DOI: 10.2478/aoj-1978-0009

HEADGEAR FORCES AND THEIR EFFECTS ON THE POSITION OF THE MAXILLARY MOLAR AND PREMOLAR TEETH—A PRELIMINARY REPORT.

Edward C. Crawford M.D.Sc.

Introduction

Extraoral forces, delivered by headgear assemblies are widely used in orthodontic practice today. Their principal uses are anchorage augmentation and the distal movement of maxillary teeth, either as single units or in blocks. In addition, effects on maxillary position, palatal plane inclination, mandibular plane angle, mandibular tooth eruption, sphenoid bone rotation and profile have all been recorded.

Headgear designs and modes of force delivery vary almost as widely as the claims associated with their effects. Force may be delivered to the maxillary first molar tooth, either alone or attached to other maxillary teeth by means of an arch-wire, or to the arch-wire itself in various positions of attachment. Extra-oral force delivery to mandibular molar teeth has also been employed. A variety of head-caps, head-nets and neck straps have permitted a wide measure of control over the direction of the force delivered by these means. It is possible that the apparent magnitude of the force, as recorded at the neck-strap/head-cap end of the system, may well be different from that delivered to the teeth themselves. Soft tissue structures, both within the oral cavity and outside, may serve to attenuate or dissipate the force.

This influence may, however, be so small as to become clinically insignificant. But as many clinical studies are based on force readings taken from the delivery end of the system, it would be desirable to know how closely these readings approximate the actual magnitude of the force delivered to the tooth. This study was designed to measure the magnitude of the force delivered by the headgear assemblies to the upper first molar and to observe its effect on that tooth and on adjacent teeth.

Experimental Method

To test the force delivered at the buccal tube attached to the upper first molar, a series of appropriately designed springs was constructed. (Fig. 1) The springs were helical torsion in design and varied in length of arm and number of coils. The load-deflection characteristics for each spring were obtained by compressing the spring in a Hounsfield Tensometer Compression Cage connected into a Shimadzu Autograph IS 5,000 machine. The machine recorded force and amount of compression of the spring, and thus a graphic representation of the load deflection characteristics was obtained for each spring.

The tests revealed that the closing forces of the springs ranged from 200gm to 1530gm. This range was considered sufficient to encompass the range of forces used in clinical practice. To test the force delivered to the upper first molar, different springs in the series were tested by sliding the spring on to the inner arm of the face-bow, interposed between the buccal tube and the molar stop on the inner arm. (Fig. 1).

Patients suitable for this study were selected from the files of the Orthodontic

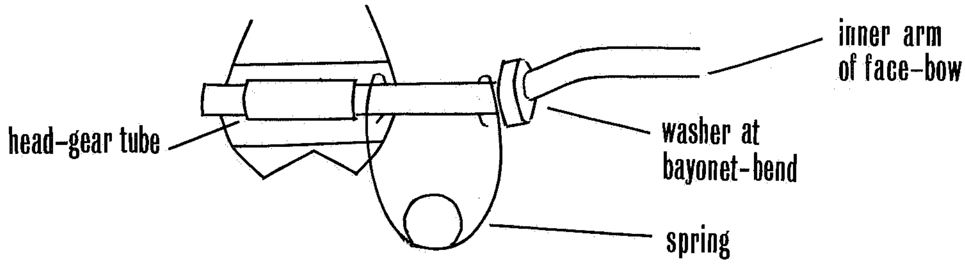

Fig. 1. Application of spring to head-gear.

Department of the Royal Dental Hospital, Melbourne. Twelve patients undergoing treatment involving direct application of headgear to the upper first molars only, uncomplicated by attachment of these teeth to an arch wire were selected. Further, consistency of headgear type worn during the observation period and consistency of the level of force delivered during that same period were essential criterea for patient selection. A lateral cephalometric radiograph was available for each patient immediately prior to headgear application and another was taken with the headgear in position.

