969; DaPrano, 1971). In the present study, the pattern of tooth movement consisted of an initial period of rapid tooth movement which lasted for about one week. All force levels demonstrated this phase of tooth movement. The data tend to indicate that the eleven ounce force level produced the most movement during this phase in the maxilla. Likewise, the eight ounce force level appeared to produce the most movement in the mandible. The statistical model precludes any inferences regarding the magnitude of specific treatment-arch interactions.

The lag phase followed in all patients at all force levels and also lasted about one week. The lag phase was characterized by a much lower rate of tooth movement. In both arches, the greatest amount of movement during this phase appeared to be produced by the eight ounce force level. The least amount of tooth movement tended to be with the two ounce force level. It appears that even with a force as light as two ounces, frontal resorption is arrested.

The lag phase was followed by a period of increased tooth movement. This phase was characterized by periods of increases and decreases of tooth movement. This pattern of increases and decreases was probably due to reorganization of the bone and the undermining resorption processes.

Total Space Closure

The average total space closure found with the intra-oral measurements was 6.01 mm. The model measurements indicated an average of 5.08 mm for total space closure, and the cephalometric radiograms revealed an average space closure of 3.91 mm. This difference in measurements may be accounted for by the accommodation for tooth rotations in the measurement techniques. As explained in Methods, the rotational effects are minimized in the model and cephalometric radiogram measurements. Also, there is a measurement discrepancy between the model and cephalometric measurements inherent in the measurement techniques. As described in Methods, the model measurements were made from cusp tip to cusp tip; however, the cephalometric radiogram measurements were made from the approximate centers of the crowns of the teeth involved. As the tooth moves, primarily in a tipping fashion, the distance X is larger than the distance Y (Figure 20). Therefore, the apparent space closure is greater by measuring from cusp tip to cusp tip than from the approximate center of the crowns of the teeth. It can be concluded that the difference



X > Y

Figure 20. Inherent Discrepancy in Measurement Techniques

in values obtained for the three measurement techniques is due to rotations and to inherent discrepancies within the measurement techniques.

The F values for the intra-oral and model measurements are significant at the 95 percent level of confidence. The cephalometric radiogram measurements are not significant at the 95 percent level of confidence.

Tukey's method for multiple comparisons was calculated for the intra-oral and model measurements. The results of these computations for the intra-oral data show that the two ounce force level is significantly different at the 95 percent level of confidence from the five, eight, eleven, and the mean of the five, eight and eleven ounce force levels. Also, Tukey's method when calculated for the model data, showed that the two ounce force level is significantly different from the eleven ounce force level at the 95 percent level of confidence. The eight ounce force level and the mean of the five, eight and eleven ounce force levels are almost significantly different from the two ounce force level at the 95 percent level of confidence. No significant difference could be found between the five, eight and eleven ounce force levels.

It can be concluded from the above that tooth movement did not vary directly with force up to the 300 gram level as described by Hixon (1969). Rather, the five, eight and eleven ounce force levels all produced a significantly greater amount

of tooth movement than did the two ounces, but were not significantly different from one another. Consequently, between the two and five ounce force levels, force is the rate-limiting factor for tooth movement. However, bone resorption appears to be the rate-limiting factor for tooth movement at the five, eight and eleven ounce force levels.

Reliability of Measurements

A summary of the statistical analyses is given in Table 28.

TABLE 28

SUMMARY OF RELATIVE STATISTICS

Source of Data	Analysis of Variance Summary		
	Tx MSQ	Error MSQ	F
Intra-oral	57.782	1.368	5.687*
Model	43.218	0.846	3.804*
Cephalometric Radiograms	5.151	4.023	1.28

From this computation, it may be seen that the model measurements appear to be the most reliable. This, perhaps, can be attributed to the use of well-defined anatomical landmarks which generally account for rotational effects. Probably for the same reason, the intra-oral measurements also had a low

error mean square value. The error mean square for the cephalometric radiograms is much larger. The cephalometric radiographic measurements are therefore questionable with regard to determining total space closure. An implant technique, along with the cephalometric radiograms, probably would have increased the accuracy of the radiographic measurements.

