SCIENTIFIC SECTION

Magnitude and reproducibility of forces generated by clinicians during laceback placement

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Objective: To determine the magnitude and reproducibility of forces generated by clinicians during laceback placement using a force-measuring typodont.

Setting: An *in vitro* investigation.

Materials and methods: An *in vitro* typodont model was developed, which incorporated strain gauges attached to a personal computer to allow measurement of the force generated on application of lacebacks. Ten operators were instructed to place lacebacks five times, on two separate occasions (T1 and T2). Inter-operator and intra-operator forces produced at T1 and T2 were compared.

Main outcome measures: Forces generated by laceback placement.

Results: The forces generated by clinicians ranged from 0 to 11.1 N. There were significant differences in the mean forces generated by the different operators ($P<0.001$), with differences between time points not being consistent across all operators ($P<0.001$). Some operators were more consistent than others in the forces generated.

Conclusion: In vitro, there was a large inter-operator variation in the forces produced during laceback placement. With the *in vitro* model used in this study, few operators applied similar forces when placing lacebacks on two separate occasions.

Key words: Lacebacks, force magnitude, typodont

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Introduction

With pre-adjusted edgewise fixed appliance systems, the characteristics of final tooth positions are programmed into the appliance components. In certain circumstances, this can be a disadvantage. When the canine is initially distally angulated, overbite control can be compromized and centre line displacement may result during the aligning and levelling phase of treatment.[1] These problems may be overcome by partial bonding of anterior teeth to allow the canine to upright without proclining the incisors[2] or by bonding the canine with the bracket designed for the same tooth in the opposite quadrant so that full expression of the canine tip is not effected by the arch wire.[3] Other means include the use of an alternative bracket system with less prescription inclination, for example, the MBT (3M Unitek, Monrovia, CA, USA) and the Tip-edge systems[4] or the use of lacebacks (tie backs).[5]

Lacebacks are figure-of-eight stainless steel ligatures that are tightened lightly between the canine and the most distally banded molar. Lacebacks have a role in bodily distal movement of a normally inclined canine to provide space for labial segment alignment. Their mode of action is believed to cause a slight distal tipping of the canine with compression of the periodontal ligament in the area of the alveolar crest in the direction of movement. This flexes an initial archwire and, as it returns to its original shape, the root apex moves distally as the canine is said to 'walk along the arch wire'. Masticatory forces are thought to be responsible for reactivating the laceback and so encouraging further distal movement of the canine crown.[2] This distal movement of the canine is said to provide some 6–7 mm of space over a 6-month period.[5] Lacebacks also have other functions, which include their use asymmetrically for centreline correction and protection of a flexible arch wire across an extraction site.[5]

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The use of 'light lacebacks' is advocated during pre-adjusted edgewise mechanics,[2] but no numerical force value has been assigned. A recent systematic review revealed that there was no optimum force magnitude for orthodontic tooth movement.[6]

In vitro, the reproducibility of placement of three types of force delivery systems by clinicians during space closure has been assessed.[7] Two types of elastomeric chain, a grey module on a stainless steel ligature and a nickel titanium closed coil spring were considered. 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. It appears that the forces generated by clinicians during laceback placement have not been assessed previously. The reproducibility of the force generated by clinicians on laceback placement has not been evaluated either.

Study design considerations

No previous *in vitro* study on force delivery systems for space closure[7] or canine retraction[8] could provide suitable information for a sample size calculation. These studies, however, can provide guidance for similar studies in relation to study design. Aspects to consider include the number and type of operators, the number of force applications by an individual operator at any one occasion, the number of occasions over which forces are applied and the time interval between occasions of recording. Eleven clinicians applied power chain for canine retraction to four sites on one occasion in a trial by Chung *et al*.[8] In a further trial, a greater number of clinicians were employed, half of whom had more than 4 years of orthodontic clinical practice and half of whom had less (included postgraduate students).[8] Various types of power chain were applied on one occasion by each clinician. In the study by Nattrass *et al.*,[7] 18 clinicians with a range of experience applied three force delivery systems once to a typodont on two occasions 2 months apart.

Study aim

The aim of this *in vitro* investigation was to determine the magnitude and reproducibility of the force generated by clinicians during laceback placement using a force-measuring typodont. The hypothesis under test was that there was no difference in the average magnitude or reproducibility of the force generated by clinicians during laceback placement using a force-measuring typodont.