The force delivered to the outer bow was measured twice. Once by conventional means and once using the series of springs constructed for this purpose. That spring which could be supported in the experimental system with its free ends almost touching was selected as the appropriate spring representing the force delivered at the buccal tube in that case. Reference to the results obtained from compression testing of the springs gave this force. This procedure was repeated for each patient to test the accuracy of the first reading. Additional details obtained were the age of patient at commencement of headgear wear, the length of time headgear was worn and the number of hours per day that headgear wear was requested from the patient. The forces delivered to the teeth, as measured by the calibrated springs were compared with the forces measured at the ends of the outer arms of the face-bow.

The maxilla, pterygomaxillary fissure and the maxillary premolar and molar teeth were traced using the initial and final radiographs for each case. Bilateral structures were bisected, the mid-point representing the overall position of that structure. For each tooth, two points were drawn, one representing the mid-point of the occlusal surface, and the other, the apex (of a single rooted tooth) or the mid-point between the apices of a multi-rooted tooth. A line joining these two points represented the axial inclination of that toothtooth (Fig. 2).

On the initial tracing a line was drawn through Anterior Nasal Spine (ANS) and Posterior Nasal Spine (PNS). This line represented the palatal plane and was designated the "x-axis". Perpendicular to this line and through the tip of the pterygomaxillary fissure another line was drawn: "y-axis". On the final tracing, points representing the end of the neck-strap (or head-cap) and the end of the outer bow were recorded. A line was drawn joining these points and represented the direction of the force delivered to the face-bow. The tracings were superimposed on the maxillae using the outline of the superior and inferior borders of the palatal plane. Any obvious internal bony architecture was used for additional registration.

