SCIENTIFIC SECTION

An *ex vivo* laboratory study to determine the static frictional resistance of a variable ligation orthodontic bracket system

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Objective: To determine the effects of static frictional resistance on varying the ligation technique in a Delta Force bracket system (Ortho Organizers Ltd, Hampton, UK) and using increasing degrees of bracket/archwire angulation to simulate binding.

Design: An *ex vivo* laboratory investigation using the Instron Universal Testing Machine (Instron Ltd, High Wycombe, UK) to generate sliding forces on an archwire through the Delta Force bracket. The system was lubricated with Saliva Orthana artificial saliva (Nycomed Ltd, Buckinghamshire, UK).

Setting: Biomaterials Laboratory, Eastman Dental Institute, London, UK.

Materials and method: Ninety Delta Force brackets were tested against 0.018-inch stainless steel wire. Three modes of ligation were tested with three different angulations: 0, 5 and 10° to simulate increasing levels of binding.

Results: The average static frictional resistance went from 0.20 N, at 0° angulation and minimum ligation, to 2.37 N with 10° angulation and maximum ligation. Results revealed that the ligation pattern was found to be highly statistically significant ($P<0.001$) in influencing frictional force. The binding angle showed a trend of increasing frictional force with increasing bracket/archwire angulation. Repeatability testing showed no evidence of bias ($P=0.171$).

Conclusions: These results suggest that the Delta Force variable ligation system does in fact enable friction to be varied, which may have implications in clinical application.

Key words: Variable ligation brackets, static frictional resistance, Delta Force brackets

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Introduction and literature review

Orthodontic tooth movement requiring sliding mechanics is achieved by encouraging brackets to slide in relation to the archwire. Wherever sliding occurs frictional resistance is encountered. Studies have shown that the proportion of applied force which may be lost due to resistance to sliding can range from 12 to 60%.[1,2] Frictional resistance is influenced by many different factors. The force pressing the wire and the bracket surfaces together is determined by the angulation between the archwire and the bracket slot, the size of the archwire and the method of ligation.[3] Drescher *et al.*[1] also identified biological resistance, surface roughness of the wire, and elastic properties as contributing factors in frictional resistance.

Various material compositions and properties, bracket designs and ligation methods have been investigated in an attempt to reduce friction within fixed appliances. Frictional resistance to sliding archwires against brackets can be reduced by modifying any or all of the major factors previously mentioned, but it cannot be totally eliminated. Stainless steel remains the gold standard for minimizing friction, both in archwire and bracket material and particularly in combination.[4]

Schumacher *et al.*[5] claimed that friction was determined mostly by the nature of ligation and not by the dimensions of the different archwires. The development of different ligation systems has brought new bracket designs onto the market. Self-ligating systems have gained popularity recently for their claims of reduced friction, shortened treatment time and chairside time

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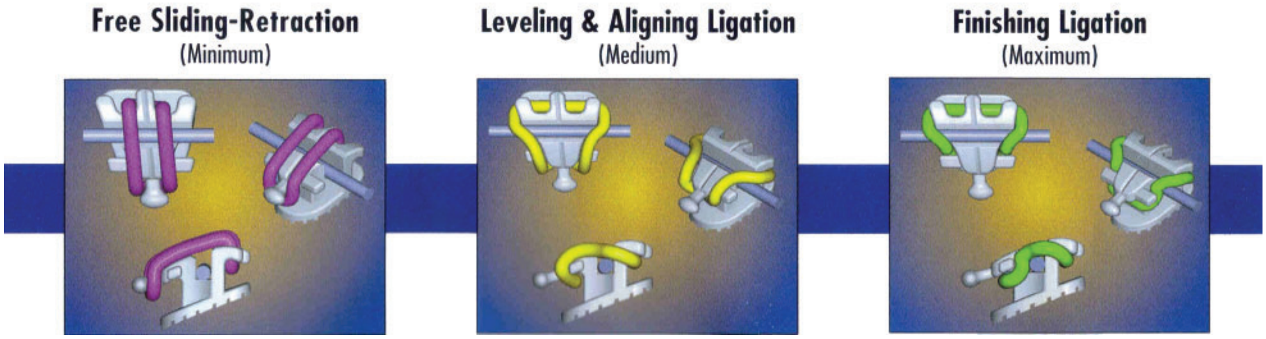

Figure 1 Variable ligation of the Delta Force bracket. Reproduced from: Ortho Organizers Inc. promotional material (2003), by permission of Precision Orthodontics

when compared with conventional bracket systems. Low friction has been clearly demonstrated and quantified in work by various authors.[6–10] However, several studies found this was only the case under certain conditions, and increasing the dimension of the wire and binding, as is the case at the stage of space closure, increased the frictional resistance.[11,12] The disadvantage of currently available self-ligating brackets is the expense.

