TOOTH MOVEMENT STUDIED WITH THE AID OF METALLIC IMPLANTS

by

H. W. MacDonald

May 3, 1968

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The author wishes to thank Doctor Ernest H. Hixon for his generous assistance in this study.

INTRODUCTION

The relationship between the rate of tooth movement and the amount of the moving force has been of primary concern to orthodonists since the turn of the century but it appears no closer to resolution than it was in Oppenheim's time. Clinically recommended forces range from the 30-50 gram "light physiologic"[1,2,3] level, to the 135-300 gram threshold-optimal or differential force strengths, up to the 600-1000 gram intensity of the Bull & Hice loops used with the edgewise appliance.

Many articles have been written extolling the virtues of these lighter forces as opposed to the "controlled pathology"[3] of heavier forces, but little evidence has been offered to test the propositions on which these treatment theories are based. Several appliance and treatment systems have been evolved which use these "physiologic"[3,4,5,6,7] and "differential"[8,9,10,11] forces. The proponents of these systems emphasize the assumptions on which their particular rationales are based but little documented evidence exists in the literature to corroborate (or disprove) these deductions.

P.R. Begg claims that the "differential force principle" makes it possible to move teeth without anchorage loss, and makes headgear wear unnecessary.[10]

J. R. Jarabak uses this idea as part of the basis for his treatment rationale also,[11] but neither he nor Begg present any evidence to validate this anchorage transfer theory.

The theory can be summarized in the following statement:

> A certain minimum force is required to initiate tooth movement and increasing this force will increase the

rate of tooth movement until an optimum force is reached. Forces beyond this optimum cause increasing capillary compression[2,12], hyalinization[2,13], and cessation of movement until the acellular material can be removed by undermining resorption[14] during which time the force can cause the anchorage unit to move. When the undermining resorption is complete the tooth will again move.

The differential force and anchorage transfer idea was a logical deduction from the above concepts and the idea that at a certain force range (150-200gms.) a tooth will move and that an increase in force (300-500 gms.) will cause it to stop moving and initiate movement in the anchorage teeth instead[10] has many adherents.

This paper seeks to examine these concepts by exploring the relationship between tooth movement and the amount of the applied force in orthodontic patients, under clinical conditions.

LITERATURE REVIEW

S. Weinstein[14], discussing studies on minimal forces and tooth movement, reported that a 2 gram force acting for a sufficient time (8 weeks) would move a tooth an appreciable (.8 mm) distance. The "biologic sensitivity" of the dental unit was acute enough to react to this gentle stimulus.

C. J. Burstone and M. H. Groves[16] used forces from 25 to 150 grams per quadrant to tip upper anterior teeth and found that their 25 gram force tipped teeth and the optimum rate of movement occurred in the 50-75 gram range.

E. Storey and R. Smith[17] applied 2 ranges of forces on 5 patients; a lighter 175-300 gram force on one side and a 400-600 gram force on the other side. Four lower arches and one upper arch were treated. They found that below 135 grams the cuspid did not move, in fact two lower cuspids withstood a force of 150 grams for over 3 weeks without moving. As the force increased cuspid movement rate increased until an optimum was reached at the 150-200 gram force range. Further increase in force led to a decrease in cuspid movement. When forces above 300 grams were applied, the cuspids did not move but the anchorage unit (molar & bicuspid) moved instead. They inferred from this that there is a threshold and an optimum force range, and that as force is increased above the optimal range, cuspid movement slows and then stops, "at least for short periods of time", and anchorage is transferred from the posterior segment to the cuspid.

In contrast to the above H. L. Bull[18] used rectangular sectional arches with a simple closed vertical loop to retract cuspids. These loops exert forces of approximately 800 grams[19] when activated to 1 mm.

Using an eccentric cervical headgear to apply a 400 gram force to one upper first molar while exerting a 200 gram force on its antimere, G. Andreasen and P. Johnson[20] undertook a study on 16 girls aged 8-10 years.

They found that the teeth subjected to the 400 gram force moved, on the average, 2½ times as far (3.25 mm) in 12 weeks as did the molars with the 200 gram force (1.30 mm). This difference was found to be significant at the 1% level of confidence. They state that the findings indicate that for the maxillary first molars a faster rate of movement can be obtained by applying a higher force within physiological limits.

A different result was noted by R. K Utley[21] who studied cuspid tipping in cats using 3 different force levels: - light (50 grams), medium (150 grams) and heavy (530 grams). He found inter alia, that:

1. Maxillary cuspids in thesame cat moved the same distance regardless of the magnitude of force applied to the right and left sides.
2. Rate of tooth movement between animals was not related to force magnitude. When forces of the same magnitude were delivered to maxillary cuspids of different cats, the rate of tooth movement was consistently different for each animal.