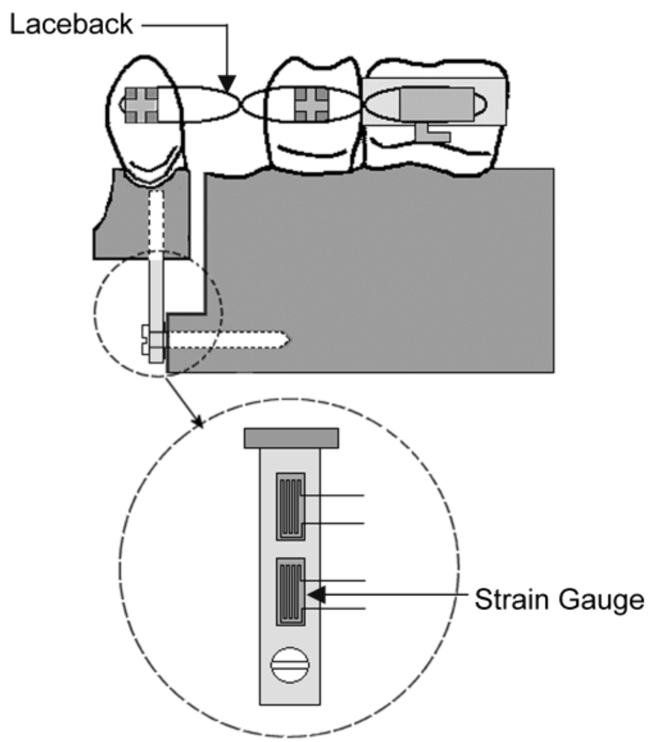

Figure 1 Diagrammatic representation of the experimental set up

Materials and methods

A study model of the lower dental arch, which exhibited distally angulated canines and moderate labial segment crowding, was selected from a university orthodontic departmental model box store. The proposed treatment plan, for the case selected, involved the extraction of both lower first premolars. A duplicate lower model was produced in self-cure acrylic resin (Orthoresin, Dentsply Ltd, Surrey, UK). The lower left first premolar and the lower left canine were removed from the acrylic model. The canine was sectioned from the model as an intact block and the premolar was ground flat to represent an extraction. The canine block was hollowed out and a rectangular stainless steel bar was inserted into the hole and secured with self-cure acrylic. Two strain gauges were attached, with epoxy resin (Araldite, Bostik Ltd, Leicester, UK), to the mesial and to the distal surfaces of the metal bar. The bar with the canine tooth block attached was then secured to the original acrylic model with a nut and bolt. The canine was in its original position but was surrounded by a space of approximately 3 mm (Figure 1).

A molar band (Roth prescription, 3M Unitek, Monrovia, CA, USA) was placed on the lower left first permanent molar and secured with a resin-modified glass ionomer cement (Fuji Ortho LC, GC Corp.

Tokyo, Japan). Pre-adjusted edgewise brackets (Roth prescription, 3M Unitek) were bonded to the lower left second premolar and lower left canine with self-curing acrylic resin. Bracket positioning was as recommended for a pre-adjusted edgewise system. The acrylic model was then secured in a vice.

Ten clinicians, five consultant orthodontists and five specialist registrars (SpR), participated in the study. The specialist registrars were within six months of completion of their 3-year training programme. The consultant orthodontists had been in post for at least 5 years.

For the present study, the number of consultant grade staff was matched with the number of SpR grade staff who were in the final stages of their training. Therefore, 10 clinicians were recruited, with five in each of the two grades. This compares favourably with the 11 clinicians used by Chung *et al.*[8] to assess forces employed for canine retraction. The sample size employed in the current study resembles closely that used in previous similar studies, which are alluded to under 'Study Design Considerations' in the Introduction.

In the investigation reported here, each clinician was asked to place and tighten a pre-formed 0.09-inch stainless steel ligature laceback (3M Unitek) on the acrylic model, from the lower left first permanent molar to the lower left canine, in the manner usually adopted clinically. Each laceback was tightened using a new Spencer–Wells clip. All clinicians were right-handed. At the final turn of the laceback, the Spencer–Wells clips were removed and the protruding section of ligature wire was shortened with ligature cutters. Data were captured from this time point for 30 seconds. Then the laceback was removed and data were collected for a further 30 seconds. This was to determine the 'unload' value, which was then substracted from the 'loaded' value to give the 'actual' laceback value. This procedure was necessary since the baseline reading recorded was not zero. The entire procedure was repeated five times consecutively for each operator (T1), taking about 30 minutes in total. The experiment was then repeated 6 months later (T2). Therefore, in total, 100 lacebacks were placed.

