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SCIENTIFIC SECTION

A clinical investigation of force delivery systems for orthodontic space closure

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Abstract

Objective: To investigate the force retention, and rates of space closure achieved by elastomeric chain and nickel titanium coil springs.

Design: Randomized clinical trial.

Setting: Eastman Dental Hospital, London and Queen Mary's University Hospital, Roehampton, 1998–2000.

Subjects, materials and methods: Twenty-two orthodontic patients, wearing the pre-adjusted edgewise appliance undergoing space closure in opposing quadrants, using sliding mechanics on 0.019 × 0.025-inch posted stainless steel archwires. Medium-spaced elastomeric chain [Durachain, OrthoCare (UK) Ltd., Bradford, UK] and 9-mm nickel titanium coil springs [OrthoCare (UK) Ltd.] were placed in opposing quadrants for 15 patients. Elastomeric chain only was used in a further seven patients. The initial forces on placement and residual forces at the subsequent visit were measured with a dial push–pull gauge [Orthocare (UK) Ltd]. Study models of eight patients were taken before and after space closure, from which measurements were made to establish mean space closure.

Main outcome measures: The forces were measured in grammes and space closure in millimetres.

Results: Fifty-nine per cent (31/53) of the elastomeric sample maintained at least 50 per cent of the initial force over a time period of 1–15 weeks. No sample lost all its force, and the mean loss was 47 per cent (range: 0–76 per cent). Nickel titanium coil springs lost force rapidly over 6 weeks, following that force levels plateaued. Forty-six per cent (12/26) maintained at least 50 per cent of their initial force over a time period of 1–22 weeks, and mean force loss was 48 per cent (range: 12–68 per cent). The rate of mean weekly space closure for elastomeric chain was 0.21 mm and for nickel titanium coil springs 0.26 mm. There was no relationship between the initial force applied and rate of space closure. None of the sample failed during the study period giving a 100 per cent response rate.

Conclusions: In clinical use, the force retention of elastomeric chain was better than previously concluded. High initial forces resulted in high force decay. Nickel titanium coil springs and elastomeric chain closed spaces at a similar rate.

Index words: Elastomeric chain, force decay, *in vivo* study, nickel titanium coil springs, space closure

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Introduction

Pre-adjusted fixed orthodontic appliances commonly utilize sliding mechanics for space closure with force delivery systems such as elastomeric chain, nickel titanium coil springs, elastomeric modules attached to wire ligatures, or intra-oral elastics. Synthetic elastomeric chain was introduced in the 1960s[1] and has been in widespread use since. When a polymer is stretched and the stress within it increases proportionally to the applied strain, the polymer is described as behaving elastically. In such circumstances, the unloading curve of the resultant stress/strain graph is identical to the loading curve. However, when elastomeric chain is stretched, it does not behave as a perfectly elastic material, because it loses energy and its unloading curve demonstrates less stress for a given stretch compared to the loading curve. This is called a hysteresis curve and is important because it is the unloading curve that is of interest to orthodontists. Indeed, it is well known that elastomeric systems lose

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force during the duration of their use.[1–3] This is thought to be due to a combination of water causing the weakening of intermolecular forces and chemical degradation,[4] and tooth movement resulting in decreasing stretch placed upon the elastomeric chain.[5,6] However, most investigations have been performed under laboratory conditions, which cannot simulate the oral environment.[7] It is not known how much force remains in a length of elastomeric chain at the end of its clinical use or for how long it may remain active.

While stainless steel coil springs have been in use since the 1930s,[8] nickel titanium (NiTi) coil springs were introduced more recently.[9] Increasingly, nickel titanium coil springs are used for space closure as they are thought to retain more force over a given time period and also provide a constant force.[10,11] This may be a more effective tooth moving force than that provided by elastomeric chain. Certainly previous studies have concluded that nickel titanium coil springs are more effective in space closure than either elastomeric modules[12,13] or intra-oral elastics,[14] although no statistically significant difference has been found between the rate of space closure with elastomeric chain or nickel titanium coil springs.[13] Force delivery from nickel titanium coil springs has been found to vary in response to the amount of activation[15,16] and temperature.[16,17] The composition of nickel titanium wires has been found to vary within batches, which has produced variable forces from custom made springs[18] and this may account for batch variation found also within coil springs[15].

