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An *Ex Vivo* Investigation into the Effect of Bracket Displacement on the Resistance to Sliding

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Abstract *This* ex vivo *study investigated the effect that repeated bracket displacement has on sliding friction and the magnitude of bracket displacement, and hence tooth movement, required to release bracket/archwire binding.*

The design consisted of an ex vivo *laboratory study. A jig was designed that allowed repeated displacement of a bracket o occur, while the resistance to sliding (friction) was measured using an Instron® universal testing machine. One type of stainless steel bracket was used in conjunction with four archwire types (0·016-inch stainless steel, 0·019 × 0·025-inch tainless steel, 0·021 × 0·025-inch stainless steel, 0·019 × 0·025-inch beta-titanium) and four magnitudes of displacement.*

Repeated bracket displacement has a significant effect on the sliding resistance at the bracket/archwire interface P < 0·001). The reduction in sliding resistance noted with displacement depended on the archwire. Over the range of displacements tested, there was an 85 and 80 per cent reduction associated with 0·021 × 0·025-inch and 0·019 × 0·025-inch tainless steel, respectively. For 0·019 × 0·025-inch beta-titanium and 0·016-inch stainless steel, these reductions were 27 and 9 per cent, respectively.

The importance of true friction, given the likelihood of bracket and/or archwire displacements in vivo, may be lessened.

ndex words: Bracket Displacement, Friction, Tooth Mobility.

ntroduction

Choice of force systems in orthodontics is influenced by an understanding of friction at the bracket/archwire interface. The selection of archwires, brackets, and ligation can all be nfluenced by some belief in friction. The interaction between bracket slot and archwire plays a most important part in how orthodontists set-up their force systems, anchorage demands, and space closure mechanics.

The literature has numerous studies related to bracket/archwire friction. Since 1970, there have been more than 70 articles reporting on friction, coefficients of friction, and he related mechanotherapy. All but three of these 70 tudies were *ex vivo* models with test fixtures that limited bracket movement and many of the conclusions from these tudies are in contradiction.

Friction is classically described as a force that retards or esists the relative motion of two objects in contact and its direction is tangential to the common boundary of the two urfaces in contact (Bowden and Tabor, 1974). The classical laws of friction state that a frictional force is proportional to the normal force component, independent of he area of contact and independent of the sliding velocity. For metals under normal conditions of use these laws are often reasonably accurate, although for other materials or or extreme conditions the laws break down.

Previous investigations into the frictional characteristics at the bracket/archwire interface have shown that the magnitude of the frictional force varies with certain mechanical or biological variables. Several mechanical variables have been investigated, such as: bracket material, bracket width, bracket/archwire angulation, bracket surface roughness, the number of brackets in series, wire material, wire shape and configuration, surface coatings and surface roughness, bracket/archwire clearance, inter-bracket distance, method and force of ligation, wear, sliding velocity, and vibration (Andreasen and Quevedo, 1970; Frank and Nikolai, 1980; Drescher *et al.*, 1989; Tidy, 1989; Kusy and Whitley, 1990a; Kusy *et al.*, 1990; Keith *et al.*, 1994; Sims *et al.*, 1993; Downing *et al.*, 1994; Tselepsis *et al.*, 1994). The biological variables suggested include saliva (Kusy *et al.*, 1991), plaque (Drescher *et al.*, 1989), acquired pellicle, corrosion, biological resistance (Drescher *et al.*, 1989), mastication, (Frank and Nikolai, 1980; Drescher *et al.*, 1989) bite force, and tooth mobility (Jost-Brinkmann and Miethke, 1991).

Most studies have investigated the mechanical variables using steady state *ex vivo* models, however, little agreement is forthcoming. Although several authors (Andreasen and Quevedo, 1970; Frank and Nikolai, 1980; Drescher *et al.*, 1989) mention the importance of the biological variables, few have investigated them. However, three investigations in the literature are worth special note. Hixon *et al.*, in 1970, reported on a combined *in vivo* and *ex vivo* testing primarily on the subject of stress magnitude. They noted

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hat the test apparatus moved with less force intra-orally han in the laboratory. This difference was attributed to a variety of oral forces, especially from mastication, which produced other motions and permitted the wire to slide hrough the tube more easily. They then redesigned their previous test fixture, to measure friction by vibrating the apparatus, and the results indicated that kinetic friction was nsignificant.

