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THE FORCE REQUIREMENTS FOR TOOTH MOVEMENT PART II: UPRIGHTING AND ROOT TORQUE

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In orthodontic treatment tooth root movement is essential, not only to obtain mesio-distal paralleling of individual tooth roots, but also to achieve correct axial inclinations in relation to basal bones and inter-incisal angles in the anterior segments. This article describes a pilot study in which paired teeth on opposite sides of the mouth and which required root paralleling as a part of orthodontic treatment, were subjected to known moments of force. The forces were exerted using helical torsion springs of pre-determined load-deflection characteristics. Average weekly moments of force were related to the weekly rates of angular movement of eight teeth in a group of four patients. The experiments lasted for up to seven weeks and were designed so that the movement of the paired teeth in each patient were concurrent.

Keywords: movement, angular movement, phase of movement.

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Introduction

In orthodontic treatment there are some forms of malocclusion associated with irregular axial inclination of the teeth which, for their correction, require controlled movement of the roots. This particular tooth movement which is Angle's third order of movement and is commonly called root torque or uprighting, constitutes the third basic type of force transmission between the appliance and the tissues surrounding the teeth studied in this investigation.[1] This particular study was designed to develop an experimental method and to determine the rate of change in axial inclination of teeth following the application of uprighting forces of widely differing magnitudes. To date, no other controlled quantitative studies of third order movement have been carried out on man.

Experimental Procedure

This experiment was designed to relate weekly changes in axial inclinations of the teeth to the average torque exerted by orthodontic springs. Three male and one female patient were selected for the study. All patients required uprighting of the incisor and bicuspid teeth with abnormal axial inclinations. In each patient the simultaneous movements of two matching teeth on opposite sides of the same dental arch were recorded.

Three of the four patients were fitted with springs which differed in the amounts of initial force exerted; three of the four were fitted with springs of different rates of release; and measurements of three of the four patients' tooth movements were taken over the same period of time.

The Orthodontic Appliance

For the purposes of this experiment the appliance used in the first[1] series of experiments was modified as follows:

Round stainless steel buccal tubes were aligned approximately parallel to the long axis of each tooth being studied, and welded to the brackets of the teeth to be moved (Fig.1). These tubes had an internal diameter of 0.025 inch (0.63 mm). A 0.024 inch (0.62 mm) diameter wire with a hemisphere of solder at one end was fitted into each tube; a measuring point (Fig.1, C) was drilled into the solder. Measuring points were also drilled into the brackets of the teeth being uprighted (Fig. 1, I) and also into the brackets of the central incisor and molar teeth (Fig. 1, A) in the same quadrant of the mouth. The measuring points on the latter teeth were used as reference points.

Uprighting helical torsion springs were used to correct the axial inclination of these teeth. To form the springs, stainless steel heat-treated wires of 0.014 inch (0.35 mm), 0.016 inch (0.40 mm) and 0.020 inch (0.51 mm) diameter and 0.018 inch (0.46 mm) x 0.022 inch (0.56 mm) rectangular wire wound 2½ times around a 0.035 inch (0.89 mm) mandrel. One end of the spring was fitted into the bracket until the coil locked the archwire into the bracket slot (Fig.2). The other end of the spring was hooked over the archwire when the spring was activated. This activation affected the arm of the spring inside the bracket, which, in turn, moved the tooth root so as to change the position of the long axis of the tooth. The uprighting force, or moment, exerted by these springs was determined by: multiplying the force exerted by the hooked portion of the spring on the