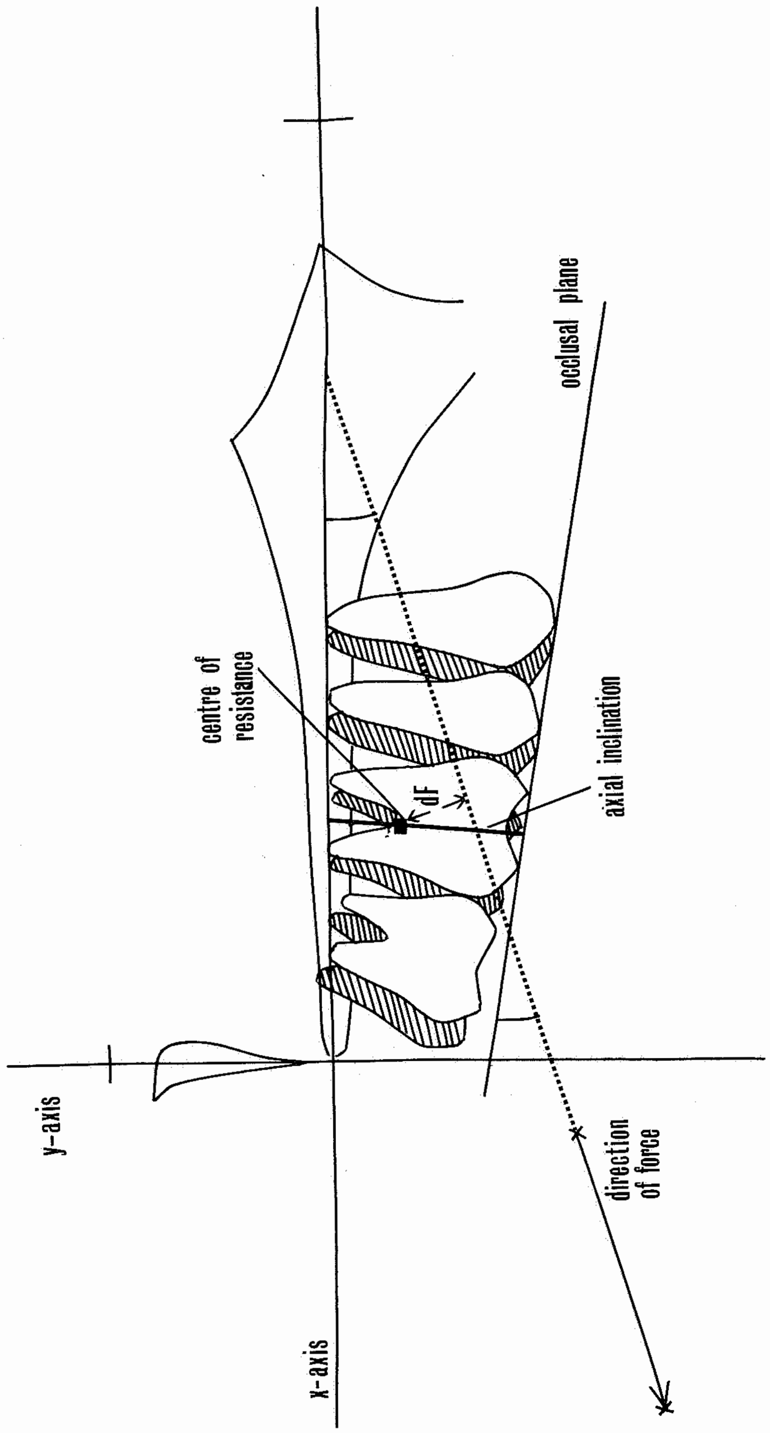

Fig. 2. Superimposed tracings showing movement of teeth and direction of force.

The rotation of each tooth was measured by a change in the angle between its axial inclination and the y-axis.

A point representing the trifurcation of the roots was drawn for each molar tooth. For the premolar teeth, a point representing the junction between the apical third and the coronal two-thirds of the root were drawn. Movement of these points parallel to both x and y axes were measured representing mesio-distal and intrusive-extrusive movements of the teeth respectively.

As the line of force direction was extended, it intersected the palatal plane and the occlusal plane which was established by joining the occlusal surface of the buccal teeth(Fig. 2). The angular relations it bore with these planes were recorded. Changes in inclination of occlusal plane were measured and recorded.

The perpendicular distance between the trifurcation point (recorded on the initial tracing) and the extension of the line of force was measured. This distance was designated dF. Its value was recorded as positive if the line of force passed inferior to the trifurcation point, and negative if the line passed above this point.

Changes in location of the tip of pterygomaxillary fissure were measured and recorded. It was intended to use these values to ascertain any relationship between the change in size of the maxilla measured at the tuberosity and extent of intra-maxillary tooth movement.

Results

Table 1 shows details of the twelve cases analysed, comprising 4 boys and 8 girls. The mean age of the patients was 12.2 years with a range from 10.6 to 15.5 years. The headgear was worn for a mean period of 4.8 months. The force delivered to the upper first molar tooth, as measured by the calibrated springs, ranged from 350 to 1,280gm with a mean of 672gm.

Table 2 compares the two methods of force measurement. A third column displays the percentage difference between these two force values, and shows that the forces calculated by reference to the calibrated springs were 15.2 per cent higher than the forces measured at the attachment of the face-bow to the headgear. In all cases but one (case 5), the spring force was greater than that measured extra-orally, probably due to friction in the buccal tubes.

The movement of teeth parallel to the x-axis is shown in Table 3. Teeth not erupted to the occlusal plane at the time of the first measurement are designated with an asterisk. The upper second molars, many of which were unerupted, moved in a similar manner to first molar teeth. The premolar teeth moved distally in most cases. The movement of the first premolar teeth, which were all fully erupted, seemed to be more closely associated with the movement of the first molar in each case than was the movement of the second premolars.

Table 4 shows the relationship between the distal movement of the maxillary first molar tooth and the force applied to the face-bow. A tendency existed for higher forces to produce greater movements and for lower forces to result in smaller movements.

Arbritrarily, the cases were divided into two groups: one in which the force-levels were greater than 500gm and the other in which the forces were 500gm and below. The mean distal movement of the upper first molar for each group was calculated and also the standard deviation(Table 5). The mean distance moved by the teeth under the influence of the higher forces was more than three times greater than

Table 1. Case details

Case No.	Age (years)	Period of Headgear Wear (mths)	Hours Worn per Day	Total Hours Worn	Force (gm)
1	11.9	6.0	14.0	2520	590
2	12.8	4.0	12.0	1440	840
3	11.3	6.0	13.0	2340	840
4	11.5	3.0	11.0	1080	350
5	16.1	2.5	15.0	1125	320
6	11.8	4.0	14.0	1680	510
7	10.9	7.0	13.0	2730	870
8	13.0	2.5	15.5	1167	490
9	11.6	2.5	12.0	900	940
10	10.6	12.0	3.0	4680	1280
11	13.0	3.5	14.0	1470	470
12	12.3	5.0	13.0	1950	560
Mean	12.23	4.83	13.29	1923.5	671.67
S.D.	1.45	2.72	1.29	1055.13	283.51