Jost-Brinkman and Meithke (1991) investigated tooth mobility and its effect on the frictional resistance. They measured bracket-archwire friction *in vivo*, when a tooth was loaded and unloaded, and compared these results to a imilar laboratory set-up. They found that the magnitude of riction was similar for both the laboratory set-up and the unloaded tooth. However, when the tooth was loaded, a ignificant reduction in friction was noted. They concluded hat, due to mastication, frictional forces occurring with orthodontic treatment are even smaller in comparison to *x vivo* experiments with immovable brackets.

Liew (1993) attempted to replicate masticatory function *x vivo* by repeated vertical displacement of an archwire under differing loads (25, 50, 100, 150, 250, and 400 g) using low frequency (91·3 cycles/min) vibration. He found that the esistance to archwire movement through an orthodontic bracket was decreased by continuous repeated vertical displacement of the wire. This reduction was as great as 85 per cent for loads in the range 100–250 g, while loads as mall as 25 g reduced friction by more than 50 per cent.

It has been noted by several authors that, clinically, he forces required to overcome friction are less than hose measured in steady state laboratory experiments Anderson, 1956; Ho and West, 1991). Results from *ex vivo* ests in the literature suggest that titanium alloys have higher friction than stainless steel and should thus be more esistant to sliding, yet clinical observations seem to ndicate the opposite. Titanium alloy archwires often sponaneously slide around the arch, while this rarely seems to occur with stainless steel. This discrepancy between clinical and experimental findings seems to suggest that other actors are of importance in governing the resistance to liding *in vivo* and the work by Hixon *et al.* (1970), Jost-Brinkmann and Miethke (1991), and Liew (1993) suggests hat masticatory function and tooth mobility may be the eason.

Translatory tooth movement along an archwire is not ontinuous, but occurs as a series of small tipping and uprighting movements (Drescher *et al.*, 1989). When a force is applied to the crown of a tooth, it tips until an equilibrium is reached between the applied force and the couple produced at the bracket-archwire interface (Frank and Nikolai, 1980; Drescher *et al.*, 1989). This binding between he bracket and archwire stops further crown movement until either wire displacement, tooth mobility or subequent remodelling releases the binding. It has even been uggested that the resistance to tooth movement, *in vivo*, is not governed by the classical laws of friction, but is a product of the binding and releasing phenomenon at the bracket-archwire interface. This seems to suggest that bracket-wire sliding *in vivo* is much more dynamic than at first imagined. The effect that mastication and tooth mobility has on this process is not fully understood and ittle is known about the magnitude of tooth mobility that is equired to release binding once it has occurred.

The objective of this study was to evaluate a laboratory model in which the resistance to a wire sliding in the bracket was measured while the bracket was displaced. Normal tooth mobility allows for bracket displacement. An *ex vivo* model which allows movement of the bracket may better define the archwire to bracket interactions and help correlate laboratory data to clinical observations. Consequently, an experimental set-up was constructed to investigate the magnitude of bracket movement and, hence, tooth movement, required to release bracket-archwire binding.

Materials and Methods

Test Samples

For the experiment, 320 upper stainless steel premolar brackets (Ormco®), with 0 degrees tip and 0 degrees torque, were assembled. Prior to shipment, the manufacturer modified the brackets by welding two strips of stainless steel over each pair of tie wings in order to eliminate the variables of ligation. The slot size was 0·022 × 0·028-inch and this was checked prior to testing by inserting a length of 0·0215 × 0·028-inch stainless steel wire through the slot. Prior to testing, each bracket was mounted onto a plastic block measuring 6 × 6 × 6 mm using an epoxy-resin adhesive (Araldite®, Ciba-Geigy). This was performed using an alignment fixture, which ensured that the bracket was placed at the centre of each block and the bracket slot was at right angles to the surface of each block.