The aims of this study were:

- To compare the static frictional resistances in each of the three modes of ligation possible with the Delta Force bracket.
- To test resistance to sliding at 0, 5 and 10° of bracket/archwire angulation to simulate increasing levels of bracket binding.

The null hypotheses (H_o) for this study stated that:

- Varying the ligation technique has no effect on the static frictional resistance.
- Increasing the bracket/archwire binding does not affect frictional resistance.

Materials and method

Delta Force (Ortho Organizers Ltd, Hampton, UK) is a variable ligation bracket system that claims to give the orthodontist the ability to control friction between archwire, bracket and elastic ligature (Figure 1). The Delta Force bracket is manufactured from 17-4PH, a cobalt–chromium alloy composition formulated to be substantially nickel-free and is manufactured using a metal injection moulding process and offers corrosion resistance comparable to grade AISI 304L stainless steel. Features of the Delta Force bracket are:

- Dimensions: 0.022 × 0.028-inch bracket.
- Multiple tie-wings to allow variable ligation and extended wings to support ligature ties.

Delta Force upper left central incisor brackets were used in this investigation because of their flat base, which facilitated mounting in the testing jig. The brackets were degreased by soaking in acetone for 24 hours before air drying and archwires were cleaned by wiping with acetone prior to testing. The bracket was then mounted onto a custom-made jig assembly and ligated, with an elastomeric module, onto a 7-inch length of 0.018-inch stainless steel archwire in one of the pre-determined modes. The ligation mode was decided by rolling an unweighted die to eliminate testing bias. Modules were placed in the desired mode using a pair of mosquito forceps. In order to maintain the wire as a straight length, a standard tensile force was applied to the wire using a 1 kg weight before tightening the wire between the turrets of the jig. A new piece of 7-inch archwire was used for each test and the system was lubricated prior to running each test by applying Saliva Orthana artificial saliva (Nycomed Ltd, Buckinghamshire, UK) to the bracket, archwire and elastomeric module assembly with a soft brush. Rectangular stainless steel archwires were not used in testing to eliminate the effect of torque on the system.

Testing was performed on an Instron Universal Testing machine (Instron Ltd, High Wycombe, UK) with a steady crosshead speed of 0.5 mm/min over a 1 mm section of archwire. Care was taken to align the archwire parallel with the vertical framework (0° binding) or to angle the jig to 5 or 10°, using a simple protractor, to simulate increasing levels of binding. The Instron was self-zeroing and self-calibrating, and was balanced prior to each test. Force levels were automatically sampled by the computer 25 times per second.

The Instron produced a steady movement of the jig (see Figures 2 and 3), sliding the bracket along the wire. The force required to initiate and maintain movement of the bracket over the 1 mm test distance was measured and recorded. The magnitude of resistance to movement