Despite their potential superiority, nickel titanium coil springs remain relatively expensive and elastomeric chain remains popular in clinical practice.

Aims

The aims of this investigation were to:

(1) investigate the force retentive properties of elastomeric chain and nickel titanium coil springs in the clinical environment;
(2) compare the rates of space closure achieved with elastomeric chain and nickel titanium coil springs.

Hypotheses

The hypotheses to be tested were:

1. Elastomeric chain loses all of its force during clinical use.
2. Nickel titanium coil springs provide a low, constant force during clinical use.
3. High initial forces result in greater space closure.
4. There is a difference in the rate of space closure between the two force delivery systems.

Method

Sample selection and sample size

Orthodontic patients attending the orthodontic departments of the Eastman Dental Hospital and Queen Mary's University Hospital, Roehampton, under the care of one clinician (CN) were selected. Patients were aged 12–18 years, wearing the pre-adjusted edgewise appliance, and required bilateral space closure of premolar extraction spaces using sliding mechanics. Supplementary intermaxillary elastic traction was not used during space closure incase this influenced the results. The sample comprised 15 patients who had both nickel titanium coil springs and elastomeric chain provided, creating 40 test quadrants, as not all patients required space closure in both arches. A total of 26 springs were tested as six quadrants required more than one spring. A further seven patients had only elastomeric chain applied in a total of 16 test quadrants. This was because the inter-hook distance was too great to attach a nickel titanium coil spring. It was not possible to attach the nickel titanium coil spring via a stainless steel ligature as two fixed points were needed as a means of measuring the extension of the spring for force delivery. A total of 36 test quadrants gave data on 53 pieces of elastomeric chain.

Randomization

A split mouth study design was used, in which nickel titanium coil springs and elastomeric chain were attached in opposing quadrants. The quadrant to receive a nickel titanium coil spring was determined initially by the toss of a coin and alternated sequentially between left and right sides for the remainder of the sample.

Outcome measures

The initial and residual force measurements were made in grammes (g) and the space closure measured in millimetres.

Appliance design and data collection

Upper and lower 0.019 × 0.025-inch posted stainless steel wires were left passive for one visit (minimum 1 month) before commencing space closure and checked to ensure free sliding. No special measures (e.g. figure of eight modules or archwire stops) were taken to prevent the archwire spinning around and this was not found to be a problem. The archwires were removed and alginate impressions taken for study models prior to starting space closure in eight patients who had both force delivery systems used. Study models were repeated at the next visit. The force delivery systems under investigation were either 9 mm nickel titanium closed coil springs or medium-spaced elastomeric chain.

Nickel titanium coil springs

The nickel titanium coil spring was placed directly between two hooks, i.e. the hook on the molar band and the archwire just distal to the lateral incisor bracket. The initial force delivered was measured using a dial push–pull gauge, calibrated in 5-g increments. The nickel titanium coil spring was not renewed at subsequent visits, unless showing signs of distortion. It was simply reattached between the hooks as is usual in clinical practice. If the extraction space was too great for a nickel titanium coil spring to be stretched directly between the two hooks, then elastomeric chain only was applied (seven additional patients).

Elastomeric chain

Elastomeric chain was placed in the opposing quadrant, stretched to provide as similar a force to that delivered by the nickel titanium coil spring as possible. The elastomeric chain was renewed at each visit and the force matched to the residual force generated by the nickel titanium coil spring.

Timing of next measurement

The patients were asked to return for routine adjustments every 4–6 weeks. However, some failed to attend at this interval, one patient returning as late as 15 weeks after application of the force delivery system. On this following visit, the residual force was measured. The procedure was repeated until space closure was complete.