In summary, recent findings are not consistent with the Oppenheim[22], Storey-Smith concept of tooth movement. If the concept of optimal force is not valid then neither is the idea of differential force.

MATERIAL AND METHOD

It was decided to examine cuspid movement using a variety of forces; with metallic implants in the jaws as reference points to determine the magnitude and direction of movement.

Eight patients, aged 10½ to 17, who required cuspid retraction as part of their orthodontic treatment, participated in the study.

The forces applied to the cuspids were as follows:

A 300 gram continuous force was applied to the right side of each patient.

Eight different forces were allocated to the left side, one to each patient. The force levels were:

0 grams
50 grams
150 grams continuous
150 grams decaying to 25
300 grams decaying to 200
900 grams decaying to 300
900 grams continuous
1500 grams continuous

Tantalum implants were placed in each patient's jaws after the method of A. Bjork[23]. The implant sites were as follows:

1. The symphysis of the mandible below the central incisors.
2. The mandible body below and just anterior to the mesial root of the first molar, right and left.
3. Just off the upper midline above the central incisor apices.
4. High in the Zygomatic area, right and left.

The implants served as reference points for superimposing the X-ray films and for measuring the amount of tooth movement in relation to the bone.

Each patient had the 4 first bicuspids removed and the first molars, second bicuspids, and cuspids were banded. To serve as a more precise identification of the movement of the cuspid and bicuspid in the X-ray films, a short piece of .022" inside diameter tubing was soldered to each cuspid and bicuspid bracket and cut over the bracket slot to facilitate fitting the arch wires. A short length of stopped .022" wire was fitted into each tube just before the X-rays were taken. It was hoped that these wires would provide a method for measuring movement of the cuspids and the posterior segments. Unfortunately as the teeth moved (cuspids and bicuspids) they rotated varying amounts. Each pin was parallel to the facial surface of the crown of the tooth it was placed on and formed an angle with the long axis of the tooth. When the teeth rotated in movement the pins were no longer parallel to the long axis of the teeth in the plane of the head-plate casette so they could not be used to evaluate tooth movement.

Radiographic Technique:

Immediately before placing the arch wires and springs, four angled lateral head films were taken. The head holder had been modified so that it could be turned right or left 25° and fixed there. The patient could be placed in a reproducible position with his face turned in 25°. The 25° was considered a reasonable approximation of $\frac{1}{2}$ of the posterior arch divergence (a series of casts were measured and found to diverge 48°) which would place the teeth nearest the casette in a position parallel to it. Thus measurements made on the headfilm would coincide more closely to the same measurements made on the same side of the jaws than would be the case with an ordinary headfilm in which the midsagittal plane was parallel to the film.

The .022 pins for the side to be X-rayed were placed and tied down, the patient was placed in the head holder and turned in 25° toward the film, and an X-ray was taken. The patient was taken out of the head holder and then returned, and another film was exposed (during this time the patient had to keep his mouth open). This procedure was repeated on each patient for both right and left sides.

As soon as the arch wires were removed at the end of the retraction period, headplates were again taken. It was felt that only 1 film on each side was necessary but in sme cases 2 were taken.

Measurement of the Radiograms:

The cephalograms were cut into upper and lower portions through the inter-occlusal space.

A line was scribed touching the inferior of the implants and a perpendicular drawn to this, which touched the distal of the posterior implant. Lines were scribed along the distal surface of the pins, and parallel to the occlusal plane at the bracket slot level. Some care was taken in scribing the lines.

The start and finish films were superimposed on the implants. In the one case where no upper posterior implant was present the cusps of the upper third molar were used to superimpose. This procedure was checked in several of the other sets of films and found to be accurate.

Some time was spent measuring movement of the pins with a travelling microscope but the results were discarded when it became evident that the teeth had rotated.

The pulp canals and chambers were used as landmarks which were relatively unaffected by the rotations. When these structures were too indistinct to use, measurement of both mesial and distal of the crown and the root at or near the apex was resorted to and the 2 measurements were averaged.

Whenever a second set of films were available, duplicate measurements were made. The standard error of the measure was computed and was found to be .21 mm for the cuspid crowns and .201 mm for the cuspid apices. In view of the many possible sources of error, this seems low.

The following measurements were made on the cephalograms:

Mandible: Root length, and crown and apex movements of the first molar, second bicuspid, and cuspid.

Maxilla: Crown movement of the first molar and second bicuspid.

Crown and apex movement and root length of the upper cuspid.

FINDINGS AND DISCUSSION

It was found that the cuspid crown measurements were different from the same measurements on the casts.[23] This discrepancy, coupled with the fact that the standard error of the cast measurements (.06) was so much smaller than the radiogram measurement error, convinced everyone that the cast measurement should be used whenever possible.

Utilizing the cast measurements for cuspid movement and the radiogram measurements for molar movement, bar graphs (Figs. 1&2) were made which depict the total cuspid and molar change.