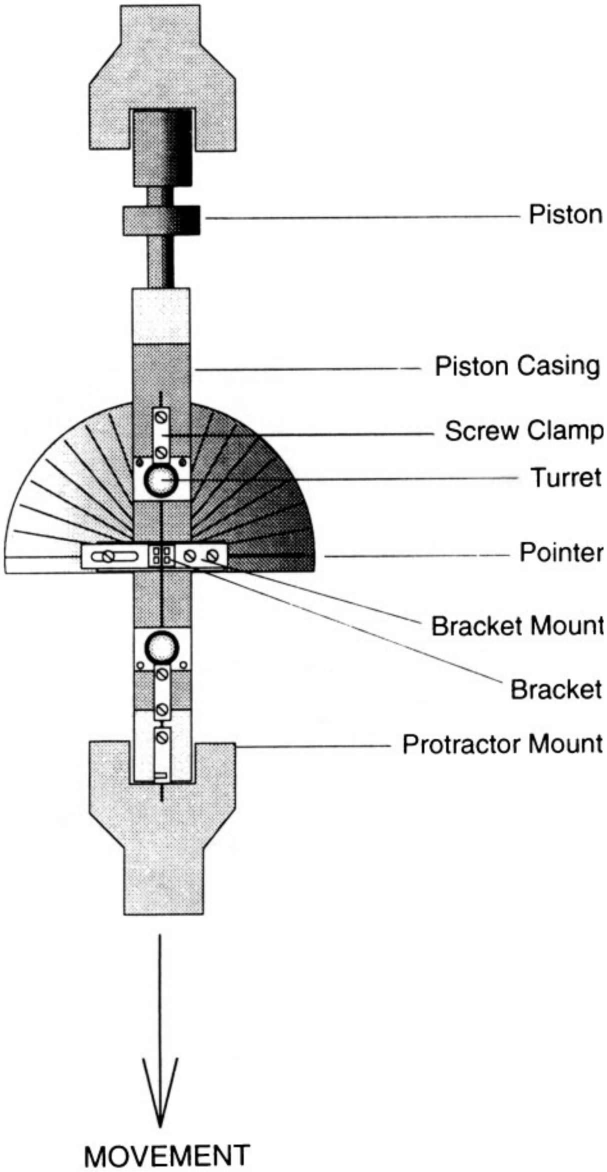

Figure 2 Anterior view of testing apparatus. Reproduced from: Read-Ward *et al.*[11]

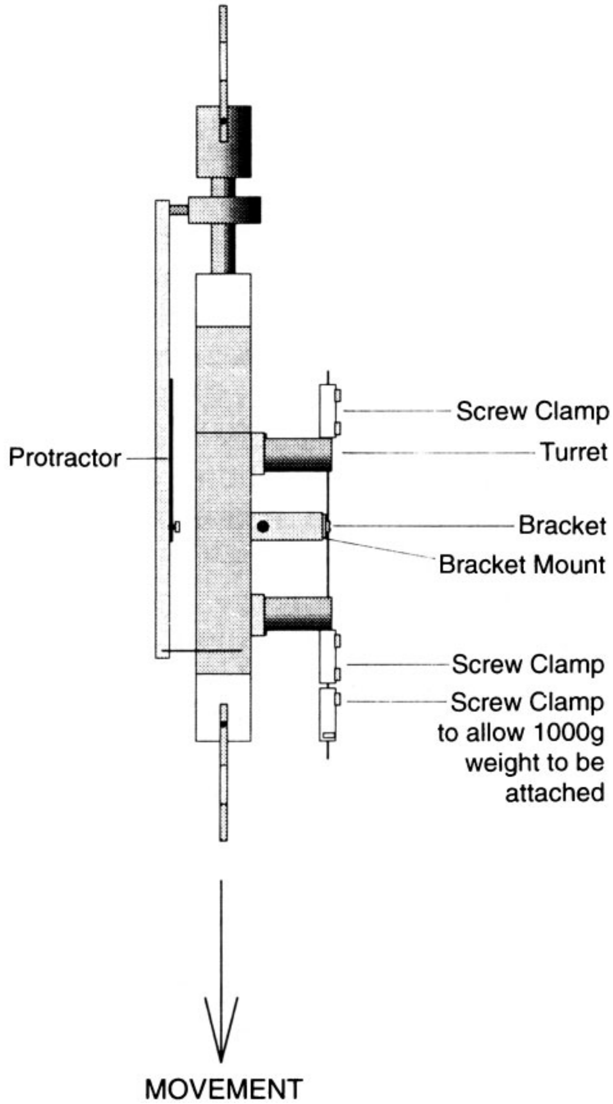

Figure 3 Lateral view of testing apparatus. Reproduced from: Read-Ward *et al.*[11]

of the archwire through the bracket was recorded in the form of a force/displacement curve with the maximum frictional resistance highlighted. Each mode of ligation was measured at three different degrees of bracket/archwire binding. A total of nine combinations were drawn from these variables.