Space closure measurement method

Mean space closure was assessed using the method described by Dixon *et al.* (2002).[13] Using Vernier callipers, the distance between the canine tip and the buccal groove of the first molar was measured. This measurement was repeated three times and the mean value taken. The mean space closure per week for each force delivery system was calculated for each patient and then summated for the sample as a whole.

Measurement error and statistics

Calibration of the force gauge

A weight of known mass was suspended from the force gauge and the resultant force was measured. This was repeated twenty times and the measurements compared with the known mass. A Bland–Altman[19] calculation was made and found the mean difference between the measurements was −0.6 g (SD 2.4) and the range within which 95 per cent of the differences lay was −5.2 to +4.1 g. Therefore, the force gauge was calibrated.

Measurement error in assessing space closure

To reduce method error associated with the measurement of the study models, the examiner was blind as to the method of space closure used in each quadrant. The study models were measured randomly, so that no start and finish models of the same patient were measured consecutively. Additionally, measurements were taken three times to reduce random error.

Intra–examiner reliability

The study models were re-measured 1 week later and these measurements compared to the mean of the initial measurements. There was no statistically significant difference between the two ($P = 0.41$).

Space closure with each force delivery system

The data were compared using a paired *t*-test after checking the data for normality. There was no statistically significant difference between these two methods of space closure ($P = 0.46$).

Results

Elastomeric chain (n = 53)

The range of initial forces applied was 70–450 g, with a mean force of 209 g, whilst the range of final forces was 50–230 g, with a mean force of 109 g (Figure 1). Fifty-nine per cent (31/53) of the sample maintained at least 50 per

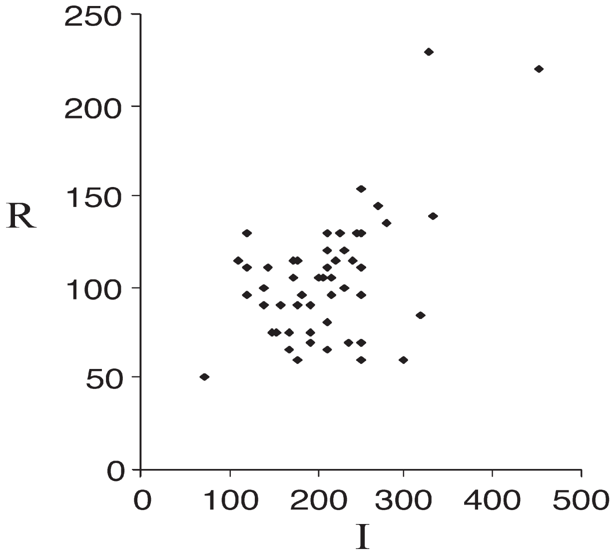

Fig. 1 Initial force (I) and residual force (R) in grammes of elastomeric chain.

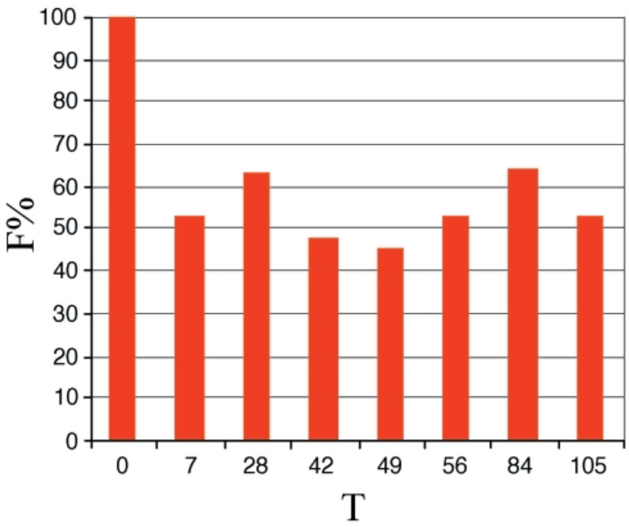

Fig. 2 Mean percentage of initial force (F%) remaining in elastomeric chain over time in days (T) (differing samples).

cent of their initial force over a time period of 1–15 weeks. No sample lost all of its force and in fact the mean force loss was only 47 per cent (range of force loss was 0–76 per cent). The chain left in place for 15 weeks retained 53 per cent of its initial force (Figure 2). The higher the initial force, the greater the force loss experienced (Figure 3).