Optimal Force

In the maxillary arch, all three methods of measurement; intra-oral, models, and cephalometric radiograms, seemed to indicate that the eleven ounce force level may produce the greatest amount of total space closure, followed by the five ounce, eight ounce, and two ounce force levels respectively. The amount of movement, however, was not directly related to the amount of force as reported by Hixon and associates (1969).

In the mandibular arch, the eight ounce level of force appeared to produce the most movement. All three methods of measurement confirm this finding also. As in the upper arch, a direct relationship was not apparent between the amount of tooth movement and the amount of force applied.

Statistically, the two ounce force level produced significantly less movement than the five, eight and eleven ounce force levels. No difference could be demonstrated between the five, eight and eleven ounce force levels.

Differential Force

The cephalometric radiograms were used as described in Methods to determine the amount of anchorage loss (mesial movement of molars) and the amount of distal movement of canines. Although the statistical analysis did not show these values significant at the 95 percent level of confidence ($F = .430$ for molars; $F = .676$ for canines), some trends are suggested by the data.

All force levels used produced more canine movement than molar movement when averages are compared. In the maxillary arch 14/20 quadrants demonstrated more canine movement than molar movement. In the mandibular arch, 16/20 quadrants showed more cuspid movement than molar movement. Thus, 10/40 ($p < .01$) quadrants demonstrated more molar movement than cuspid movement. Of these ten quadrants, five were within Storey and Smith's ideal range. Likewise, 10/40 demonstrated movement similar to that found by Storey and Smith. Storey and Smith's movement was characterized by very little mesial displacement of the molar and bicuspid, with the major movement being the distal displacement of the canine. Of these ten, five were outside Storey and Smith's range. From the above data, there appears to be no overall rule concerning differential force.

By comparing the average values for cuspid and molar movement to the total movement, percentages were calculated for the four forces and are presented in Table 29.

TABLE 29

CANINE AND MOLAR MOVEMENT

(percent of total)

Force	Maxilla		Mandible	
	Canine	Molar	Canine	Molar
2	66	34	57	43
5	72	28	58	42
8	54	46	65	35
11	58	42	77	23

Friedman's two-way analysis of variance on ranked data was computed on these percentages. No significant difference could be demonstrated for these data.

It should be pointed out that arch effects and treatment-arch interactions were not tested with the statistical analyses used in this study. An approximation was calculated by means of an incomplete block analysis of variance. No treatment-arch interactions were shown with this method. This analysis of variance was not reported in Results, inasmuch as ten patients constituted 2.5 replications, rather than the whole numbers required for exact interpretation.

By failing to reject the null hypothesis, it can be concluded that this study does not statistically support the concept of differential force as described by Storey and

Smith (1952). In other words, no significant difference could be found between the two, five, eight, and eleven ounce force levels with regard to cuspid and molar movement. How might this discrepancy be explained?

If one examines the appliance used by Storey and Smith, it is evident that the canine is free to move (Figure 21). However, the molar and bicuspid are connected with a sectional arch wire and sliding yoke which is attached to a sectional arch wire connecting the four anterior teeth. In order for the molar and bicuspid to move, friction must be overcome. Therefore, in Storey and Smith's comparison of molar movement to canine movement, a friction system was being compared with a frictionless system. Hixon and associates (1970) found that a wire (.0215 x .028") with a span of seven millimeters will deflect in an occlusal direction one millimeter when 200 grams of force are applied. This deflection will cause binding of the yoke in Storey and Smith's appliance, thus preventing bicuspid and molar movement, or at least force them to move bodily, not to mention the forward displacement of the upper and lower anterior teeth and lips.