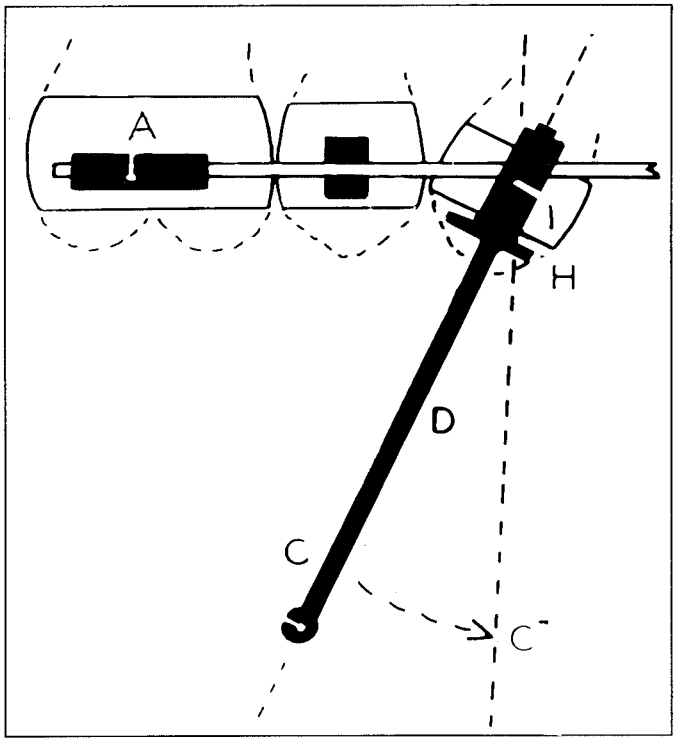


Figure 1. Experimental arrangements for uprighting movement (root torque).
A Measuring point on buccal tube.
C Measuring point at end of rod.
C' Position of point C at end of movement.
H Stop on rod D.
I Measuring point on tube soldered to bracket.

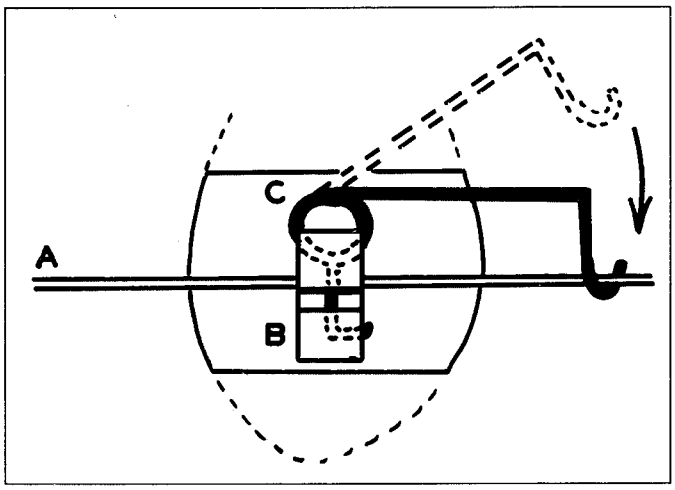


Figure 2. Diagram showing the experimental arrangement for the investigation of the relation between root torque and the rate of angular movement.
A Archwire.
B Bracket to which is attached 0.025" (0.63mm) internal diameter tube.
C Uprighting spring shown in the passive and activated positions. Arrow indicates path of activation of spring.

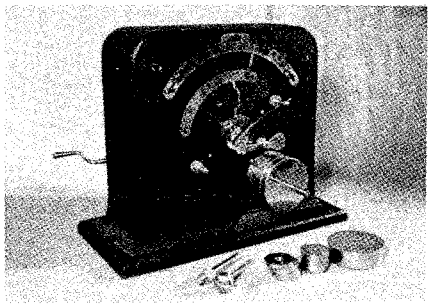


Figure 3. Wire-bending machine used for determination of load-deflection characteristics of uprighting springs.