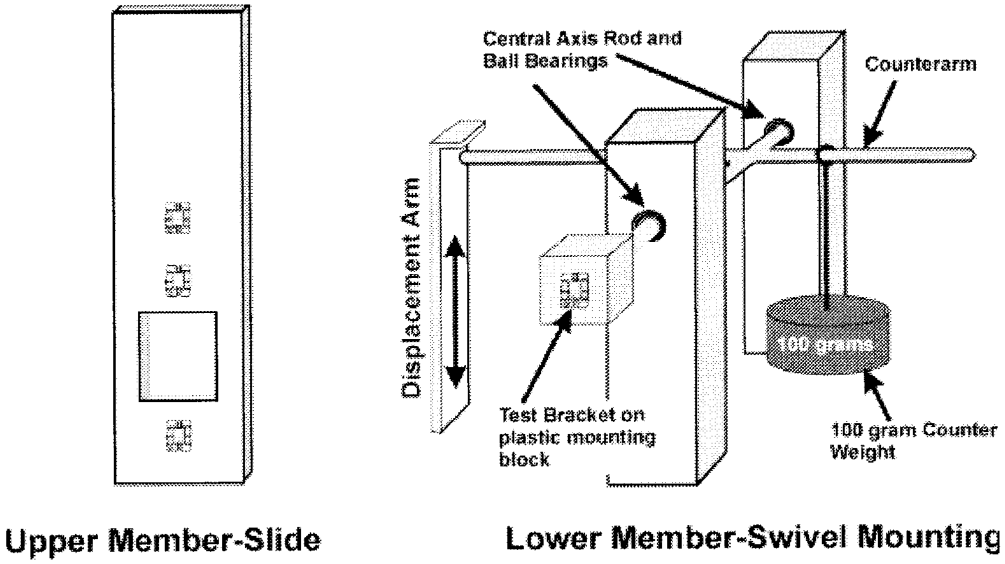
Four different archwire types were selected for investigation: 0·019 × 0·025-inch stainless steel, 0·019 × 0·025-inch beta-titanium, 0·021 × 0·025-inch stainless steel, and 0·016-inch stainless steel. The archwires used were straight sections, 5 cm in length, with a 90-degree bend at one end. This bend ensured that the archwire did not slip through the fixed brackets during testing. The archwires chosen for investigation represent a variety of dimensions, flexural strengths, and frictional properties.

Measurement Technique

A testing apparatus was constructed to simulate the clinical situation whereby the centre of resistance of a tooth is not in the same plane as that of the bracket. This results in some tipping of the bracket slot relative to the archwire leading to two-point contact between the wire and bracket. This is similar to the method used by Tidy (1989), Drescher *et al.* (1989), Bednar *et al.* (1991), and Omana *et al.* (1992).

The apparatus consisted of two parts (Figure 1): a lower member, swivel mounting, which supported the test bracket and an upper member slide that supported the fixed brackets and the test archwire. The lower member consisted of a mounting mechanism at one end of a freely rotating central axis. Attached to this central axis were two 10-cm long brass arms of equal weight. The mounting mechanism allowed the test bracket to be locked into place during testing and afterwards removed with ease. When the bracket was mounted the slot axis lay at right angles to the two brass arms. Attached to one arm, at a point 10 mm from the central axis, was a 100-g weight.

The upper member slide consisted of a strip of aluminium measuring 150 × 21 × 1·5 mm. A window in the



IG. 1 Schematic representation of two part test apparatus.

trip measured 19 × 13·5 mm. Fixed to this strip, with poxy-resin adhesive, were three brackets, two above the vindow and one below. These brackets were positioned so hat their slots were perpendicular to the surface of the luminium strip and in alignment with a scribe line that isected the strip and window. These precautions ensured hat once mounted the effect of torque or third order inding was minimised. The distance between the two rackets either side of the window measured 19·2 mm, vhich according to Moore and Waters (1993) is the average listance between a lateral incisor bracket and a second remolar bracket.

The vibrating machine (LDS Oscillator®, Model D207) ontacted the displacement arm and thus produced the racket displacement. An electromagnetic functional genrator allowed control of both amplitude and frequency. A requency of 1·35 Hz (81 cycles/min) was used throughout he experiment and this lies within the reported range for ormal chewing (Picton, 1964; De Boever *et al.*, 1978a,b). n Instron® 1011 universal testing machine was used to neasure the forces encountered during testing. The rosshead speed used throughout the experiment was mm/min.

Prior to testing the selected wire was wiped with an lcohol wipe and the bracket slot was cleaned with a piece f dental floss soaked in alcohol. The lower member of the est apparatus was attached to the Instron® crosshead, vhile the upper part was attached to the universal joint and oad cell (Figure 1). The test bracket was aligned in the ixture with a straight section of 0·0215 × 0·028-inch stainess steel wire. After assuring a passive alignment of the ixture, the 0·0215 × 0·028-inch wire was removed and the est wire placed through all four brackets in series.

