British Journal of Orthodontics/Vol. 24/1997/127–131

Scientific Section

An Investigation Into the Placement of Force Delivery Systems and the Initial forces Applied by Clinicians During Space Closure

CLAIRE NATTRASS, M.SC., B.D.S., F.D.S R.C.S. (ENG.), M.ORTH. R.C.S (EDIN.)
Department of Child Dental Health, Bristol Dental Hospital, Lower Maudlin Street, Bristol BS1 2LY, U.K.

ANTHONY J. IRELAND, PH.D., M.SC., B.D.S, F.D.S., M.ORTH. R.C.S. (ENG.)
Department of Orthodontics, Royal United Hospital, Bath BA1 3NG, U.K.

MARTYN SHERRIFF, PH.D.
Department of Materials Science, United Medical and Dental Schools, Guy's Tower, London Bridge, London SE1 9RT, U.K.

Abstract: *This* in vitro *investigation was designed to establish not only how clinicians apply forces for space closure when using the straight wire appliance and sliding mechanics, but also to quantify the initial force levels produced. A single typodont, with residual extraction space in each quadrant, was set up to simulate space closure using sliding mechanics. On two occasions, at least 2 months apart, 18 clinicians were asked to apply three force delivery systems to the typodont, in the manner in which they would apply it in a clinical situation. The three types of force delivery system investigated were elastomeric chain, an elastomeric module on a steel ligature, and a nickel-titanium closed coil spring. A choice of spaced or unspaced elastomeric chain produced by a single manufacturer was provided. The amount of stretch which was placed on each type of system was measured and, using an Instron Universal Testing Machine, the initial force which would be generated by each force delivery system was established. Clinicians were assessed to examine their consistency in the amount of stretch which each placed on the force delivery systems, their initial force application and their ability to apply equivalent forces with the different types of force delivery system.*

The clinicians were found to be consistent in their method of application of the force delivery systems and, therefore, their force application, as individuals, but there was a wide range of forces applied as a group. However, most clinicians applied very different forces when using different force delivery systems. When using the module on a ligature the greatest force was applied, whilst the nickel titanium coil springs provided the least force.

Refereed Paper

Introduction

Orthodontic treatment with fixed appliances commonly involves moving teeth along an archwire, for example, to retract canines or to close residual extraction spaces. When clinicians select a force delivery system for this purpose, they hope that it will apply a force which will be of sufficient duration to achieve tooth movement in an efficient and effective manner, without causing damage to the tooth or periodontal structures. Unfortunately, the well documented studies on root resorption (Brezniak and Wasserstein, 1993a,b), suggests this optimal situation may rarely be seen. The recent introduction of nickel-titanium coil springs, which theoretically provide a low, but constant force, may make this ideal more readily attainable, although not all coil springs demonstrate super-elastic behaviour (Melson *et al.*, 1994). Although nickel-titanium coil springs have proved to be clinically effective (Samuels *et al.*, 1993; Sonis, 1994), their high cost means that elastomeric products tend to remain the system of choice for most operators, certainly for those involved with this study. It is impossible to apply a constant force using any system, as all experience some force decay to a greater or lesser degree. Exactly how much active force will exist between visits is impossible to predict. Not only is there variation between individual specimens within each force delivery system (Melson *et al.*, 1994) and between those produced by different manufacturers, but *in vitro* investigations cannot accurately simulate intraoral conditions. Nevertheless, it is still important that a clinician has some knowledge of the forces which are applied by each type of force delivery system.

Orthodontists rely on the fact that teeth will move under an applied force, yet when at rest from an actively applied force, exist in a position of equilibrium with the surrounding tissues. How much force is required for tooth movement is debatable, particularly since factors such as friction and the effects of the oral environment need to be

0301-228X/97/002000+00$02.00

taken into consideration. Earlier publications recommend quite heavy forces (Smith and Storey, 1952; Hixon *et al.*, 1969; Boester and Johnson, 1974). However, following a critical appraisal of the previous work, Quinn and Yoshikawa (1985) suggested that 100–200 g is optimal for canine retraction. Proffit (1978, 1986) concluded that the duration of applied force is far more influential than its magnitude, *i.e.* that light forces acting for at least 4–6 hours have greater effect on the dentition than heavy forces which are sustained momentarily. This is because bone remodelling is not initiated by momentary heavy forces, but by repeated forces, provided that these are above a minimum load (Frost, 1990). For this reason, it is important that any space closing system used in orthodontics is capable of applying a force of sufficient magnitude and duration to achieve tooth movement without causing irreversible damage to the root and periodontal ligament.