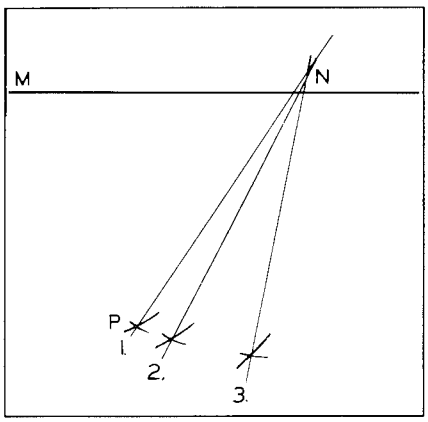


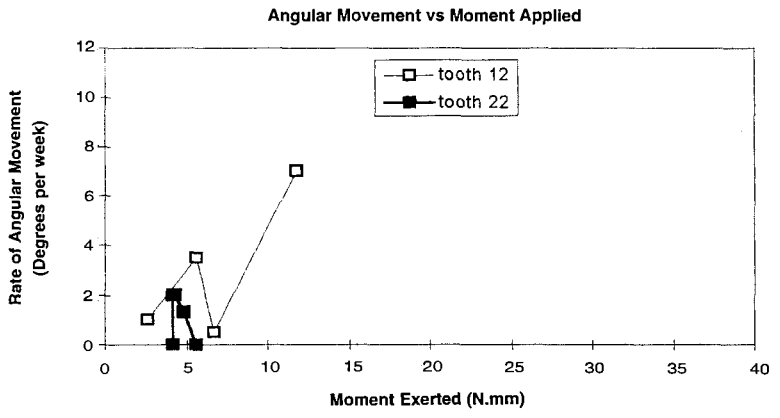
Figure 4. Triangulation plots for successive weekly axial tooth positions. P. 1, 2 and 3. Line MN represents the archwire.

archwire by the distance along the archwire from the coil to the hook. The moment was expressed in Newton-millimetres of force. The product of force by length of arm gave the amount of turning effect, or moment, applied at the bracket of the tooth. The load-deflection characteristics of each spring had been previously determined using a Tinius Olsen wire-bending machine (Fig.3).

The long axis of the tooth in the alveolar bone was located as follows: The measuring rod described earlier was made as long as possible with the anatomical relations within the oral cavity of each patient having been taken into account. The distance between the measuring point on the brackets of the tooth undergoing movement (Point I, Fig. 1) and the first permanent molar (Point A, Fig.1) were measured with a pair of needle calipers. The distance between the measuring points on these teeth and the measuring points (Point C, Fig. 1) at the end of the rod inserted into the buccal tube on the tooth undergoing uprighting was also recorded. The uprighting spring was then hooked over the archwire. The force exerted by the uprighting spring at the archwire was then measured using a dial gauge as a dynamometer. This measurement was taken at weekly intervals; and the average moment (or torque) was then calculated by taking the mean of the readings at the beginning and end of that particular week and multiplying the force readings by the length of the spring arm.

The angular movement of the teeth during any particular week was determined by using dividers and a micro-divider-setter[1] to take measurements of the distances between the three measuring points A, I and C. (Fig.1). Point A was the measuring point on the molar buccal tube in patients where the cuspid or bicuspid teeth were moved. If lateral incisors were moved, Point A was the measuring point on the central incisors; Point I was the measuring point on the buccal tube of the tooth undergoing movement; and Point C was the measuring point at the end of the measuring rod inserted into the tube soldered to the bracket of the tooth (Fig. 1). These measurements were recorded, magnified ten times and then plotted on graph paper. A protractor was used to determine angular changes in the position of the measuring rod (Fig. 4).

Table I. Figure 5.
Showing the Relation between Duration of Movement after One Activation, Change in Inclination and Average Torque Per Week for Four Patients.



PATIENT D.P.

Tooth	Spring[1]	Duration[2]	Change[3]	Torque[4]	Release[5]	Movement[6]
12	0.16" (0.40mm)	7	7.0	11.76	0.33	7.0
		14	0.5	6.66		
		21	3.5	5.59		
		28	1.0	2.65		
			12.0			
22	0.014" (0.35mm)	7	1.3	4.85	0.17	2.0
		14	2.0	4.31		
		21	2.0	4.17		
		28	0.0	4.17		
			5.3			

1 Spring: Dimension of Spring (Diameter of Wire). In each case 2.5 turns of the wire were wound on a 0.035" (0.89mm) mandrel.
2 Duration: Duration of Movement (days) after one activation.
3 Change: Change in Inclination (degrees per week).
4 Torque: Average torque (N.mm).
5 Release: Rate of release of spring in N.mm per degree (activated 20 degrees).
6 Movement: Maximum rate of angular movement (degrees per week).