A sample size calculation was carried out using data from previous work[13] to determine the numbers of samples required using Altman's nomogram.[14] Edwards *et al.*[13] tested a stainless steel archwire in a stainless steel bracket with modules in place. They determined a mean static frictional resistance of 1.118 N with a standard deviation (SD) of 0.118. It was initially estimated that a difference of 10% would be clinically relevant and this was taken as the postulated true difference, i.e. 0.1118 N.

$$\text{Standard difference} = \frac{\text{Postulated true difference}}{\text{Estimated standard deviation}} = \frac{0.1118}{0.118} = 0.947$$

At a power of 90% and significance level of 0.05 this indicated a sample size of almost 50 brackets in each group. However, it was not feasible to carry out this number of tests. Consequently a 20% clinically relevant difference was chosen. This give a standardized difference of 1.89 and a sample size of 10 brackets in each

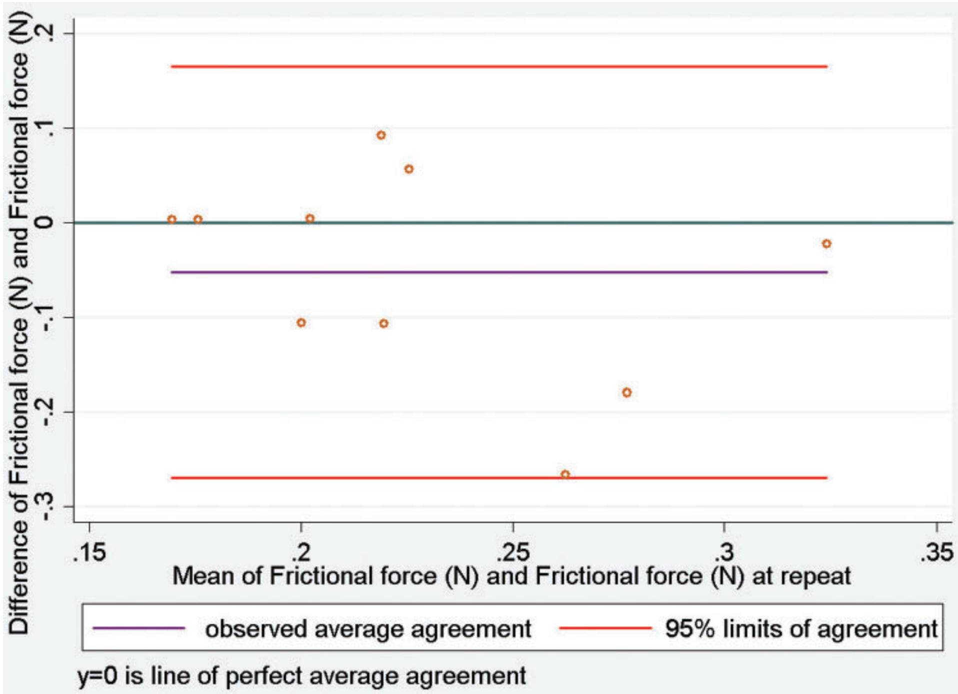

Figure 4 Limits of agreement

group at each method of binding and degree of angulation (alpha=0.05; beta=0.85) – giving a total of 90 brackets tested and 10 brackets were retested for repeatability.

Ten per cent of the sample was used in repeatability testing. A single repeat test was carried out on the ten brackets which were tested at 0° angulation and minimum ligation. Brackets were labelled so the two tests could be compared for each of the specified brackets. Brackets were numbered and repeatability testing was carried out on a separate occasion. Results were plotted on a Bland–Altman plot (Figure 4) and demonstrated no bias between first and second tests (P=0.171).

Analysis of the data was performed using the SPSS package (SPSS for Windows, Release 11.0.1.2001, SPSS Inc., Chicago, IL, USA). Analysis involved:

- Two-sample t-test for inter-group examination.
- A two-way analysis of variance (ANOVA) to test for effects of the two factors separately and together (their interaction).
- Assessment of reliability using the Bland–Altman method.[15]

Results

The data were entered into SPSS. When seen visually as a box-and-whisker plot, the increase in frictional force can be seen to correlate with change in module ligation and increasing bracket/archwire angulation. Figure 5 illustrates the median, the interquartile range and the range that contains the central 95% of the observations (reference range) for each of the nine sets of tests