How much force do clinicians actually apply in practice? Chung *et al.* (1989) assessed the force values normally used by clinicians for retracting canines. From 20 sets of pre-treatment models, the mean molar–canine distance was established and a typodont was set up to simulate this. In two separate experiments, clinicians were asked to apply elastomeric chain in each quadrant. These specimens of elastomeric chain were then removed from the typodont, stored for 24 hours (to allow for stress relaxation) and restretched on an Instron Universal Testing Machine to measure the resultant force. It was found that all clinicians used between 4 and 7 modular units, which generated a wide-range of force between 125–310 g. No differences between junior and senior operators were found, but clinicians were found to be consistent in the length of the chain applied, *i.e.* those who used short chains used short chains throughout, irrespective of the brand. A shortcoming of this work was that the model used was not necessarily representative of the clinical distance over which force delivery systems are applied, as it did not take arch length change as a result of loss of extraction space or initial alignment into account. Also, restretching chain which has already been stretched on a typodont is not an accurate method of measuring the initial force which it would apply on the first time of use.

The aims of the following investigation were to:

1. Assess the most frequent stretch placed on force delivery systems by clinicians and the forces which these provide.
2. Assess if clinicians are consistent in the stretch which they placed on force delivery systems and their force application on separate occasions.
3. Assess the ability of clinicians to apply the same level of initial force whilst using different force delivery systems.

Materials and Methods

First, a preliminary clinical investigation was conducted in which the distance between the hooks on the molar band and on the archwire was measured in 80 patients (241 quadrants), each wearing upper and lower straight wire (A Company, San Diego, California, U.S.A.) appliances and undergoing space closure. The most frequent distance over which force delivery systems were applied was found to measure 25 mm.

FIG. 1 The typodont demonstrating the application of the elastomeric chain and the nickel-titanium coil spring.

In order to investigate how clinicians use force delivery systems and the forces which are applied for space closure, a single typodont was set up with residual extraction space remaining in each of the four quadrants. Upper and lower 0.019″ × 0.025″ stainless steel hooked archwires (Precision Orthodontics, Surrey, U.K.) were tied into straight wire appliances on this typodont using elastomeric modules (Ortho-Care (UK) Ltd., Bradford, West Yorkshire, U.K.). The distance between the hooks on the molar bands and on the archwires (determined from the preliminary clinical investigation) measured 25 mm in each quadrant. Eighteen clinicians were asked to apply three types of force delivery systems to the typodont in the manner in which they would use each in the clinical environment, *i.e.*. they chose the degree of stretch placed on each (Fig. 1). The force delivery systems investigated were elastomeric chain (a choice of yellow medium spaced or blue unspaced *Durachain* (Ortho-Care (UK) Ltd., Bradford, West Yorkshire, U.K.) was provided, each reel recently delivered by the manufacturer), a grey module (Ortho-Care (UK) Ltd., Bradford, West Yorkshire, U.K.) on a stainless steel ligature and a 150g nickel titanium closed coil spring (medium, Ortho-Care (UK) Ltd., Bradford, West Yorkshire, U.K.). These systems were chosen as they are in common use at the clinical centres involved in this study. A record was made of the type of chain and number of links used. The stretch placed upon both the module on a steel ligature and the nickel-titanium coil spring was also measured. A minimum of 2 months later the clinicians were asked to repeat this procedure in order to assess their consistency in their method of placement of the force delivery systems and the resultant initial force application.

Using an Instron Universal Testing Machine (Instron Corporation, Canton, Massachusetts, U.S.A.) and customized hooked attachments set at a distance of 25 mm to simulate the distance on the typodont, the initial loading force obtained with each type of elastomeric chain used by the clinicians in the typodont exercise was determined. The ambient room temperature and humidity were noted. Twenty specimens of each combination of chain/number of links used were then stretched between the hooks and the mean initial load was determined. The same customized hooked attachments were then used to measure the initial force applied by the elastomeric modules on a ligature and the nickel-titanium coil springs as used by the clinicians in the typodont exercise. Twenty specimens of each were used in order to establish the mean loading force applied by each stretch of elastomeric module on a ligature and nickle titanium coil spring. A total of 580 specimens were tested in this way.