Results

The results for eight uprighted teeth are given in Tables I and II and in Figs. 5-11. Table I gives the duration of movement, change in inclination per week and the average moment exerted per week. Table II gives the duration of movement, initial average moment, the total amounts of clinical crown and angular movement, and release rates of springs used.

In the first week angular movement in the eight teeth undergoing movement (hereafter referred to as 'cases') ranged from 1.3 to 7.3 degrees per week. Of these, five reached or exceeded 4 degrees per week. The range of movement in the second week was from 0.5 to 5.6 degrees. In that same week, six cases showed a reduction in the rate of movement and two (D.P.22 and J.V.13) showed an increase. In the six cases in which the angular changes in the second week were less than in the first, readings varied from 0.5 degrees per week to 3.7 degrees per week. Over the next two weeks, rates in five cases increased to maxima. Two cases (G.K.23 and H.S.45) showed a reduction; but one case (G.K.13) achieved a high rate of movement during the sixth week. The range of maximum rates of movement following the second week varied from 2 to 12 degrees per week.

The relation between total amounts and duration of movement (Table II) indicate considerable differences not only in the total amounts of tooth movement in different cases but also between different teeth in the same patient: for example, patients H.S. and D.P. showed large discrepancies in total amounts of movement for teeth moved for the same length of time; in patient J.V., the upper right cuspid moved twice as far as the upper left cuspid during the same time period; patient H.S. showed greater movement of one tooth moved for a shorter time than of one moved for a longer time.

As no special precautions were taken to prevent movement of teeth along the arch, clinical crown movement occurred during the uprighting process. This varied from 0.05 mm to 0.96 mm per week.

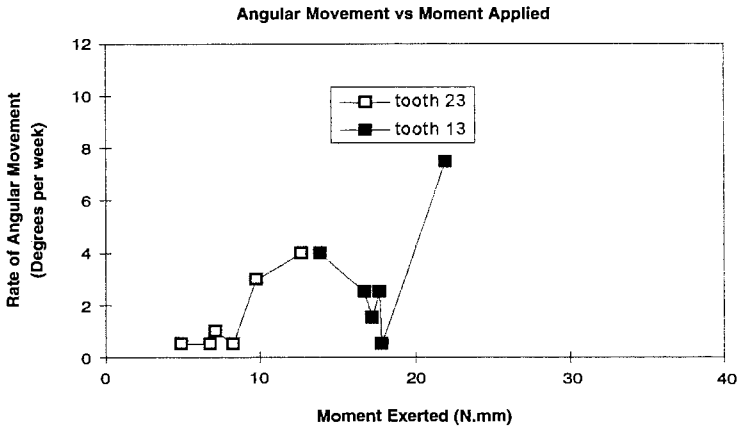
The range of torque force exerted during the initial phase of rapid movement was 11.76 to 36.75 Newton millimetres. The low rates of movement in the initial phase occurred when moments ranged from 6.86 to 36.9 Newton millimetres. The high rates of movement in the second phase occurred when moments ranged from 5.29 to 27.93 Newton millimetres.

Discussion

Six of the eight cases demonstrated tooth movement patterns comprising one or more complete phases of movement. The remaining cases showed tooth movement patterns which were atypical with regard to the pattern described earlier.[1] This was to be expected because the magnitudes of the torque forces exerted in this experiment were chosen at random; unlike the tipping-bodily investigations,[1] no previous study was available as a guide for selecting initial forces.