The change in resistance produced by the four strain gauges on laceback placement/removal was detected through a data acquisition board and interpreted by software (DataScan, Wellingborough, UK) on a personal computer (Elonex, London, UK). The data were stored, exported as an ASCII file and then imported into Excel (Excel 2000, Microsoft Corporation, Redmond, WA, USA) for analysis.

The strain gauge was calibrated between each operator by turning the typodont through 90° to allow weights to hang freely from the canine bracket. A series of weights 50, 100, 200, 400, 800 and 1000 g were hung from the canine bracket and the change in resistance of the strain gauge was recorded as for each clinician. These data were also stored, exported as an ASCII file and then imported into an Excel 2000 (Microsoft Corporation, Redmond, WA, USA) spreadsheet for analysis.

Statistical analysis

Data were exported from Excel to Minitab Version 13 (Minitab Inc., Pennsylvania, USA) for statistical analyses. Repeated measures analysis of variance was used to determine whether there were significant effects of operator, group [consultant (operators 1–5) or SpR (operators 6–10)], time point and attempt on the mean force generated, with group, time point and attempt modelled as fixed effects and operator modelled as a random effect. The intra-operator variability was examined via the coefficients of variation[9] (standard deviation/mean) for each operator at each time point and also by determining the within operator standard deviation pooled across the two time points. The inter-operator reproducibility was estimated using the inter-class correlation coefficient, which was determined using the components of variance method, with the components in turn being estimated through the repeated measures analysis of variance. This estimated how much of the total variability was accounted for by the variability between operators.

Results

Table 1 contains the mean, standard deviation, range and coefficient of variation of the forces generated by each operator at each time point. These descriptive statistics clearly show the large variability in forces generated, both within and between operators.

Initial plots of the raw data indicated that the variability across operators was not consistent. Figure 2 contains boxplots of the raw force data by both operator and time point. From these plots it is clear that there is much variability, both within a given operator and between operators. For some operators there are differences between time points (e.g. operator 10), but other operators are relatively consistent across time points (e.g. operator 9). Operators 5 and 6 both generated lower forces, in general, than the other operators.

The repeated measures analysis of variance indicated that there was no significant effect of group, i.e. there were no statistically significant differences, on average, between the consultant and SpR groups, either as a

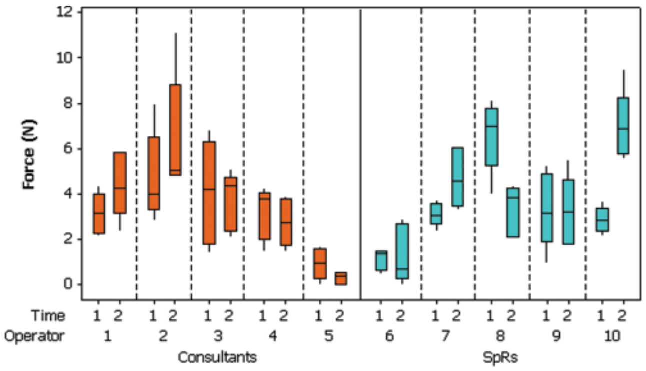

Figure 2 Boxplots of forces generated by each operator at each time point labelled by operator and group. The ends of the box correspond to the upper and lower quartiles of the data; the line in the box represents the median value; and the end of the whiskers correspond to the maximum and minimum values