Results

The results (Table 1) were analysed using both Stata Version 3.1 (Stata Corp., Texas, U.S.A.) and StatXact 2.4a (StatXact, Cambridge, U.S.A.) statistics packages. The Shapiro–Francia test was used to test for departures from normality. The data was found to be non-normal and so non-parametric procedures were used.

The Wilcoxon Rank Sum Test was used to determine the effect of time on the force applied by clinicians using each of the force delivery systems. The probability values for the elastomeric chain, elastomeric modules on a steel ligature and nickel titanium coil springs were 0·88, 0·51, and 0·69, respectively. These confirmed that there was no difference in the force applied over the two time periods, *i.e.* the clinicians were consistent in the level of force which they applied on two different occasions when using the same type of force delivery system.

As the clinicians were consistent in the force which they applied on each occasion when using the individual force delivery systems, the data for each force delivery system (initial force values) were pooled in order to determine the effect of the type of force delivery system on the initial force applied. The Kruskall–Wallis one-way analysis of variance, to which a Bonferroni's correction was applied, was used (Table 2). This demonstrated a significant difference in the forces applied by the three different force delivery systems.

The number of consistent placements of force delivery systems made by each clinician is shown in Table 3. The clinicians were not asked to try to apply an equivalent force with the different types of force delivery systems, but it is interesting to consider if they attempted to do so. As the nickel-titanium coil springs gave a predetermined maximum force of about 150 g, the clinicians were unable to apply a force similar to the elastomeric systems when using this system, even if they should have wanted to do so. Therefore, in order to assess their ability to apply equivalent force levels with the different systems, it was decided to compare only the elastomeric systems. The table has been ordered with the clinicians ranked from the most to the least consistent, in terms of their ability to apply an equivalent force between the two elastomeric systems.

Discussion

It is interesting that, in general, these clinicians tended to place the same stretch on the force delivery systems and, therefore, the same force with each system, on different occasions. This may be a reflection of a personal preference which leads the clinician to habitually choose the same type of chain or place an identical stretch on a module, or confidence in a system which has worked well for them in the past. Similarly to this investigation, Chung *et al.* (1989) found that clinicians were consistent in their choice of elastomeric chain. Not surprisingly, the clinicians in the current study showed the greatest consistency when applying nickel-titanium coil springs, which were of identical length and most commonly stretched directly

TABLE 1 *A summary of the placement of space delivery systems and of the initial forces applied by 18 clinicians across a distance of 25 mm on a typodont at Time 1 and Time 2*

Space closing system	Time 1			Time 2		
	Most frequent stretch	Mean most frequent force applied (N)	Range of mean force applied (N)	Most frequent stretch	Mean most frequent force applied (N)	Range of mean force applied (N)
Elastomeric chain	4 links spaced (yellow)	2·17	0·61–2·67	4 links spaced (yellow)	2·17	0·44–2·67
Elasteromeric module	8·0 mm	3·05	2·45–3·54	7·0 mm	3·08	2·40–3·54
Nickel titanium closed coil spring	25 mm	1·51	0·87–1·51	25 mm	1·51	1·20–1·51

TABLE 2 *The Kruskall–Wallis test to determine the effect of different methods of force delivery systems on the initial force applied confirmed that each system applied a different force*

Mechanism	Mean load (N)	N	Kruskall–Wallis test with Bonferroni's correction applied
Elastomeric chain	2·15	36·00	
Module	2·99	36·00	$P' = 0{\cdot}003$
NiTi spring	1·41	36·00	

TABLE 3 *The consistency in force application between two occasions shown by 18 clinicians using three different force delivery systems. The clinicians are ranked from the most to the least consistent in terms of their ability to apply an equivalent force between two elastomeric systems. The force discrapancy between T1 and T2 is the difference between the mean initial forces. The force discrepancy between the elastomeric groups (final column) is the difference between the highest and the lowest mean force applied by either the elastomeric chain or elastomeric module*