Patient H.S.'s lower right second bicuspid movement showed no phasic differentiation until the reading taken in the fourth week; which may have represented the end of Phase 2: not Phase 1, as demonstrated in earlier experiments.[1] This could have occurred if the initial moment was close to the level required for the high rate of movement in Phase 2. By comparison, H.S.'s lower left second bicuspid showed earlier phase differentiation following the application of similar initial torque forces. H.S. was the one female patient in this group, and results of her tooth movement may reflect the cyclic variations in rates of movement during the menstrual cycle.[2] Although springs exerting similar initial moments were used for this patient, the 35 spring had a

Table I. Figure 6.
Showing the Relation between Duration of Movement after One Activation, Change in Inclination and Average Torque Per Week for Four Patients.



PATIENT G.K.

Tooth	Spring[1]	Duration[2]	Change[3]	Torque[4]	Release[5]	Movement[6]
23	0.020" (0.51mm)	7	4.0	12.64	0.61	4.0
		14	3.0	9.7		
		21	0.5	8.23		
		28	1.0	7.06		
		35	0.5	6.76		
		42	0.5	4.85		
			9.5			
13	0.020" (0.51mm)	7	7.5	21.95	0.61	7.5
		14	0.5	17.84		
		21	2.5	17.7		
		28	1.5	17.15		
		35	2.5	16.74		
		42	4.0	13.86		
			18.5			

1 Spring: Dimension of Spring (Diameter of Wire). In each case 2.5 turns of the wire were wound on a 0.035" (0.89mm) mandrel.
2 Duration: Duration of Movement (days) after one activation.
3 Change: Change in Inclination (degrees per week).
4 Torque: Average torque (N.mm).
5 Release: Rate of release of spring in N.mm per degree (activated 20 degrees).
6 Movement: Maximum rate of angular movement (degrees per week).

much lower rate of release than the 45 spring.

The upper right cuspid of patient J.V. demonstrated no initial rapid rate of angular movement which could have been described as a separate phase; however, it clearly demonstrated one distinct phase beginning at the initial application of force, reaching a maximum rate of movement in the third week.

In patient G.K., similar springs fitted to each side of the mouth on similar teeth exerted different amounts of torque because the springs were activated in different amounts. Although rates of release of these springs were the same, the pattern of the tooth-movement curves differed.

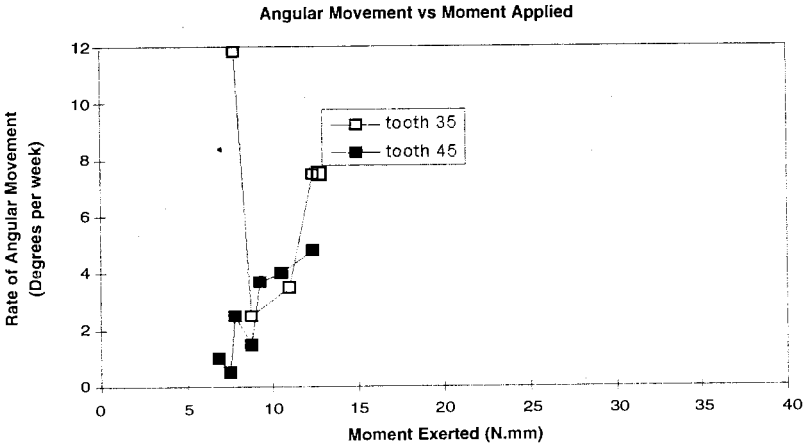
Three patients, J.V., H.S. and D.P., had springs of different rates of release fitted to teeth on opposite sides of the mouth. The first two showed differing rates of movement, in accordance with the observation made earlier,[1] that lower rates of release produced greater amounts of tooth movement per week. In patient D.P., the spring with the higher rate of release produced a greater maximum rate of movement; however, initial moments of force were widely disparate in this patient and much less so in the other two patients.

Patients J.V. and H.S. underwent similar ranges of torque force on both sides of the mouth; however, differences existed in the rates of release, the result in both cases being that greater maximum rates of movement were demonstrated by teeth on which springs of lower rates of release were used.

A comparison of the movements of the lower left second bicuspid of patient H.S. and the upper right lateral incisor of patient D.P., on both of which similar amounts of torque with similar rates of release were exerted, showed that different maximum rates of movement occurred: H.S.'s lower left second bicuspid was 12 degrees; D.P.'s upper right lateral incisor was 3.8 degrees.