It can be seen that the right cuspids which were under the influence of a fairly constant force, displayed a varied response. Range of movement for the lowers was from 1.20 mm to 2.65 mm and for the uppers it was from 1.13 mm to 3.53 mm. The mandibular molars also showed a wide range of movement under this 270-340 gram force category, with movements extending from -.3 mm to 1.75 mm.

All but one of the patients wore a cervical headgear so the upper molar movements were not utilized.

Scattergrams were made to show cuspid crown movement (Figs. 3&4), and also display a wide interpatient variability at the 300 gram level. This is similar to the response noted by Utley[21]. However, the intrapatient response which is not constant is in disagreement with Utley's findings.

Utilizing measurements from the casts and the radiograms a composite table was constructed (Table #3), which summarizes total tooth movement, cuspid movement, and the weekly rate of cuspid movement.

A graph was constructed to compare upper cuspid movement with lower cuspid movement (Figs. 5&6). In seven cases out of eight upper cuspids moved further than lower cuspids.

Forces that averaged 128, 65, and 64 grams were capable of moving cuspids (Table #3). These forces are well below the threshold suggested by Storey and Smith[17].

Increased forces increase the rate and amount of tooth movement (Figs. 3&4). This trend tends to refute the Storey-Smith theory[17] and to coincide more with Andreasen and Johnson's idea[20]; however the sample is too small and the tendency not clear enough to warrant a stronger statement.

On activation of the 300 gram springs most patients experienced some mild to moderate pain of short duration. The 900 gram springs made the teeth very sore for a week and then the pain subsided but did not completely disappear. The 1500 gram spring caused pain and discomfort also. Even though this force is well beyond that required to move teeth, it apparently did not exceed the "physiologic limit" of the periodontal ligament.

CONCLUSION

1. Measuring tooth movement on superimposed X-rays with metallic implants provides a means of assessing tooth movement in relation to the bones of the cranium. More error is inherent in this method (SEM .21 mm), however the advantages of relating the tooth movement to the underlying bones are important.
2. Increased force produces greater tooth movement than lighter forces (at least through the 50 to 300-800 gram range).
3. There is a wide variability of interpatient response to a similar force.
4. Intrapatient response to forces did vary in contrast to Utley's[21] findings on his cat study.
5. The magnitude of force which can be tolerated without symptoms is quite high (1500 grams).

BIBLIOGRAPHY

1. H. Halderson, E. Johns, and R. Moyers: The Selection of Forces for Tooth Movement, Am. J. Orth. 39: p. 25, 1953.

2. A. M. Schwartz: Tissue Changes Incidental to Orthodontic Tooth Movement, Int. J. Orth. 18: p.331, 1932.

3. H. Halderson: Routine Use of Minute Force, Am. J. Orth. 43: p.750, 1957

4. A. E. Howes: The Philosophy Behind the Johnson Twin Wire Appliance, Am. J. Orth. 29: p.459, 1943.

5. R. Waldron: The Philosophy Behind the Universal Appliance Advocated by Dr. Atkinson, Am. J. Orth. 29: p.435, 1943.

6. D. MacEwan: Treatment of a Typical Distoclusion Case: Am. J. Orth. 40: p.350, 1954.

7. M. M. Stoner: Force Control in Clinical Practice, Am. J. Orth. 40: p.163, 1954.

8. C. J. Burstone: Rationale of the Segmented Arch, Am. J. Orth. 48: p.805, 1962.

9. P. R. Begg: Differential Force in Orthodontic Treatment, Am. J. Orth. 42: p.481, 1956.

10. P. R. Begg: Light Arch Wire Technique, Am. J. Orth. 47: p.30, 1961.

11. J. R. Jarabak: Development of a Treatment Plan in the Light of One's Concept of Treatment Objectives, Am. J. Orth. 46: p.481, 1960.

12. B. Gottleib: Some Orthodontic Problems in Histologic Illumination, Am. J. Orth. & O.S. 32: p.113, 1946.

13. K. Reitan: Tissue Behaviour During Orthodontic Tooth Movement, Am. J. Orth. 46: p.881, 1960.

14. K. Reitan: Tissue Reaction as Related to the Age Factor, Dental Record 74: p.271, 1954.

15. S. Weinstein: Minimal Forces in Tooth Movement, Am. J. Orth. 53: p.881, Dec.,1967.

16. C. J. Burstone and M. H. Groves: Threshold and Optimum Force Values for Maxillary Tooth Movement, J. Dent. Res. 39: p.695, July, 1960.