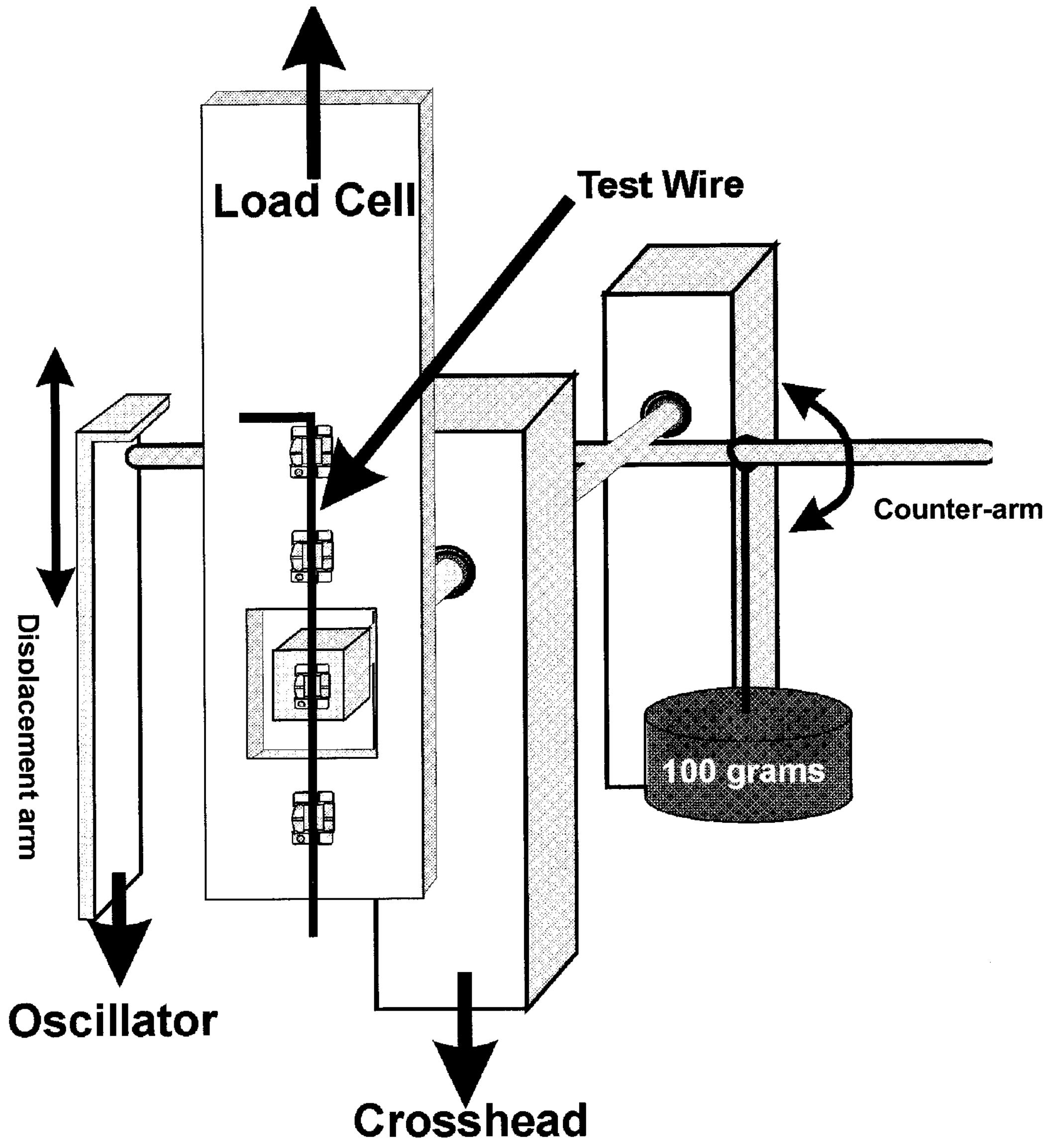
The controls on the Instron® testing machine were djusted until the readout showed zero. The 100-g weight vas gently applied and the entire set-up left to settle for pproximately 1 minute prior to testing. Then the displacenent arm, attached to the vibrating machine, was carefully owered until it just contacted the end of the counter-arm (Figure 2). If this procedure altered the force reading on the testing machine, the displacement arm was removed and the entire set-up allowed to settle again. This was repeated until the reading remained unaltered. The oscillator was started and the whole apparatus left to settle, at the chosen amplitude and frequency, for a period of about 10 seconds. Prior to setting up the displacement arm, the amplitude of displacement was checked using a clock gauge and this was repeated after every five test runs to ensure that the amplitude was constant. The test run was then initiated by starting the movement of the crosshead of the Instron® test machine. Each test run lasted 1 minute and the load cell values were recorded by stylus on a strip chart recorder. After each test the offset weight was removed, and the test bracket and archwire were carefully detached and stored. Each bracket and archwire was used only once.