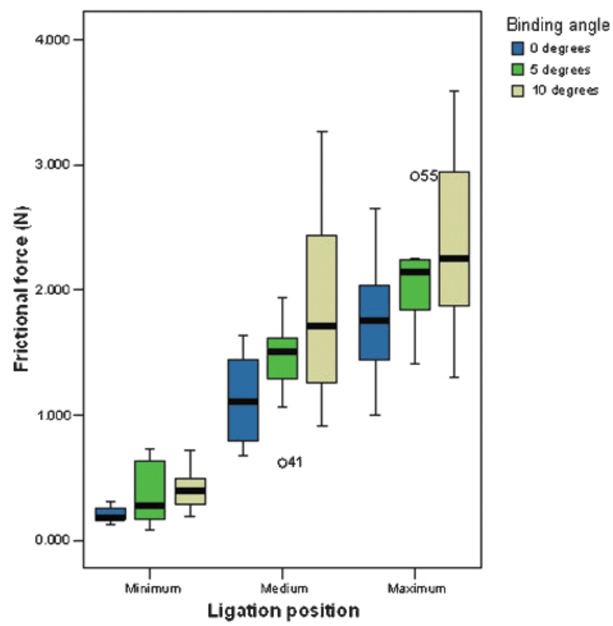

Figure 5 Box-and-whisker plot of static frictional resistance for the different positions of ligation and different degrees of binding

undertaken. The plot shows a normal distribution and parametric tests were therefore carried out to investigate statistical difference between groups.

Table 1 gives the mean for each data set together with the confidence interval (CI), SD and standard error of the mean (SEM) for the group. All data are corrected to two decimal places. The table shows a clear trend of increasing mean frictional resistance as the ligation method is varied from 'minimum' through 'medium' to 'maximum'. Similarly, there is an increase in friction with changing the degree of angulation. The SD is also seen to increase across the groups as the ligation method is changed, with the SD and 95% CI being generally higher for the maximum friction ligation. This correlates with the wider range of values obtained with this method of ligation. The minimum ligation shows the most consistent results, with the smaller SEM reported.

The reproducibility study showed no significant difference between first and second tests ($P=0.171$). Ninety-five per cent of the results are seen to be within 0.4 N difference of each other (twice the SD 0.22 N shown in the paired samples *t*-test). Agreement and repeatability was measured by the Bland–Altman method.[15] The mean of the two results has been plotted against the difference (Figure 4). Although the results show some outliers, the spread is narrow and close to zero, indicating good repeatability.

Tests of between-subjects effects

The analysis of variance (ANOVA) tests the effect of the variables and their interactions. R-squared value was calculated as 0.753, indicating how much of variation between samples can be explained by the parameter, i.e. how predictive the model is. The result indicates that 75% of variation between the samples can be explained by knowledge of the angle and binding method, and 25% is down to chance. This shows a very high predictive possibility.

Influence of ligation on frictional resistance

Table 2 shows the mean increase in frictional resistance with the different ligation patterns:

- Minimum to medium ligation was shown to have an average 1.15 N increase in force.
- Minimum to maximum ligation showed an average 1.74 N increase in force.
- Medium to maximum ligation showed an average 0.58 N increase in force.

All three results proved to be highly statistically significant, with $P<0.001$.

Influence of binding on frictional resistance

Table 3 shows the mean increase in frictional resistance for the different binding angles:

- 0–5° showed an increase of 0.27 N, which was not statistically significant ($P=0.083$).
- 0–10° showed an increase of 0.54 N, which was statistically significant ($P<0.001$).
- 5–10° showed an increase of 0.27 N, which was not statistically significant ($P=0.074$).

Table 1 Descriptive statistics.

		Minimum ligation	Medium ligation	Maximum ligation
0° angulation	Number tested	10	10	10
	Mean frictional resistance (N)	0.20	1.13	1.74
	95% CI	0.16–0.24	0.91–1.34	1.43–2.04
	SD	0.06	0.34	0.49
	SEM	0.02	0.11	0.16
5° angulation	Number tested	10	10	10
	Mean frictional resistance (N)	0.36	1.43	2.07
	95% CI	0.21–0.50	1.20–1.66	1.82–2.33
	SD	0.23	0.37	0.41
	SEM	0.07	0.12	0.13
10° angulation	Number tested	10	10	10
	Mean frictional resistance (N)	0.42	1.88	2.37
	95% CI	0.32–0.52	1.38–2.39	1.94–2.81
	SD	0.17	0.81	0.69
	SEM	0.05	0.26	0.22

Table 2 Pairwise comparison of ligation.