17. E. S. Storey and R. Smith: Force in Orthodontics and Its Relation to Tooth Movement, Aust. J. Dent. 56: p.11, 1952.

BIBLIOGRAPHY
continued

18. H. L. Bull: Obtaining Facial Balance in the Treatment of Class II Division I, Angle. Orth. 21#3: p.138, 1951.

19. G. E. Callow: Thesis, U. of O. Dental School Orthodontic Dept.

20. G. Andreasen and P. Johnson: Experimental Findings on Tooth Movements Under Two Conditions of Applied Force, Angle Orth. 37: p.9, 1967.

21. R. K. Utley: The Activity of Alveolar Bone Incident to Orthodontic Tooth Movement as Studied by Oxytetracycline-Induced Fluorescence, Am. J. Orth. 54: p.167, 1968.

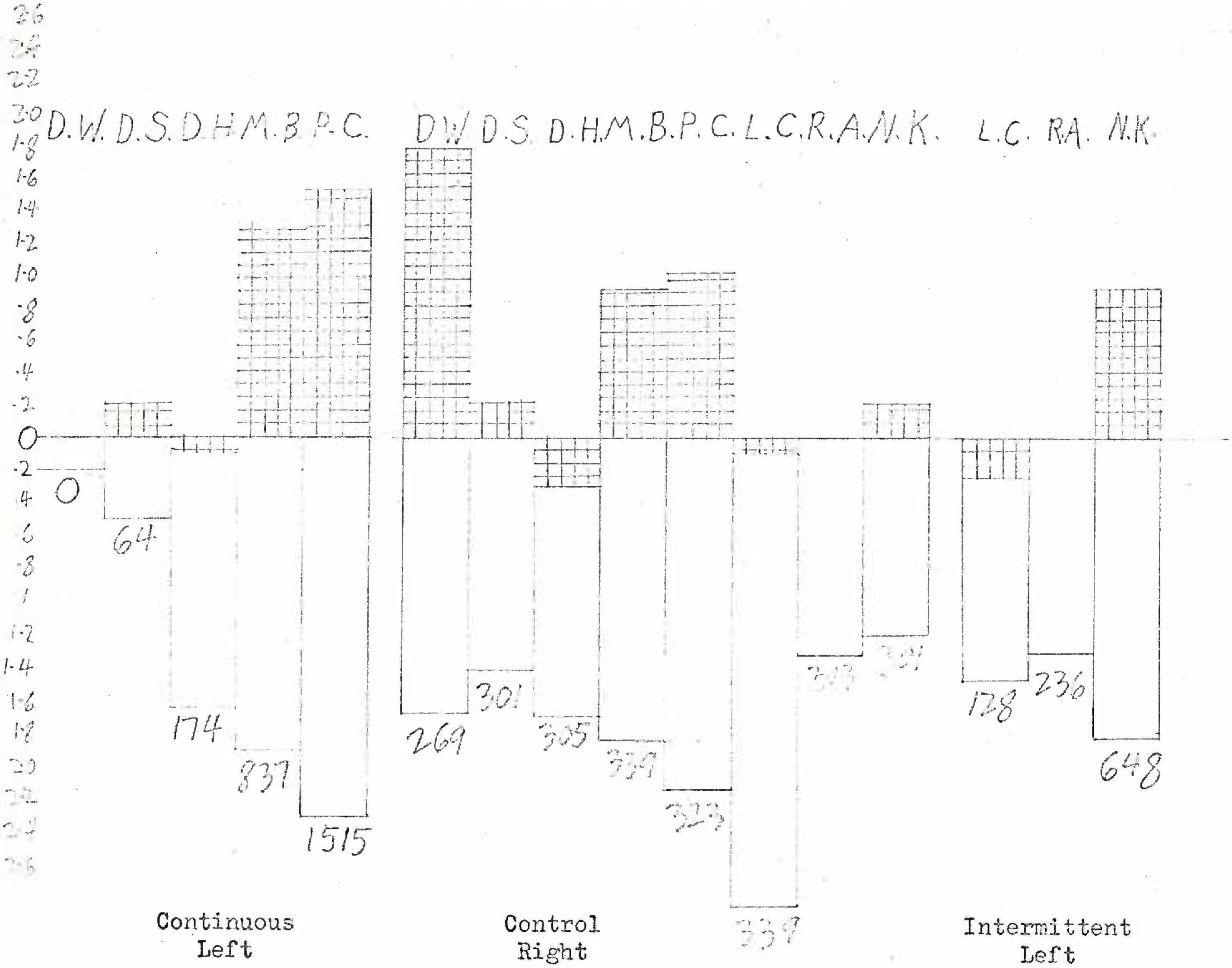
22. A. Oppenheim: A possibility for Physiologic Orthodontic Tooth Movement, Am. J. Orth. 30: p.277-328, 344-368, 1944.