Table 2. Comparison of force delivered to upper first molar tooth as measured by calibrated springs and measured extra-orally

Case no.	Force Measurement (gm) Calibrated springs	Extra-oral	Percentage difference (%)
1	590	500	18.0
2	840	750	12.0
3	840	600	40.0
4	350	325	7.9
5	320	350	− 8.6
6	510	500	2.0
7	870	850	2.4
8	490	425	15.3
9	940	625	50.4
10	1280	1000	28.0
11	470	450	3.6
12	560	500	12.0
Mean	671.66	572.92	15.21
S.D.	283.51	204.07	16.90

Table 3. Movement of teeth parallel to X axis

Case No.	$\underline{6}$ (mm)	$\underline{7}$ (mm)	$\underline{5}$ (mm)	$\underline{4}$ (mm)
1	0.0	0.0*	0.0*	0.0
2	1.0	0.5*	− 1.0	0.0
3	0.5	0.5*	0.0*	—
4	1.0	0.0*	0.0*	− 1.0
5	0.0	0.5	1.0	0.5
6	1.0	2.0*	2.0*	1.0
7	2.0	2.0*	1.0*	1.5
8	1.5	2.0	2.0	3.0
9	3.0	2.0*	2.0*	2.0
10	3.0	2.0*	3.0*	2.0
11	0.5	0.0*	−0.5	0.5
12	0.0	0.5	−1.0	0.0
Mean	1.13	1.00	0.63	0.77
S.D.	1.07	0.91	1.19	1.27

Table 4. Relationship between magnitude of force measured extra-orally and distal movement of upper first molar tooth

Case no.	Force (gm)	Distal movement (mm)
1	500	0.0
2	750	1.0
3	600	0.5
4	325	1.0
5	350	0.0
6	500	1.0
7	850	2.0
8	425	1.5
9	625	3.0
10	1000	3.0
11	450	0.5
12	500	0.0
Mean	572.92	1.13
S.D.	204.07	1.07

Table 5. Distal movement of upper first molar tooth at force-values above and below 500 gm.

Group A (Forces above 500 gm)		Group B (Forces: 500 gm and below)	
Case no.	Movement (mm)	Case no.	Movement (mm)
2	1.0	1	0.0
3	0.5	4	1.0
7	2.0	5	0.0
9	3.0	06	1.0
10	3.0	08	1.5
		11	0.5
		12	0.0
Mean	1.9 mm		0.57 mm
S.D.	1.14 mm		0.61 mm

the distance moved by the teeth in the lower force group. The standard deviations for each group were large and did not automatically point to a significant difference between the groups. However, when a "t-test" was applied to compare the groups(Table 5), the t-value indicated a significant difference at the 0.05 level of confidence.

Table 6 indicates that there is little or no clear relationship between the distal movement of the first molar tooth and the total number of hours that the headgear was estimated to be worn. For example, Case 9 experienced 3.0mm of distal movement during 900 hours of headgear wear, whilst in Case 3, 2340 hours of headgear wear resulted in only 0.5mm of distal movement of the first molar tooth.

In probing the possible factors involved in distal movement of the upper first molar tooth, the combined effect of force applied to the face-bow and the total number of hours worn was examined. Table 7 indicates the absence of any clear relationship between distal movement of the molar tooth and the combined values of force and time.