Ligation position (I)	Ligation position (J)	Mean difference (J–I) (N)	Standard error (N)	*P*†	95% CI†	
					Lower	Upper
Minimum	Medium	1.15*	0.12	<0.001	−1.44	−0.86
Minimum	Maximum	1.74*	0.12	<0.001	−2.03	−1.45
Medium	Maximum	0.58*	0.12	<0.001	−0.87	−0.29

Based on estimated marginal means.
*The mean difference is significant at the 0.05 level.
†Adjustment for multiple comparisons: Bonferroni.

The difficulty with multiple significance testing is that it gives a high probability of giving a significant difference just by chance. One such test designed to combat such errors is the Bonferroni correction (Tables 2 and 3). It is a *post hoc* adjustment to the *P*-value to take account of the number of texts performed in multiple hypothesis testing situations.

Discussion

The findings of the study show that the ligation pattern was highly statistically significant in influencing frictional force of the Delta Force bracket. Three ligation patterns are possible with this bracket and these were compared.

Many factors influence the frictional resistance in any bracket/archwire system during sliding mechanics. This laboratory study was designed to attempt to standardize these factors, as far as possible, in order to study the effects of varying ligation within the system. The two variables studied were the ligation method and degree of bracket/archwire angulation (to simulate binding).

Increasing the bracket angulation resulted in increasing resistance to sliding. This was shown to be statistically significant between 0 and 10° of angulation. A trend was observed between 0 and 5° and 5 and 10°. The increase in frictional resistance has been attributed to increased notching and binding at higher angulations.

Taking into account the triangular shape of the bracket, and measuring the actual slot size and archwire diameter, the critical angle (θ_c) for binding as described by Kusy and Whitley[16] was calculated to be 3.203° for the Delta Force bracket with 0.018-inch wire. At 5 and 10° angulation the critical angle (θ_c) is exceeded, resulting in increased resistance to sliding, as a result of binding and notching of the archwire against the bracket.

The use of round 0.018-inch wire was chosen as it removed the influence of torque from the system. It therefore has to be remembered that the results may not be identical where rectangular wire is used for sliding mechanics. This may be considered to be a weakness of the study.

The simple study design looks at the mechanics of sliding and examines the influences of both ligation pattern and binding in a lubricated system. The results support the manufacturer's claim that the bracket enables friction to be varied and controlled by the orthodontist by the method of ligation. This has implications for clinical practice and can be usefully employed in different stages of treatment.

Conclusions

1. The method of ligation was shown to be a highly significant influence on the frictional resistance of

Table 3 Pairwise comparison of binding.

Binding angle (I)	Binding angle (J)	Mean difference Newtons (J–I) (N)	Standard error (N)	*P*†	95% CI for difference†	
					Lower	Upper
0°	5°	0.27	0.12	.083	−0.56	0.02
0°	10°	0.54*	0.12	<0.001	−0.83	−0.25
5°	10°	0.27	0.12	.074	−0.56	0.02

Based on estimated marginal means.
*The mean difference is significant at the 0.05 level.
†Adjustment for multiple comparisons: Bonferroni.

the Delta Force system. This supports the manufacturer's claims that friction can be varied by selecting an appropriate ligation mode.

2. Delta Force brackets produced a trend of increasing frictional resistance with increasing bracket/archwire angulations.
3. Interaction of the combined effect of the binding angle and ligation position was found to be not significant ($P=0.407$), i.e. each factor influences the frictional resistance in an independent way.

Hence, the null hypothesis is not supported.

Contributors

Miss Joanna Haskova was responsible for data collection, drafting, critical revision and final approval of the article. Mr Steven Jones was responsible for study design, critical revision and final approval of the article. Mr Graham Palmer was responsible for technical support and study design. Miss Haskova is the guarantor and, as such, accepts full responsibility for the study, has access to the data and controlled the decision to publish.

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