Clinician no.	No. of agreements	Force discrepancy between T1 and T2 (N)			Force discrepancy between the elastomeric groups (N)
		Chain	Module	NiTi spring	
3	3/3	0·00	0·00	0·00	0·24
17	2/3	0·00	0·03	0·00	0·48
15	2/3	0·00	0·03	0·00	0·48
1	2/3	0·07	0·00	0·00	0·48
4	1/3	0·50	0·43	0·00	0·66
11	0/3	0·35	0·03	0·06	0·83
2	1/3	0·07	0·05	0·00	0·87
10	2/3	0·00	0·14	0·00	0·88
9	2/3	0·00	0·17	0·00	0·91
5	2/3	0·00	0·17	0·00	0·91
7	2/3	0·00	0·07	0·00	0·94
16	2/3	0·00	0·37	0·00	1·25
14	0/3	0·22	0·38	0·06	1·36
18	1/3	0·50	0·49	0·00	1·37
6	0/3	0·70	0·08	0·02	1·44
13	1/3	1·47	0·09	0·00	1·99
8	0/3	1·25	0·15	0·02	2·16
12	0/3	0·52	0·48	0·39	2·47

between the two fixed hooks. Nickel-titanium coil springs are designed to deliver a low constant force at most extensions (those which are most frequently used clinically) and so, unlike the elastomeric systems, the force applied is primarily material dependent rather than primarily clinician dependent. As a result, the majority of clinicians were at their most consistent in their force application when using these. Only one clinician applied forces differing by more than 0·1 N and 0·39 N) when using coil springs. When the forces applied by the elastomeric force delivery systems were examined, a slightly different pattern was revealed. The majority of clinicians (11 when using elastomeric chain and 13 when using elastomeric modules) applied forces differing by less than 0·25 N on the two occasions. However, those few who were inconsistent in their force application in the elastomeric chain group demonstrated a wide range of force differences, between 0·38 N and 1·47 N. This range of inconsistency was not so great in the module group, 0·37–0·49 N.

An interesting question arose as to whether clinicians demonstrated consistency in force application between systems in addition to within systems, *i.e.* do clinicians stretch modules and coil springs to give a force equivalent to that applied by their choice of elastomeric chain? As the nickel titanium coil springs were designed to generate a force of about 150 g at most stretches, the clinicians were unable to apply a force equivalent to that generated by the elastomeric systems, even if they had intended to do so. Therefore, only the elastomeric groups were compared to assess if the clinicians had applied equivalent forces with the different systems. Only one clinician showed force application differing by less than 0·25 N between the two groups (Table 3). The remainder showed a wide range of disparity, between 0·48 N and 2·47 N. Predictably, the clinicians who demonstrated the best (Clinician 3) and worst (Clinicians 13, 8, and 12) consistency in their choice of elastomeric chain and modular stretch, also demonstrated the least and the greatest force ranges, respectively. However, inconsistent placement did not necessarily result in inconsistent force application. Clinician 11 demonstrated no agreement in the stretch of the force delivery systems, yet was the sixth most consistent in the application of force. Likewise, clinicians 4 and 2 had only one agreement in terms of stretch, but were, respectively, the fifth and seventh most consistent in terms of force application.

It might be considered that clinicians who have the greatest experience of orthodontics would be the most consistent in their application of force. In fact, the most consistent clinicians in their equivalent application of force when using the two different elastomeric systems were, ironically, the least experienced. This is a contrast to the work of Chung *et al.* (1989) who found no differences between junior and senior operators. Chung *et al.* investigated only one type of force delivery system, elastomeric chain, and did not investigate the ability of clinicians to apply equivalent force with different systems. However, clinicians were found to apply different forces with different brands of elastomeric chain. In the current study, the five most consistent clinicians in their force application were all under consultant level, and the three least consistent clinicians were all consultants. However, when the reason for this finding is considered, it can be seen that the less experienced orthodontists tend to apply quite heavy forces, *i.e.* their choice of elastomeric chain applied a force similar to that created by the stretch which they placed upon the module. The three clinicians who were the least consistent tended to apply low forces with the method of space closure which they use most frequently, the elastomeric chain. When using a system with which they were relatively unfamiliar, *i.e.* the grey module on the steel ligature, these clinicians applied a high initial force. This is not surprising as the module applies a high load when stretched only slightly and clinicians tend to stretch it substantially (7–8 mm). Therefore, the disparity between the loads applied by these systems in the hands of the least consistent clinicians was great.

Clearly, clinicians do not apply similar forces with different force delivery systems, as the initial forces applied by the three systems were quite different from one another. The heaviest forces were applied by the modules and the lightest by the nickel-titanium coil springs.

It has long been established that elastomeric products exhibit force decay with time (Andreasen and Bishara, 1970; Lu *et al.*, 1993; Nattrass, 1996), whereas nickel-titanium coil springs retain the majority of their initial force (Han and Quick, 1993; Nattrass, 1996). Therefore, clinicians may compensate for this by applying heavier initial forces when using elastomeric systems than with nickel-titanium coil springs.