A look at the general pattern of tooth movement revealed similarities in the rate of angular movement-applied torque curves and the force-rate curves for tipping and bodily movement. Movement of the root within the socket until the apical portion of the root meets the surrounding bone on the pressure side, represents the low rate of movement in Phase 1 of the root torque experiment. As the root moves farther through the bone, the pressure exerted by the root is reduced by a dissipation of the force exerted by the spring and, probably, because of the conical shape of the root and socket, by the rapid increase in the area of contact between root and bone. This approximation of root and socket occurs more rapidly in tipping movement with bracket engagement because of differences in the centre of rotation of the respective tooth movements. Root movement (uprighting and labio-lingual root torque) creates pressure along the entire leading edge of the root being moved; in this way, it more closely approximates true bodily movement;[3] which creates areas of tension and compression along both the leading and trailing edges respectively of the root undergoing movement. The rate of tooth movement varied within the one patient when springs of different rates of release and different amounts of initial torque force were exerted. These variations are similar to those discussed in the experiment described earlier[1] and may be explained in a similar manner.

Table I. Figure 7.
Showing the Relation between Duration of Movement after One Activation, Change in Inclination and Average Torque Per Week for Four Patients.



PATIENT H.S.

Tooth	Spring[1]	Duration[2]	Change[3]	Torque[4]	Release[5]	Movement[6]
35	0.016" (0.40mm)	7	7.5	12.35	0.33	4.0
		14	3.5	11.03		
		21	2.5	8.82		
		28	11.8	7.84		
			25.3			
45	0.020" (0.51mm)	7	4.8	12.35	0.61	4.8
		14	4.0	10.58		
		21	3.7	9.31		
		28	1.5	8.82		
		35	2.5	7.84		
		42	0.5	7.55		
		49	1.0	6.86		
			18.0			

1 Spring: Dimension of Spring (Diameter of Wire). In each case 2.5 turns of the wire were wound on a 0.035" (0.89mm) mandrel.
2 Duration: Duration of Movement (days) after one activation.
3 Change: Change in Inclination (degrees per week).
4 Torque: Average torque (N.mm).
5 Release: Rate of release of spring in N.mm per degree (activated 20 degrees).
6 Movement: Maximum rate of angular movement (degrees per week).

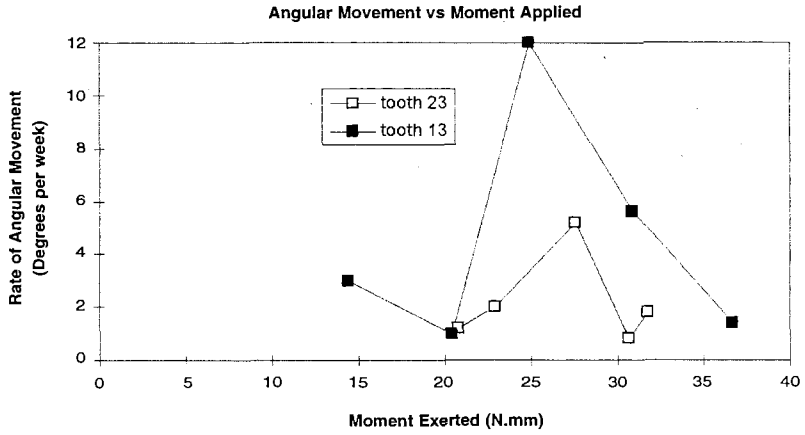
No experiment was carried out in which all variable factors (tooth selection, the rate of release of the springs and the amount of torque exerted) were controlled, so, at this stage, it is not possible to estimate whether any other factors could cause variations in the rate of movement. Further experimentation with the above factors controlled should clarify this point.