It appears that when the heavy forces used by Storey and Smith were applied, the force may have been great enough to overcome this binding, and the cuspid as well as the molar and bicuspid moved. When the forces were lighter, the arch wire deflection occurred and caused the binding. The force was not

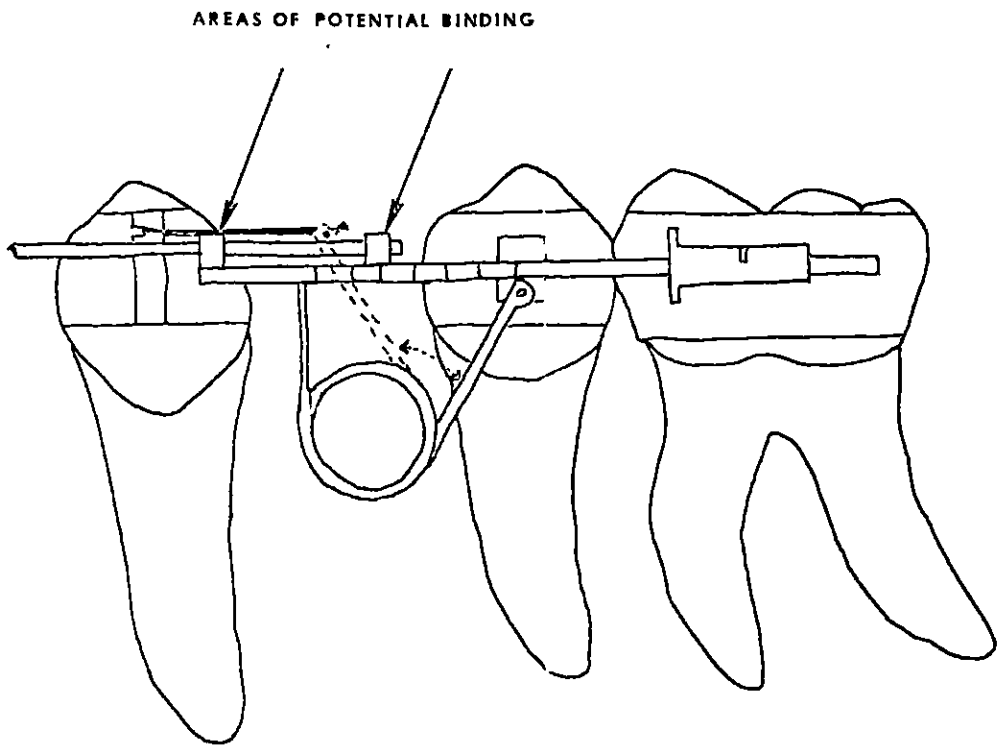


Figure 21. Cuspid-Retraction Appliance: Modified After Figure 7 of Storey and Smith, 1952

great enough to overcome the binding, and consequently the molar and bicuspid moved very little or not at all. The cuspid was free to move, however, and did so.

The force system used in the present study was a frictionless system. The molar and bicuspid were free to move uninhibited by friction. The same was true for the canine. Under these conditions, a statistically significant force value which could be labelled "differential" was not found.

The data of the present study also do not confirm the results of Hixon and associates (1969) that tooth movement increased directly with force until the 300 gram level is reached. The data do support the findings of Hixon and associates (1970) that:

1) Wide variation in response was found between individuals.

2) The large variation between patients prevents the formulation of simple theories regarding forces and anchorage.

With regard to tooth discomfort, there appears to be much variability both within the same patient and between patients. Friedman's two-way analysis of variance for ranked data showed no significant difference ($p = .50$) between the two, five, eight, and eleven ounce force levels with regard to tooth discomfort. Therefore, the commonly-held idea that light forces produce less discomfort was not demonstrated in this study.

In summary, the results of the present study indicate that no significant difference could be shown between the five,

eight, and eleven ounce force levels, although the two ounce force level was shown to produce significantly less movement. Specific tooth movements, in this study, were shown to be quite variable, in that no statistically significant support for the concept of differential force could be demonstrated. Also, with regard to tooth discomfort, no significant difference was shown between the two, five, eight, and eleven ounce force levels.