The extremely wide range of forces (0·44–3·54 N) applied by clinicians with essentially similar training suggests that most clinicians do not consciously think about the force level which they are applying, other than whether it is heavy or light. As all of the participating clinicians frequently successfully close extraction spaces, this would suggest that tooth movement can be accomplished by a wide range of forces, perhaps demonstrating biological variation in the response of each patient. If, in fact, forces required for bone remodelling are much lower than previously thought (Frost, 1990), then most clinicians probably apply too much force.

Conclusions

The following conclusions were drawn:

1. Clinicians were consistent in their placement of force delivery systems and the initial forces applied as individuals on two separate occasions, although showed a wide range in the level of force which they applied as a group.
2. However, these clinicians applied very different forces when using each of the three force delivery systems investigated in this study, namely elastomeric chain, elastomeric modules and nickel-titanium coil springs.
3. Clinicians apply heavier forces when using elastomeric modules than elastomeric chain and apply the lightest forces with nickel-titanium coil springs.

Acknowledgements

We are grateful to the clinicians who took part in this study and to Phil Bessant who set up the typodont.

References

Andreasen, G. F. and Bishara, S. (1970)
Comparison of *Alastik* chains with elastics involved with intra-arch molar-to-molar forces,
American Journal of Orthodontics, **40,** 151–158.

Boester, C. H. and Johnston, L. E. (1974)
A clinical investigation of the concepts of differential and optimal force in canine retraction,
The Angle Orthodontist, **44,** 113–119.

Brezniak, N. Wasserstein, A. (1993a)
Root resorption after orthodontic treatment: Part 1,
The Angle Orthodontist, **103,** 62–66.

Brezniak, N. Wasserstein, A. (1993b)
Root resorption after orthodontic treatment: Part 2,
The Angle Orthodontist, **103,** 138–146.

Chung, P. C. K., Wei, S. H. Y. and Reynolds, I. R. (1989)
In vitro testing of elastomeric modules,
British Journal of Orthodontics, **16,** 265–269.

Frost, H. M. (1990)
Skeletal structural adaptations to mechanical usage (SATMU): 1. Redefining Wolff's Law: the bone modeling problem,
The Anatomical Record, **226,** 403–413.

Hans, S. and Quick, D. C. (1993)
Nickel-titanium spring properties in a simulated oral environment,
The Angle Orthodontist, **63,** 67–72.

Hixon, E. H., Atikian, H., Callow, G. E., McDonald, H. W. and Tracy, R. J. (1969)
Optimal force, differential force and anchorage,
American Journal of Orthodontics, **55,** 437–457.

Lu, T. C., Wang, W. N., Tarng, T. H. and Chen, J. W. (1993)
Force decay of elastomeric chain—a serial study. Part II,
American Journal of Orthodontics and Dentofacial Orthopedics, **104,** 373–377.

Melson, B., Topp, L. F., Melson H. M. and Terp, S. (1994)
Force system developed from closed coil springs,
European Journal of Orthodontics, **16,** 531–539.

Nattrass, C. (1996)
An investigation into the force delivery properties of elastomeric space closing systems and nickel titanium coil springs,
Master's thesis, Department of Orthodontics, University of Bristol.

Proffit, W. R. (1978)
Equilibrium theory revisited: factors influencing position of the teeth,
The Angle Orthodontist, **48,** 175–186.

Proffit, W. R. (1986)
On the aetiology of malocclusion,
British Journal of Orthodontics, **13,** 1–11.

Quinn, R. S. and Yoshikawa, D. K. (1985)
A reassessment of force magnitude in orthodontics,
American Journal of Orthodontics, **83,** 252–260.

Samuels, R. H. A., Rudge, S. J. and Mair, L. H. (1993)
A comparison of the rate of space closure using a nickel-titanium spring and an elastic module: a clinical study,
American Journal of Orthodontics and Dentofacial Orthopedics, **103,** 464–467.

Sonis, A. L. (1994)
Comparison of NiTi coil springs vs elastics in canine retraction,
Journal of Clinical Orthodontics, **28,** 293–295.

Smith, R. and Storey, E. (1952)
The importance of force in orthodontics: the design of cuspid retraction springs,
Australian Dental Journal, **56,** 291–304.