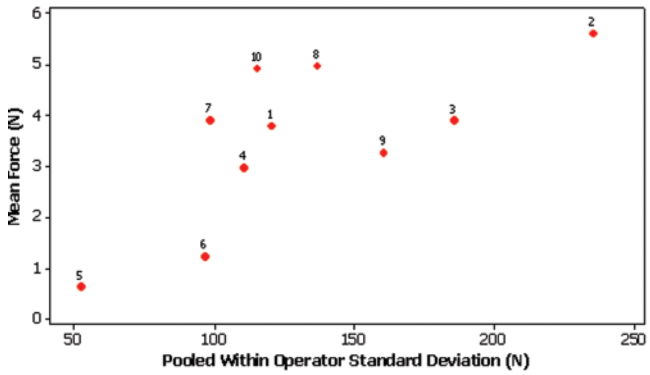

Figure 3 Plot of mean force generated vs. within operator standard deviation; labelled by operator

main effect (P=0.799) or in combination with any of the other factors (all P>0.1), on the force generated. After removing the group factor, there was a statistically significant interaction effect of operator and time point (P<0.001). This was, in part, due to the difference between time points not being consistent across all operators and also the variability across operators not being consistent. The only significant main effect was the operator effect (P<0.001; time effect: P=0.212; attempt effect: P=0.307). Using the statistical model generated, an approximate prediction interval for the force generated by a randomly selected operator is (0.0, 8.0) N.

Using the components of variance method, the inter-operator reproducibility (interclass correlation coefficient) was estimated to be 45% i.e. the variability between operators only accounted for approximately 45% of the total variance.

Figure 3 illustrates the mean force across all 10 attempts for each operator against the within operator standard deviation, pooled across the two time points. This pooled within operator standard deviation gives a further indication of the intra-operator reliability of that individual. The plot clearly illustrates that as the within operator variability increases so too does the mean force. The plot also shows no obvious pattern between the groups of operators (consultants and SpRs).

Discussion

Within the limitations of this study, it has been shown that using an *in vitro* typodont model, clinicians vary widely in the magnitude of force generated on application of a laceback ligature. It was also demonstrated that it is very difficult to predict, with any precision, the likely force to be generated on laceback application for a randomly chosen operator. Few previous studies have addressed laceback placement by clinicians. A prospective study involving 57 extraction cases, half treated with lacebacks and half without, found that in the group treated with lacebacks, the lower incisors proclined less during treatment.[10] Randomized clinical trials have

Table 1 Mean (SD) and range values in N for each operator at each time point.

		Time 1				Time 2			
Group	Operator	Mean	SD	Range	Coeff of variation (%)	Mean	SD	Range	Coeff of variation (%)
Consultant	1	3.13	0.90	2.17–4.38	28.7	4.46	1.45	2.36–5.82	32.4
Consultant	2	4.74	1.97	2.86–7.96	41.6	6.48	2.68	4.77–11.10	41.3
Consultant	3	4.08	2.29	1.44–6.82	56.2	3.72	1.28	2.13–5.12	34.4
Consultant	4	3.18	1.17	1.46–4.27	36.6	2.74	1.04	1.49–3.91	38.0
Consultant	5	0.95	0.69	0–1.67	72.4	0.30	0.27	0–5.5	90.2
SpR	6	1.13	0.45	0.48–1.54	40.1	1.33	1.29	0–2.91	97.2
SpR	7	3.10	0.52	2.36–3.76	16.7	4.72	1.30	3.33–6.11	27.5
SpR	8	6.59	1.58	3.98–8.15	24.0	3.33	1.11	2.08–4.35	33.3
SpR	9	3.34	1.66	0.96–5.24	49.6	3.19	1.55	1.73–5.50	48.4
SpR	10	2.86	0.57	2.14–3.68	20.0	6.99	1.53	5.59–9.52	21.9

compared the effectiveness of canine lacebacks in the upper[11] or lower[12] arch. Upper incisor proclination of the order of 1 mm was prevented by lacebacks and their effect on mesial molar movement was insignificant.[11] In contrast, in first premolar extraction cases, the use of laceback ligatures did not convey any difference in anteroposterior or vertical position of the lower labial segment, but led to a statistically and clinically significant increase in the loss of posterior anchorage.[12] Several operators were involved in the upper arch lacebacks trial[11] and the force generated by the clinicians in tying the lacebacks was not determined. The authors state that at each appointment the lacebacks were adjusted so that there was 'enough' tension in the ligature wires, but the lacebacks were passive. The possible large variation in forces generated by clinicians during laceback placement was not addressed. Only one operator took part in the lower arch lacebacks trial and again the operator's variability in force application was not accounted for.[12]

The force magnitude used by clinicians for canine retraction has been assessed.[8] Clinicians were asked to apply elastomeric chain to a typodont in which the distance between the canine and molar bracket was 28 mm. The specimens of chain were then removed and re-stretched, to 28 mm, on an Instron Universal Testing Machine and the resultant force measured. The results showed there was a large variation in forces generated by each clinician ranging from 1.22 to 3.04 N.