23. A. Bjork: Facial Growth in Man Studied with the Aid of Metallic Implants, Octa. Od. Scand. 19: p.9, 1955.

24. R. Tacy: Certificate Thesis, U. of O. Dental School Orthodontic Dept.

Figure #1

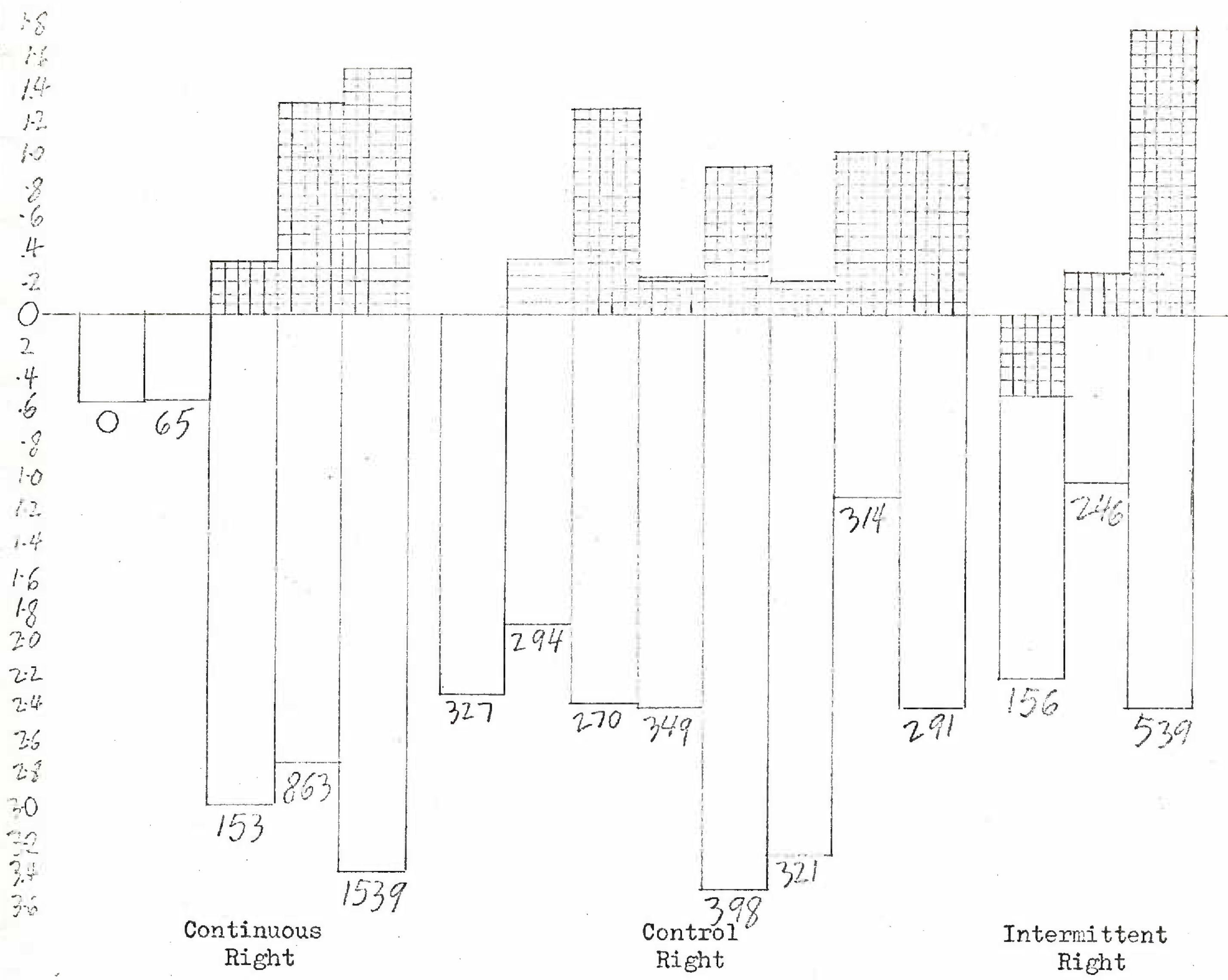
MANDIBULAR CUSPID & MOLAR MOVEMENT



Hatched areas represent molar movement.
All measurements are from the zero reference line.
Hatched areas below the reference line represent distal molar movement.