SUMMARY AND CONCLUSIONS

A study was conducted to investigate space closure during canine retraction in ten randomly selected patients who presented themselves for orthodontic treatment, and who were diagnosed as four first bicuspid extraction cases.

The data were collected and analyzed by three methods:

1) Direct intra-oral measurements to determine the total amount of space closure.

2) Measurements derived from beginning and final study casts to determine the amount of total space closure.

3) Cephalometric radiographs (22.5^{o}) to determine the amount of total space closure, the amount of distal canine movement, and the amount of mesial molar movement.

The results of the intra-oral and model measurements were statistically significant at the 95 percent level of confidence ($F = 5.687^{*}$ for intra-oral; $F = 3.804^{*}$ for models). The cephalometric measurements were not found to be statistically significant at the 95 percent level of confidence. Tukey's method for multiple comparisons was used to contrast the data with statistically significant F values. Friedman's two-way analysis of variance on ranked data was used on the cuspid and molar radiographic data and on the tooth discomfort data. In both cases, no significant differences were found within the data.

The results of the intra-oral measurements and the model

measurements were more reliable but less valid due to the rotations of the teeth and the inherent discrepancies in the measurement techniques.

The cephalometric radiograms were more valid but not as reliable due to the inaccuracy in the method of measuring the space closure.

The results can be summarized as follows:

1) The two ounce force level produced significantly less tooth movement than the five, eight, and eleven ounce force levels.

2) No significant difference could be demonstrated between the five, eight, and eleven ounce force levels with regard to tooth movement (total space closure).

3) No statistically significant evidence was found to support the concept of differential force. Anchorage loss and canine retraction were relatively independent of the force levels.

4) No statistically significant difference was found between the two, five, eight, and eleven ounce force levels with regard to tooth discomfort. Tooth discomfort was relatively independent of the force levels.

APPENDIX I

Patient Consent Form

CASE WESTERN RESERVE UNIVERSITY

SCHOOL OF DENTISTRY

PATIENT CONSENT FOR STUDIES

Title of Project: INVESTIGATION OF CONCEPT OF DIFFERENTIAL AND OPTIMAL FORCE IN CANINE RETRACTION

The following information is given to you regarding a clinical study of which you may become part, if you so elect. Please read the following items carefully, and if you would like to become part of the study, please sign at the bottom of the form.

1) The purpose of this study is to examine the rate of movement of cuspid, second bicuspid and first molar into extraction sites.

2) The patients are selected on the basis that all teeth involved in the investigation could be banded at one time.

3) Candidates to be selected for the investigation would be patients whose treatment plan has been arrived at by standard diagnostic procedures and approved by the Orthodontic Staff. Specifically, it must call for the extraction of four first bicuspids in order to achieve the optimal orthodontic result.

4) Special appliances will be constructed for each patient and placed in the appropriate site at the time of extraction.

5) The candidate is assured that it is the consensus of the Orthodontic Staff that the investigation will in no manner affect the outcome of the proposed treatment and will not alter to any significant extent the period of orthodontic treatment.

6) At the end of the investigation, each candidate will be treated to completion as they normally would have been if they had, or had not, participated in this investigation.

7) You will receive a reduction in the total fee to cover the cost of the extractions performed at the School of Dentistry, Case Western Reserve University.

8) You may withdraw from this study at any time.

I, the undersigned, understand that I have been asked to be a cooperating participant in this project to be conducted in the School of Dentistry at Case Western Reserve University. The studies above described have been explained to me by the Project Investigator, and I agree to participate therein as a volunteer patient.

In consideration of the foregoing, I hereby release the School of Dentistry of Case Western Reserve University and any of their servants and agents, from any and all claims and causes of action arising out of the foregoing project.

SIGNATURE _____ AGE ___ DATE _____

PARENTAL CONSENT _____ DATE _____

WITNESSED BY _____ DATE _____

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