The movement of teeth parallel to the y-axis is shown in Table 8. Unerupted teeth are designated with an asterisk. The upper first molar tooth extruded in six cases (up to 3mm), intruded in two cases (up to 1mm) and displayed no vertical movement in the remaining four cases. Only one of the upper second molar teeth was observed to intrude. That was in Case 5, which corresponded to one of the

Table 6. Relationship between distal movement of upper first molar and total hours of headgear wear

Case no.	Hours of headgear wear	Distal movement (mm
1	2520	0.0
2	1440	1.0
3	2340	0.5
4	1080	1.0
5	1125	0.0
6	1680	1.0
7	2730	2.0
8	1167	1.5
9	900	3.0
10	4680	3.0
11	1470	0.5
12	1950	0.0

Table 7. Relationship between Distal Movement of the Upper First Molar Tooth and the Product of Force Applied and Total Hours of Headgear Wear

Case No.	Distal Movement (mm)	Force × Time (kg hrs)
1	0.0	1660
2	1.0	720
3	0.5	1345
4	1.0	324
5	0.0	338
6	1.0	833
7	2.0	2321
8	1.5	496
9	3.0	810
10	3.0	5990
11	0.5	698
12	0.0	1092

Table 8. Movement of teeth parallel to Y-axis.

Case No.	$\underline{6}$ (mm)	$\underline{7}$ (mm)	$\underline{5}$ (mm)	$\underline{4}$ (mm)
1	0.0	2.0*	1.0*	1.0
2	0.5	0.5*	0.0	0.0
3	1.0	4.0*	8.0*	—
4	−0.5	3.0*	3.0*	0.0
5	−1.0	−1.0*	−0.5*	0.0
6	0.0	1.0*	0.0*	0.0
7	1.0	1.0*	2.5*	2.0
8	3.0	1.5	2.0	2.5
9	0.0	0.0*	1.0	0.0
10	0.5	0.0	4.0*	0.0
11	0.0	0.0*	0.0	0.0
12	1.0	0.0	0.5	0.0
Mean	0.46	1.04	1.79	0.46
S.D.	1.01	1.43	2.40	0.92

two intruded first molar teeth. Both of these teeth intruded to the same extent (1mm). Four second molar teeth showed no vertical movement. The remaining teeth displayed extrusive movements, in general, to a greater degree than shown by the corresponding first molar tooth.

As with the second molar, only one of the second premolar teeth intruded similarly, this was in Case 5, which corresponded to one of the intruded first molar teeth. Three second premolar teeth showed no vertical movement and the remaining eight extruded to varying degrees, some greater than the corresponding first molar, others less. Very little vertical movement was observed with the first premolar teeth. In no case was intrusion seen and three cases displayed extrusion, the greatest amount being 2.5mm(Case 8) which corresponded with the largest extrusion observed in the first molar teeth. The remaining cases showed no vertical movement.

Table 9 indicates a relationship between extrusion of the upper first molar tooth and the magnitude of the force applied to the face-bow. In general, forces above 500gm caused extrusion. Forces between 450gm and 500gm caused no vertical movement and at force-levels below this value intrusion of the molar tooth occurred(Cases 4 and 5). However, some of the cases did not appear to fall within the bounds of this relationship. For example, Case 8 displayed 3mm of extrusion with a 425gm force. In Cases 9 and 10, the only two cases where combination headgear was used, high forces were associated with little or no extrusion.

Table 10 shows the relationship between the vertical movement of the upper first molar tooth and the angle which the direction of force makes with the palatal plane and indicates the absence of any direct relationship between extrusion or intrusion of the first molar tooth and the direction of the headgear force with respect to the palatal plane. For example, Case 6 involved an angle of 14.5° without extrusion whereas Case 8 involved a similar angle of 15° and extrusion of 3.0mm occurred. In Cases 9 and 10, combination head-cap and neck-strap headgear had been used. This type of headgear is designed to deliver intrusive forces to the first molar tooth. However, in this instance intrusion was not demonstrated. In fact, in Case 9, the first molar tooth extruded 0.5mm, and in Case 8, no vertical movement occurred.

Table 9. Relationship between vertical movement of upper first molar tooth and applied force

Case no.	Vertical movement (mm)	Force (gm)
1	0.0	500
2	0.5	500
3	1.0	575
4	− 0.5	300
5	− 1.0	300
6	0.0	460
7	1.0	850
8	3.0	425
9	0.0	900
10	0.5	1280
11	0.0	475
12	1.0	560

Table 10. Relationship between vertical movement of upper first molar tooth and angle between force-direction and palatal plane