Displacement Amplitudes

Prior to the main investigation, a pilot study was conducted to determine the oscillator displacement amplitudes to be used in the study. From this study, which used only 0·019 × 0·025-inch stainless steel, a substantial change in sliding resistance was recorded over the range of amplitude 0–1 mm. Therefore, in the main part of the investigation, four amplitudes were chosen for investigation; 0 (control), 0·25, 0·5, and 1 mm. A total of 16 cohorts (four wires and four amplitudes) with 20 specimens in each group was assembled.

Data Analysis

The results of the friction tests were recorded graphically on a strip chart recorder in Newtons. The graph of each represented the change in sliding resistance over a period of one minute. Examples of typical recordings are given in Figure 3. The test runs without displacement showed a



IG. 2 Schematic representation of assembled test apparatus.

elative levelling off after a period of about 15 seconds, vhile with repeated displacement the curve appeared as a eries of peaks and troughs with a periodicity equal to the requency of displacement. The troughs represent the eriods when the displacement was at its maximum, while he peaks represent the periods when the displacement vas zero. Eighty-one peaks are evident throughout each est run and these were labelled from T0 through to T80. he force value for each peak, which is representative f the static friction at that point, was recorded and lotted against time. To allow the displacement and non-lisplacement graphs to be compared, force values along the ion-displacement graphs corresponding to the time values 0–T80 in the displacement graphs were taken and these alues were then plotted against time.

Statistical analysis indicated that all 81 frictional values ieed not be analysed. Therefore, a preliminary analysis was performed to ascertain the number of points required to represent the overall data. Several test runs that displayed frictional variation with time were chosen and analysed using moving averages. Intervals of two, three, four, and five were chosen for analysis. Friction-time graphs using the actual and predicted data (using different intervals) were superimposed and an arbitrary decision was made regarding the degree of similarity between the two-line plots. From this appraisal, it became apparent that an analysis of every fifth time value would give an adequate representation of the total data. Therefore, for each curve the values at sixteen time points were chosen (T5, T10, T15, T20, T25, T30, T35, T40, T45, T50, T55, T60, T65, T70, T75, T80). The frictional values for the 20 replicates at each of the 16 periods were used in the final analysis.

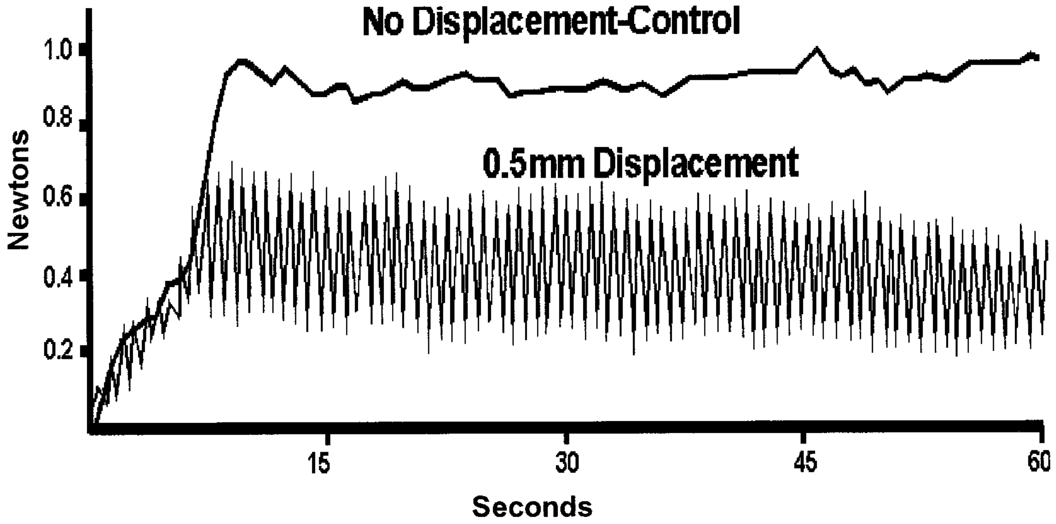
Analysis using the Wilks Lambda test, which is a multiple repeated measures analysis of variance (MANOVA) est, was performed on the data to assess the importance hat wire type, displacement, and time has on the sliding esistance. This analysis found that over the time period 20–T80, which represents the flat part of the curve, the liding resistance recorded for each wire type was ndependent of time. This means that the data recorded for ny single time point along the flat part of the curve is epresentative of all the data from T20-T80. Therefore, for tatistical analysis, the data related to only one time point eed be analysed. T50 was arbitrarily chosen for analysis as his point lies half-way along the flat part of the curve.