The force measurements recorded in this study on application of lacebacks ranged from 0 to 11.1 N. Nattrass *et al.*[7] found the forces generated for space closure, using three different force delivery systems, to range from 0.44 to 3.54 N. The smaller range in forces reported in that study compared to those recorded here may have been because the clinicians chose the same number of links of power chain and stretched the elastomeric to the same extent to generate a force for space closure. During laceback placement, it is not possible for a clinician to use any methods to determine the force by which the laceback is tightened. Some clinicians may wish to leave the laceback 'passive' which explains why a force of 0 N was recorded for two operators in the present study, but others may deem a greater force to be 'necessary'. There is little immediate feedback from the patient regarding the force generated by a laceback, since any discomfort will arise some time later and may be compounded by the forces created by an accompanying arch wire change. The large inter-operator variation in force application by lacebacks found in this study is similar to that recorded by Nattrass *et al.*[7] for application of space-closing mechanics.

As the study reported here was conducted *in vitro*, interpreting the significance of the findings from a clinical viewpoint is difficult. This is because the effects of the reported force levels on the canine or on the adjacent anchor teeth (second premolar and first permanent molar) will also depend particularly on occlusal and archwire factors, which were not evaluated here. One of the proposed mechanisms by which lacebacks exert their effect is by ensuring that the forces generated by archwire deflection act so as to distalize the canine root rather than allowing the canine crown to move mesially.[1,2] It is possible that the forces exerted on the canine crown by the deflected archwire in the early stages of treatment may act against those produced by the lacebacks. Furthermore, the resistance to canine crown movement as a result of periodontal and archwire forces may influence the force levels applied by clinicians during laceback placement. As the archwire forces may vary depending on the size of deflection and the type of archwire, these factors may be of differing importance depending on the stage of treatment.

Few operators in the study (consultant 4 and SpR 9) appeared to be reasonably consistent in the forces they applied with laceback ligatures across the two occasions. This contrasts with the findings of a study investigating intra-operator reproducibility of different force delivery systems.[7] A wide range of forces, however, was applied among the 18 operators in that study. In our study, the large inter-operator variation produced during laceback placement may be due in part to the figure-of-eight type configuration, above and below the brackets, which was adopted before tightening. This may have made it difficult for the operator to gauge forces applied when tightening as opposed to when a straight length of power chain or coil spring, run parallel to or along the arch, is used for space closure.

Three operators in the study reported here generated maximum forces between 8.15 and 11.1 N during laceback placement, which in the clinical situation, would probably impose strain on anchorage units. Anchorage loss in the lower arch has been described with laceback ligatures.[12] In the interest of clinical outcome, it would be worthwhile to be cautious when placing and 'tightening' lacebacks in order to avoid generating heavy forces, particularly during the early stages of treatment.

Apart from the *in vitro* nature of the study reported here, there are a number of other factors that should be borne in mind with regard to interpretation of the findings. There were only a modest number of recordings (five) made per operator on each of two occasions. This is similar to the number of recordings (three), each with a different space closure system, which were made by each operator on two occasions in an investigation of orthodontic space closure mechanics.[7] It is acknowledged that in the present investigation, a greater number of recordings may have facilitated further statistical handling of the data. Given there were only five measurements per operator at each time point, it is difficult to determine robust estimates of, e.g. the variability within and between operators, and this should be borne in mind when interpreting the results. Furthermore, the non-statistically significant differences determined, e.g. between groups, could possibly be attributed to the modest sample size. Employing a greater number of operators at consultant and SpR grade may have identified more meaningful indicators with respect to the effect of level of operator experience on force generated on laceback application. Repeating the test procedure on more than two occasions would also help to identify if reproducibility increases with further exposure to the procedure.

Conclusions

- *In vitro*, there was a large inter-operator variation in the forces produced during laceback placement.
- With the *in vitro* model used in this study, few operators applied similar forces when placing lacebacks on two separate occasions.

Contributors

Balvinder Khambay was responsible for study design, data collection, drafting and final approval of the article. Declan Millett gave advice on study design and data analysis, and was responsible for drafting, critical revision and final approval of the article. Siobhan McHugh undertook data analyses. Balvinder Khambay is the guarantor.

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