Case no.	Vertical movement (mm)	Angle: Force to palatal plane (degrees)
1	0.0	11.0
2	0.5	4.0
3	1.0	13.0
4	− 0.5	11.0
5	− 1.0	12.5
6	0.0	14.5
7	1.0	21.0
8	3.0	15.0
9	0.0	− 15.0
10	0.5	− 16.0
11	0.0	14.5
12	1.0	10.0

Table 11 presents the relationship between the vertical movement of the upper first molar tooth and the angle which the direction of force makes with the occlusal plane. A graph indicated that when the angle between the force-direction and the occlusal plane is less than 20°, intrusion of the first molar tooth occurred. At angles above this, zero vertical movement and extrusion were observed. The two cases where combination headgear was employed(Cases 9 and 10) did not appear to fit this relationship. In both cases a zero angle between force-direction and occlusal plane existed. However, Case 9 displayed no vertical movement and Case 10 displayed a small extrusion.

Table 12 indicates that in all cases where cervical headgear was employed, a linear relationship existed between changes observed in the occlusal and the angle between the force-direction and the occlusal plane. At force-occlusal plane angles below 20°(Cases 4 and 5) negative changes in occlusal plane occurred. With the exception of Case 1, force-occlusal plane angles greater than 20° were associated with an increasing tendency for positive changes in occlusal plane inclination. The cases where combination headgear was used (Cases 9 and 10) did not fit this relationship. In both of these cases a zero force-occlusal plane angle existed. However, one case showed a positive occlusal plane change and the other case a negative change.

Table 11. Relationship between vertical movement of upper first molar tooth and angle between force-direction and occlusal plane

Case no.	Vertical movement (mm)	Angle: Force to occlusal plane (degrees)
1	0.0	28.0
2	0.5	21.0
3	1.0	28.0
4	− 0.5	18.0
5	− 1.0	12.0
6	0.0	24.0
7	1.0	30.5
8	3.0	28.0
9	0.0	0.0
10	0.5	0.0
11	0.0	21.0
12	1.0	32.0

Table 12. Relationship between change in occlusal plane and angle between force-direction and occlusal plane

Case no.	Occlusal plane change (degrees)	Angle: Force to occlusal plane (degrees)
1	− 1.5	28.0
2	3.0	21.0
3	3.0	28.0
4	− 2.5	18.0
5	− 4.0	12.0
6	2.0	24.0
7	6.5	30.5
8	1.5	28.0
9	− 2.0	0.0
10	1.0	0.0
11	3.0	21.0
12	4.0	32.0

Rotations of the teeth in the sagittal plane are shown in Table 13. Unerupted teeth are designated with an asterisk. All first molar teeth rotated. In seven cases the rotation was characterised by a distal movement of the crown with respect to the apex, the greatest being 6°. In the remaining five cases, the apex moved distally with respect to the crown, the greatest being 5°. The upper second molar teeth experienced rotations in both directions but predominantly of the type in which the crown moved distally with respect to the apex. There appeared to be little or no relation between rotations of the second molars and those of the first molar teeth.

Table 13. Rotation of teeth in sagittal plane

Case no.	6 (degrees)	7 (degrees)	5 (degrees)	4 (degrees)
1	6.0	−0.5*	15.0*	3.0
2	4.0	·4.0*	4.0	5.0
3	2.0	7.0*	−0.8*	—
4	−5.0	1.0*	−1.0*	−1.5
5	1.0	4.0*	4.0	2.5
6	6.0	3.0*	−5.0*	4.5
7	1.0	−2.5*	1.0*	−2.0
8	−1.0	00.0	3.0	3.5
9	3.0	5.0*	4.0	−15.0
10	−5.0	3.0*	7.0*	4.0
11	−1.0	06.0*	−1.0	−1.0
12	−5.0	3.0*	−2.5	−3.0
Mean	0.5	2.6	02.3	0.0
S.D.	4.01	2.96	5.24	5.74

The upper second premolar teeth were observed to rotate in both directions to a wide range of degrees. In those cases where the second premolars were unerupted, there was no apparent relationship between the rotations of those teeth and of the first molars. A stronger correlation existed in those cases that displayed full eruption. The upper first premolar teeth also experienced rotations in both directions. All first premolars were fully erupted. Despite this, there existed no apparent uniformity of rotational behavior between this tooth and that of the first molar.