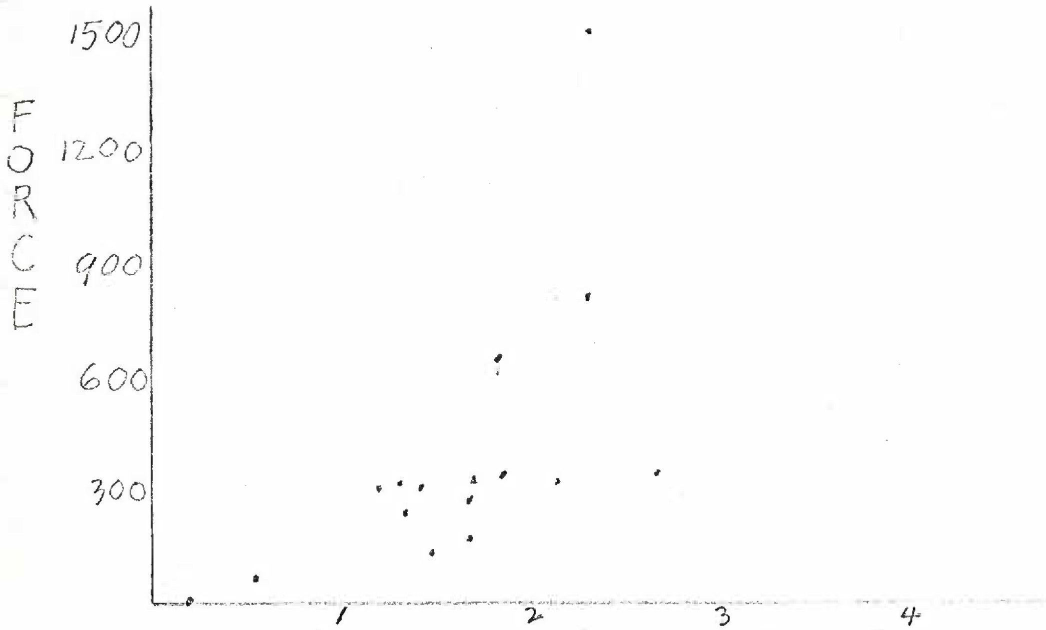
Figure #2

MAXILLARY CUSPID & MOLAR MOVEMENT



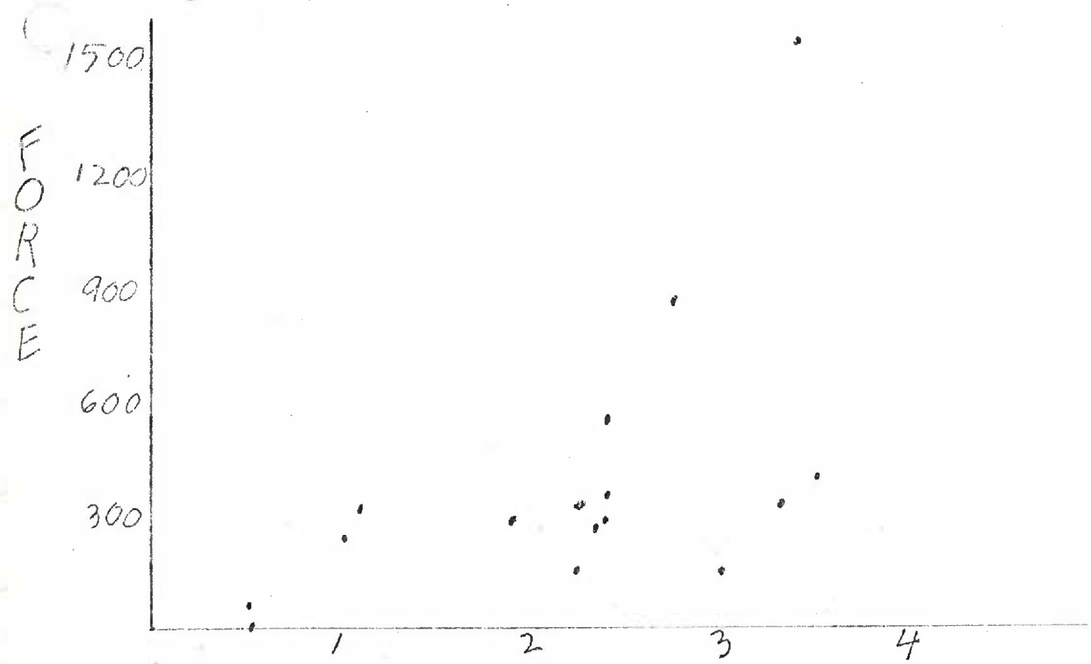
Hatched bars represent molar movement.
All measurements are from the zero reference line.
Hatched area below reference line portrays distal molar movement.