Nickel titanium coil springs (n = 26)

The range of initial forces applied was 150–460 g, with a mean force of 300 g, whilst the range of final forces

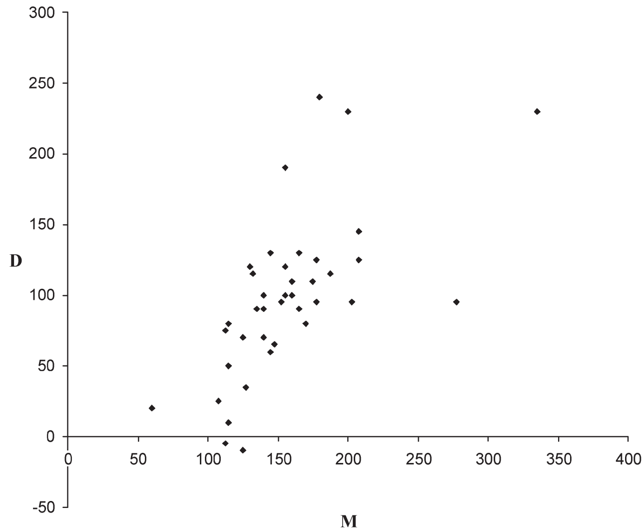

Fig. 3 Elastomeric chain: the difference (D) between the initial and final forces versus the mean (M) of the two forces (T1–T2).

was 95–255 g, with a mean force of 149 g. Nickel titanium coil springs lost force rapidly over the initial 6 weeks and then the force levels plateaued for the remainder of their use (Figure 4). Forty-six per cent (12/26) maintained at least 50 per cent of their initial force over a time period of 1–22 weeks. No spring lost all of its force and the mean force loss was 48 per cent (range = 12–68 per cent). Again, the higher the initial force, the greater the force decay (Figure 5).

Space closure (22 sites)

Space closure was assessed for eight patients (providing 22 space closure quadrants). Space closure was monitored for a mean of 67 days (range = 42–182, SD = 48). Four quadrants had complete space closure within one visit. The mean weekly space closure achieved with elastomeric chain was 0.21 mm (range 0.00–0.55 mm) and with nickel titanium coil springs, 0.26 mm (range 0.00–0.83 mm; Table 1). There was no statistically significant difference between these two methods of space closure (P = 0.46). The relationship between the initial force applied and the rate of space closure was also investigated (Figure 6). The wide scatter demonstrates no relationship between the two parameters.

Discussion

The clinical performance of elastomeric chain was found to be better than anticipated. The degree of force retention