The effect of varying rates of release on the rate of movement has been demonstrated in two of the three cases in which this situation existed. The moments exerted during the rapid rate of movement in Phase 2 were exerted over a greater range of movement when springs with low rates of release were used than when springs with higher rates of release were used. Consequently, more movement occurred in the weeks during which 'optimum' torque forces were exerted. When springs of identical rates of release were used on teeth of different denominations, differences in maximum rates of movement (in H.S.35 and D.P.12) were observed. Also, the magnitude of the torque forces exerted were seen to vary when these maximum rates of tooth movement occurred. This suggests that differences in root size cause differences in the stress levels at the bone-periodontal membrane interface, resulting in different patterns of tooth movement. This is to be expected if the hypothesis: pressure is more important than force in determining the maximum rate of tooth movement is valid for this clinical situation.

Radiographs verified the nature of the uprighting movement found in these experiments. The tooth's centre of rotation was seen to be located slightly apical to the bracket area at the level of the archwire. Graphical plotting of the axial inclinations of the experimental teeth confirmed this. The experimental teeth moved along the arch in every case. Movement of this type may be prevented, if necessary, by ligature wires tied appropriately. This movement also occurs in mass root torque situations, and steps should be taken to anticipate its effects during the treatment of malocclusion. The amount of clinical crown movement (Table II) appears to be related to time, total amount of angular movement and rate of release of spring. The amount of clinical crown movement would depend upon whether or not the tooth were tied back and if space were available for such movement. In this study no teeth were tied back, and no record was made of the available space. Clinical crown movement during uprighting or root torque is a feature of orthodontic treatment well known to orthodontists. It is a potent factor which may cause whole arch movement or space opening between teeth being uprighted in opposite directions. Such movement varies with crown size and the distance from the level of the bracket to the centroid of the root.

The experimental technique used in this particular study appears valid. However, further experiments should be designed to control all factors, including root size, and to ensure that tying back is sufficient to prevent all but minimal amounts of crown movement. A similar technique could be used to investigate lingual root torque; although this is more complicated and may require a radiographic measurement system.

Table I. Figure 8.
Showing the Relation between Duration of Movement after One Activation, Change in Inclination and Average Torque Per Week for Four Patients.



PATIENT J.V.

Tooth	Spring[1]	Duration[2]	Change[3]	Torque[4]	Release[5]	Movement[6]
23	0.016x0.022" (0.46x0.56mm)	7	1.8	31.78	1.96	4.0
		14	0.8	30.62		
		21	5.2	27.56		
		28	2.0	22.96		
		35	1.2	20.83		
			9.0			
13	0.020" (0.51mm)	7	1.4	36.7	0.61	12.0
		14	5.6	30.87		
		21	12.0	24.9		
		28	1.0	20.44		
		35	3.0	14.41		
			18.0			

1 Spring: Dimension of Spring (Diameter of Wire). In each case 2.5 turns of the wire were wound on a 0.035" (0.89mm) mandrel.
2 Duration: Duration of Movement (days) after one activation.
3 Change: Change in Inclination (degrees per week).
4 Torque: Average torque (N.mm).
5 Release: Rate of release of spring in N.mm per degree (activated 20 degrees).
6 Movement: Maximum rate of angular movement (degrees per week).

Table 2. Showing the relation between total amount of clinical crown movement, total amount of angular movement, initial average torque and rate of release of springs concerned.

Patient	Tooth	Duration of Movement (Weeks)	Initial Ave. Torque (N.mm)	Total Amt. of Angular Movement (Degrees)	Rate of Release of Spring (N.mm per Degree)	Total Amt. of Clinical Crown Movement (mm)
D.P.	12	4	11.76	12.0	0.33	0.38
	22	4	4.85	4.3	0.17	0.50
G.K.	22	6	12.64	7.0	0.61[1]	0.96
	13	6	21.95	18.5	0.61[2]	0.78
H.S.	35	4	12.25	24.0	0.33	0.12
	45	7	12.35	20.0	0.61	0.05
J.V.	23	5	31.78	11.0	1.96	0.11
	13	5	36.70	23.0	0.61	0.30

1 40 degrees activation
2 20 degrees activation

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