The relationship between the rotation in the sagittal plane of the upper first molar tooth and the perpendicular distance from the trifurcation point of that tooth to the line representing the direction of the force(dF) was also studied. For most cases, positive values of dF are associated with positive rotations.

The relationship between the distal movement of the upper first molar tooth and the change in size of the maxilla as measured by an absolute change in position of the pterygomaxillary fissure is shown in Table 14. Cases which displayed the greatest distal molar movement (Cases 7,8,9 and 10) also showed the greatest change in maxillary size. In an attempt to explore further the factors in the change in maxillary size, other measurements were tabulated and plotted against maxillary size change. These were age, time of headgear wear, the product of time and applied force, and force. No relationship could be found between these factors and change in maxillary size. However, a definite correlation was observed between force applied to the face-bow and change in size of the maxillary tuberosity. Cases where large forces had been applied(for example Cases 7,9 and 10) also revealed the largest change in size of maxillary tuberosity.

Isolating the four cases which showed significant changes in maxillary size (Cases 7,8,9 and 10) and comparing the force applied to the face-bow with the distal movement of the first molar tooth, suggested a relationship between force and tooth movement.(Table 15).

Table 14. Relationship between distal movement of upper first molar tooth and increase in maxillary size as measured at distal border

Case no.	Distal movement (mm)	Increase in maxillary size (mm)
1	0.0	0.0
2	1.0	0.0
3	0.5	0.0
4	1.0	0.0
5	0.0	0.5
6	1.0	1.0
7	2.0	2.0
8	1.5	3.0
9	3.0	2.0
10	3.0	2.0
11	0.5	0.0
12	0.0	0.0

Table 15. Relationship between force and distal first molar tooth movement in the four cases which showed significant increase in maxillary size as measured at distal border

Case no.	Force (gm)	Distal Movement of $\underline{6}$ (mm)
7	850	2.0
8	425	1.5
9	900	3.0
10	1280	3.0

Summary and Conclusions

The degree and direction of extra-oral forces applied by orthodontic headgear to the maxillary first molar teeth in twelve patients were determined by a mechanical spring device and cephalometry respectively. The mechanical method of measuring the force-level was no more accurate than the conventional extra-oral reading.

The significant findings obtained from this study were:

- Extra-oral forces greater than 500gm produced significantly larger distal movements of the upper first molar tooth than forces below 500gm.
- Distal movement of the upper first molar tooth appeared to be directly related to a change in size of the maxillary bone as measured at its distal border.
- Extrusion of the upper first molar tooth occurred, accompanied by changes in the cant of the occlusal plane. It was related to the force-level and in the cases where cervical headgear was used, to the angular relationship between the force-direction and the occlusal plane. In conflict with previous reports, which contend that cervically directed extra-oral forces result in extrusion of the attached tooth, the results of this study suggested the existence of a threshold angle between the force-direction and the occlusal plane of about 20 – 25 degrees. Below this value, tooth intrusion was observed and above it extrusion of the first molar tooth occurred. A delicate balance between intrusion and extrusion was implied. Failure to appreciate this fact, in the instance of occlusal plane changes, is the possible cause of discrepancies existing in the literature. Vertical movement of teeth occurring as a result of extra-oral force is apparently of a more complex nature than suggested previously.

- Rotation of the upper first molar tooth during extra-oral force application occurred in a predictable manner in accordance with previous reports, and was irrespective of headgear type. The crucial factor in tooth rotation was the spatial relationship between the force-direction and the trifurcation point on the first molar tooth.
- Teeth adjacent to the upper first molar tooth were studied. Distal movements of these teeth approximately reflected the distal movement of the upper first molar tooth. However, vertical and rotational movements bore little relation to those of the molar tooth.
- Factors that did not appear to be related to the distal movement of the upper first molar tooth were time of headgear wear, the product of force applied and time of headgear wear and the patient's chronological age.
- The two different headgear types studied produced variable results in particular with vertical tooth movements. This suggested that a number of mechanisms are operative when different headgears are used and indicated that new headgear designs should be clinically tested before predictions concerning their effects are made.

16 Collins Street,
Melbourne. 3000
Victoria