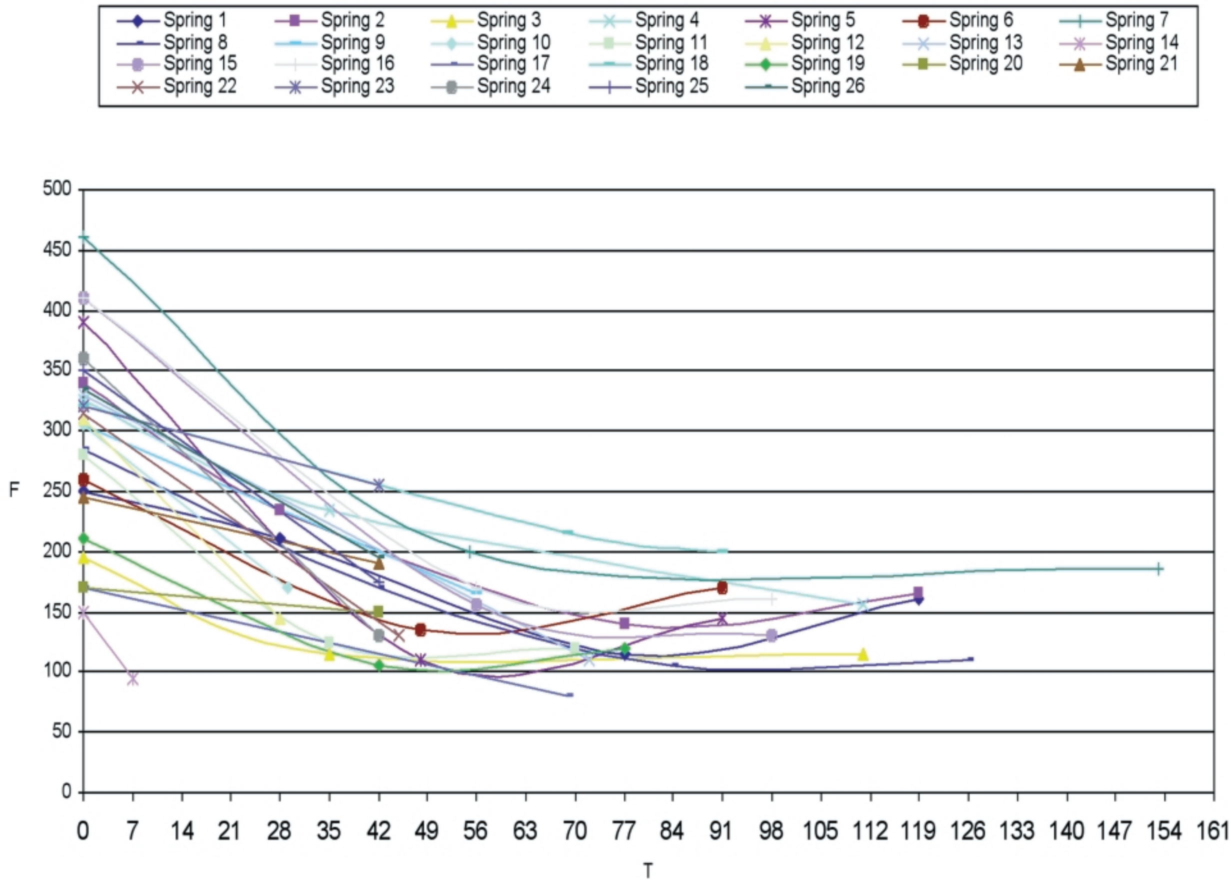

Fig. 4 Force in grammes (F) remaining in nickel titanium coil springs over time in days (T).

was very acceptable over a long period of time and the rate of space closure achieved was similar to that with nickel titanium coil springs. Interestingly, high initial forces did not achieve greater space closure, but resulted in greater percentage force decay.

How long does the force last?

The patients were asked to return every 4–6 weeks for routine adjustments. However, some failed to return until much later, which provided useful information about the activity of elastomeric chain over longer periods of time, which would have been ethically unacceptable if this had been planned. Elastomeric chain provided acceptable levels of force for substantial periods of time, challenging the view that it rapidly loses all of its force. In fact, all the samples retained some residual force at each visit and the elastomeric chain *in situ* for 15 weeks had 53 per cent of initial force remaining. The *in vivo* mean force loss of 47 per cent compared well with a mean force loss of 45.6 per cent found *in vitro* by Killiany and Duplessis, (1986),[2] despite the view that elastomeric chain in the oral environment would be less force retentive than that in a laboratory. The nickel titanium coil springs also performed well over a time period of up to 22 weeks. This is encouraging, as it suggests that the clinical practice of using the same nickel titanium coil springs over several visits is sound.

Nickel titanium coil springs do not provide a low, constant force

The nickel titanium coil springs gave variable forces, even when stretched the same distance, and so do not appear to provide a predictable force. This is an unexpected finding as nickel titanium has traditionally been considered to be more reliable in its behaviour than elastomeric chain. Certainly, the high initial forces suggest the superelastic plateau (Figure 4) was exceeded for some of the sample, which would explain why it took 6 weeks before the plateau of constant force delivery was witnessed.