Figure #3



MANDIBULAR CUSPID CROWN MOVEMENT

Figure #4



MAXILLARY CUSPID CROWN MOVEMENT

RIGHT MAXILLARY AND MANDIBULAR CUSPID MOVEMENTS COMPARED

Figure #5

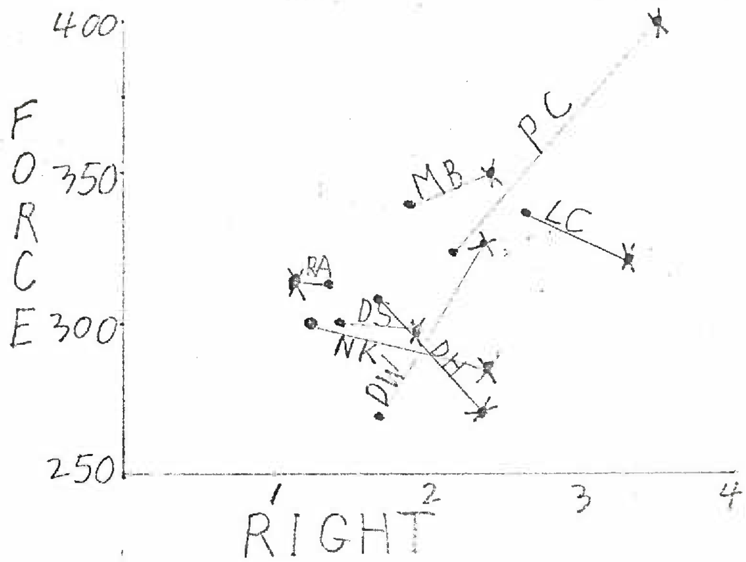
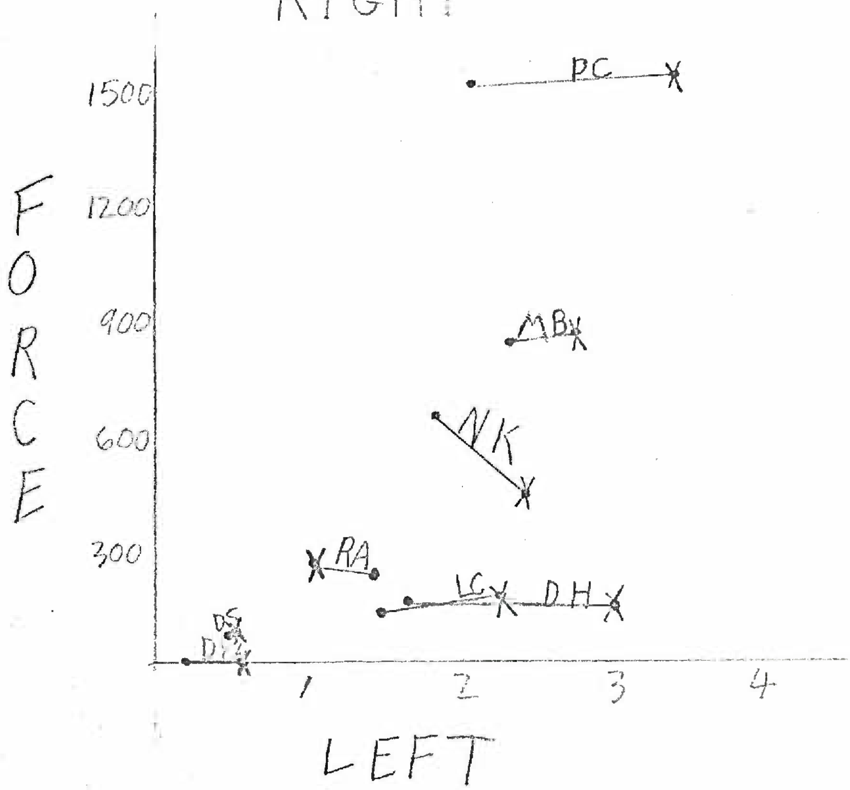


Figure #6



X— MAXILLARY CUSPID MOVEMENT

•— MANDIBULAR CUSPID MOVEMENT

TABLE I

HEAD FILM MEASUREMENTS

MANDIBLE

Pt.	Side	Force	Molar			Bicuspid			Cuspid		
			Cr	Ap	RL	Cr	Ap	RL	Cr	Ap	RL
D.W.	Rt	269	1.75	-2.30	19	3.75	-.87	17.50	1.25	0	19
	Lt	0	0	0	20.5	1.42	-.57	19.00	.42	25	20
D.S.	Rt	301	.20	-.15	18.5	.80	.42	16.00	1.25	1.35	18
	Lt	64	.20	.10	15.5	.25	.50	15.00	.35	.25	21.0
D.H.	Rt	305	-.30	.87	18	-.40	+.5	16.50	1.7	-.2	18.0
	Lt	174	-.1	.10	16.5	-.45	1.91	16.00	1.65	0	18.5
M.B.	Rt	339	.92	0	21.5	.75	.92	22.50	2.25	-8.01	24.25
	Lt	837	1.25	.50	21.0	2.00	.75	21.00	1.35	1.75	27.25
P.C.	Rt	323	1.00	.70	21.5	1.70	-.65	21.50	2.15	--	21.5
	Lt	1515	1.5	.70	18.5	1.75	-.92	20.00	2.25	-.87	22.5
L.C.	Rt	339	-.10	0	17.5	0	.42	19.00	2.57	-.5	21.0
	Lt	128	-.25	.12	19	0	.5	18.50	1.92	0	20
R.A.	Rt	313	0	0	21.5	0	-.25	23.50	1.37	.25	22.5
	Lt	236	0	0	21.0	0	0	22.00	1.00	.20	23
N.K.	Rt	301	.20	.50	19.5	.50	.35	21.00	1.15	-.92	23
	Lt	648	.92	0	18	1.35	1.00	23.00	2.35	1.35	18