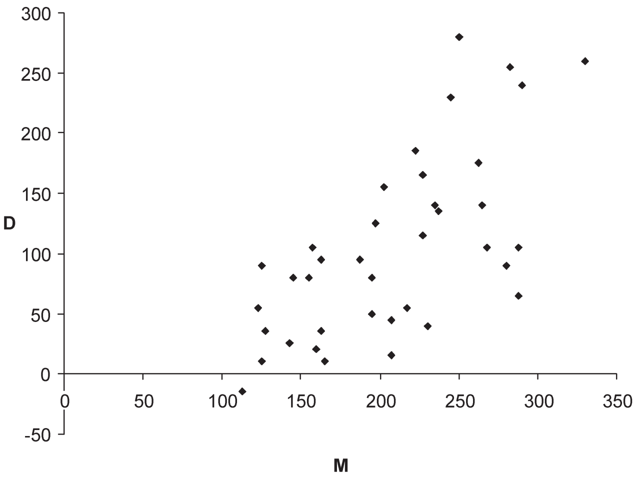

Fig. 5 Force with nickel titanium coil springs in grammes: the difference between the initial and final forces (D) versus the mean of the two forces (M; T1–T2).

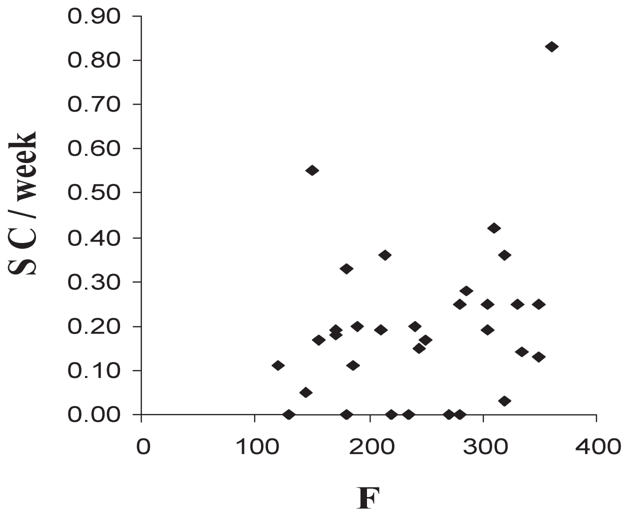

Fig. 6 The relationship between the initial force in grammes (F) and the mean weekly space closure in mm (SC/week).

Table 1 Mean weekly and monthly rates of space closure for elastomeric chain and nickel titanium coil springs

	Elastomeric chain (mm)	Nickel titanium coil springs (mm)
Mean weekly rate (SD)	0.21 (0.13) Range 0.00–0.55	0.26 (0.20) Range 0.00–0.83
Mean monthly rate (SD)	0.84 (0.52)	1.04 (0.80)

How much force is clinically necessary?

It is not known exactly how much force is required to move teeth. Indeed, clinicians apply a wide range of forces for space closure[20] and there is no evidence of an optimal force level in the orthodontic literature.[21] Quinn and Yoshikawa (1985)[22] suggested that 100–200 g is optimal for canine retraction and the residual force provided by nickel titanium coil springs during the plateau period of force delivery after 6 weeks fell into this range. Elastomeric chain provided residual forces lower than this, mostly between 50 and 150 g, yet space closure continued successfully. The initial forces applied were generally outside this range, especially with nickel titanium coil springs. It is surprising that no apparent relationship was demonstrated between the initial force placed and the space closure achieved. This may reflect the small sample size but is more likely to indicate the wide range of individual response to orthodontic forces. One patient achieved no space closure at all over a period of 10 weeks, despite a range of forces (135–270 g) being applied.

Nickel titanium coil springs and elastomeric chain close space at a similar rate

The rate of space closure of the two systems was very similar, which is comparable to findings by Dixon *et al.* (2002),[13] who, in a larger sample of patients, found mean monthly (4 weeks) rates of space closure to be 0.58 mm for elastomeric chain and 0.81 mm for nickel titanium coil springs. This compares with rates of 0.84 and 1.04 mm, respectively, in this current study. Whilst this difference was not statistically significant this may be considered clinically significant when large spaces are to be closed. Theoretically, a 10-mm space (remaining after the loss of a first molar) would take 47.6 weeks for closure with elastomeric chain, but 38.8 weeks with nickel titanium coil springs.

Method issues

Force loss is due to both the inherent properties of the force delivery system and the decreasing stretch placed upon it as the extraction space closes. For clinical effectiveness it is necessary for a system to deliver sufficient force to move teeth throughout its period of use and the composite final force is most relevant. Due to the many variables in this study (differing inter-hook distances, lengths of time between appointments, oral environment) it is not feasible to draw absolute comparisons between the two force delivery systems with respect to force retention. Instead, this study aims to describe how the two perform in a normal clinical environment.

Sample size

The modest sample size in this study reflected the availability of patients from the single operator (CN) and was further influenced by the exclusion of patients using inter-maxillary elastics from the study. The conclusion of Dixon *et al*. (2002)[13] that inter-maxillary traction had no effect on the rate of space closure, suggests that these inclusion criteria may not have needed to be so rigid. A power calculation on the sample size gave a result of 0.45, i.e. there was only a 45 per cent chance of having a statistically significant result. To increase the power of the study to 0.85, 100 samples of both elastomeric chain and nickel titanium coil springs would have needed to be tested.

Fixed hooks

Two fixed hooks were required for clear identification of the extension of the force delivery system. This was essential to measure the force generated. Therefore it was not possible to use nickel titanium coil springs attached to a ligature or to control the force delivery from the springs in the manner described by Manhartsberger and Seldenbrusch (1996).[15] Hence, this reduced the sample size further.

Split mouth design

Whilst it might be anticipated the archwires may swivel asymmetrically under the influence of differing forces from the two force delivery systems, this was not identified as a problem in this study.

Space closure

The complete space closure in four quadrants was considered a potential problem as it was not known when space closure occurred, although it had happened within one visit (4–6 weeks). However, recalculation of the mean space closure excluding these quadrants did not alter the results and these quadrants have remained in the sample. The investigation of rate of space closure was incorporated latterly into the study, hence only patients recruited later on had study models taken, which may skew the results. Therefore, the data should be interpreted cautiously, but it is still comparable to the results of previous studies.

The purpose of this study was to describe the performance of elastomeric chain and nickel titanium coil springs in typical clinical use, hence, the study design was not rigid with respect to initial forces applied or the time period over which the space closure system was used. Nevertheless, useful information has been summated which may be helpful for future understanding of the role of forces within orthodontics and the selection of force delivery systems for use in sliding mechanics.

Conclusions

1. A greater percentage of initial force was retained in clinical use by elastomeric chain than previously concluded.
2. Elastomeric chain remained active for substantial periods and patients did not need to return every 4 weeks simply to change it.
3. In this study, nickel titanium coil springs did not exert a continuous force until used for at least 6 weeks, suggesting that the initial force application overcame the super-elastic property of these springs.
4. Nickel titanium coil springs can exert very heavy forces when stretched directly between fixed hooks, therefore consideration should be given to attaching them via stainless steel ligatures at less stretch, or use longer springs.
5. Heavy forces resulted in high force decay. Hence, it is not appropriate to apply heavy forces in an attempt to counter the effects of force decay.
6. There was no relationship found between the initial force applied and the amount of space closure achieved.
7. The rates of space closure achieved with elastomeric chain and nickel titanium coil springs were similar.

Acknowledgements

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Contributors

Claire Nightingale originated the idea, was responsible for study design, data collection and interpretation and writing up. She is also the guarantor for the study. Steve Jones helped interpret the results and the writing of the paper. Fiona Read provided statistical support and analysis.

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