HEAD FILM MEASUREMENTS

MAXILLA

Pt.	Side	Force	Molar Cr	Bicuspid Cr	Cuspid Cr	Cuspid Ap	Cuspid RL
D. W.	Rt.	327	0	0	2.30	-.42	19.5
	Lt.	0	0	0	.87	0	19.0
D. S.	Rt.	294	.35	.30	1.85	-.85	20
	Lt.	65	0	.20	.30	0	19
D. H.	Rt.	220	1.25	X	3.4	-.4	19
	Lt.	153	.35	X	1.42	.35	21
M. B.	Rt.	349	.20	0	2.25	0	23.5
	Lt.	863	1.30	1.35	2.42	-.30	24
P. C.	Rt.	398	.92	1.25	2.85	0	19
	Lt.	1539	1.50	1.50	3.00	.75	21
L. C.	Rt.	321	-.20	0	3.00	-.75	23.5
	Lt.	156	-.5	.5	2.75	0	21.5
R. A.	Rt.	314	1.00	1.00	.62	0	21.5
	Lt.	246	.25	.67	.87	0	19.0
N. K.	Rt.	291	1.00	1.35	1.92	-.15	25.5
	Lt.	539	1.65	1.70	1.70	-.25	23.0

SPACE CLOSURE AND RATE OF MOVEMENT*

Patient	Age	Mandibular Right: Force (grams) M ± SD	Total Space Closure (mm.)	Av. Rate of Space Closure (mm/wk)	Total Cuspid Movement (mm.)	Av. Rate of Cuspid Movement (mm/wk)	Mandibular Left: Force (grams) M ± SD	Total Space Closure (mm.)	Av. Rate of Space Closure (mm/wk)	Total Cuspid Movement (mm.)	Av. Ra of Cus Moveme (mm/wk
[illegible]	13-2	269±35	3.43	.462	1.68	.226	0	.05	.007	.20	.027
[illegible]	11-1	301±19	1.62	.202	1.42	.178	64± 3	.68	.085	.48	.060
[illegible]	10-5	305±43	1.41	.165	1.71	.200	174±28	1.55	.181	1.65	.193
MB	11-9	339±21	2.78	.330	1.86	.221	837±62	3.70	.439	2.32	.275
PC	13-7	323±60	3.15	.401	2.15	.274	1515±124	3.82	.486	2.32	.295
[illegible]	12-2	339±22	2.55	.302	2.65	.314	128±17†	1.72	.204	1.47	.174
[illegible]	16-11	313±30	1.33	.160	1.33	.160	236±41††	1.33	.160	1.33	.160
[illegible]	14-4	301±20	1.40	.158	1.20	.135	648±119†††	2.75	.310	1.83	.207
Patient	**Age**	**Maxillary Right: Force (grams) M ± SD**	**Total Space Closure (mm.)**	**Av. Rate of Space Closure (mm/wk)**	**Total Cuspid Movement (mm.)**	**Av. Rate of Cuspid Movement (mm/wk)**	**Maxillary Left: Force (grams) M ± SD**	**Total Space Closure (mm.)**	**Av. Rate of Space Closure (mm/wk)**	**Total Cuspid Movement (mm.)**	**Av. Rat of Cusp Movemen (mm/wk)**
[illegible]	13-2	327±24	2.34	.315	2.34	.315	0	.55	.074	.55	.074
DS	11-1	294±18	2.25	.281	1.90	.238	65±15	.53	.066	.53	.066
[illegible]	10-5	270±53	3.62	.422	2.37	.277	153±18	3.33	.389	3.00	.350
[illegible]	11-9	349±31	2.60	.308	2.40	.285	863±66	4.05	.480	2.75	.326
[illegible]	13-7	398±14	4.45	.566	3.53	.449	1539±120	4.90	.623	3.40	.433
[illegible]	12-2	321±25	3.50	.415	3.30	.391	156±15'	1.73	.205	2.23	.265
RA	16-11	314±39	2.13	.257	1.13	.136	246±36''	1.30	.157	1.05	.127
[illegible]	14-4	291±21	3.40	.384	2.40	.271	539±210'''	4.15	.468	2.40	.271

*Space closure was measured on models. Cuspid movement is this space closure minus molar movement as measured on radiographs.

†175 decaying to 100 g.
††300 decaying to 200 g.
†††900 decaying to 450 g.

'175 decaying to 150 g.
''300 decaying to 200 g.
'''900 decaying to 200 g.