Because the data for T50 were reasonably normally istributed with minimal skewness, a one way analysis of ariance (ANOVA) was performed and the Tukey–Kramer Honest Significant Difference (HSD) test was used o adjust for multiple pairwise comparisons.

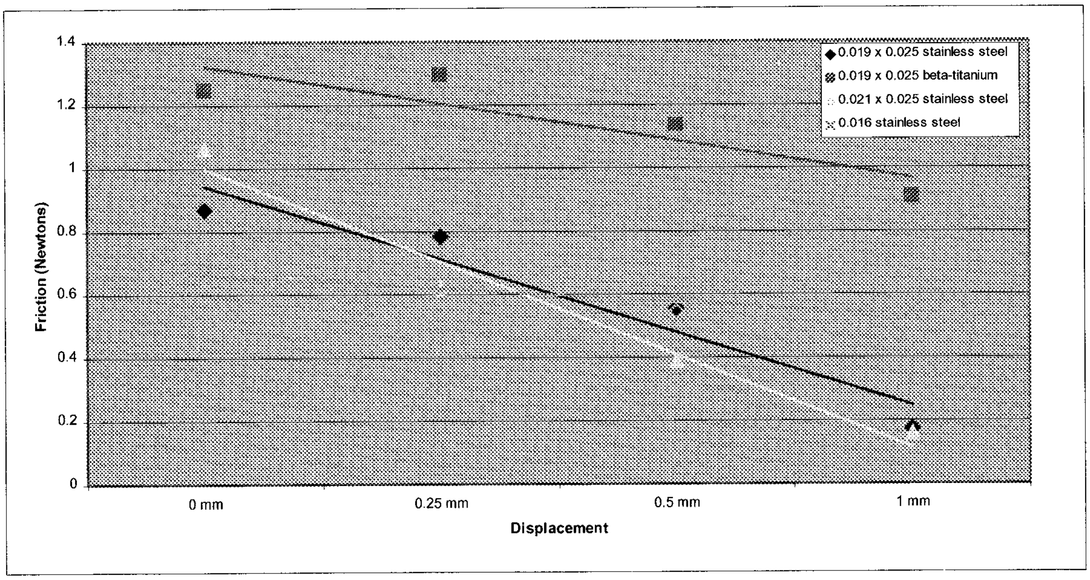
Results

The effect of displacement was shown to have a significant effect on sliding resistance ($P < 0{\cdot}001$) and this was found to be the case whether wire type was considered or not. The relationship between displacement and friction appears to be linear. Linear regression lines shown in Figure 4 show the effect of displacement by wire type.

When the control group with no displacement was considered, the data for T50 were analysed using a one way analysis of variance (ANOVA) and the Tukey–Kramer Honest Significant Difference (HSD) test was used to adjust for multiple pairwise comparisons. These tests demonstrated significant differences for all the wires tested ($P < 0{\cdot}05$). With no displacement, the highest levels of resistance were found in 0·019 × 0·025-inch beta-titanium,



IG. 3 Sample strip chart recordings (0·019 × 0·025 stainless steel).



IG. 4 Linear regression lines for each archwire demonstrating reduction in sliding resistance with bracket displacement.

ABLE 1 *Summary statistics (Newtons) for each archwire*

isplacement	0·019 × 0·025 stainless steel			0·019 × 0·025 beta-titanium			0·021 × 0·025 stainless steel			0·016 stainless steel		
	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range	Mean	SE	Range
mm	0·870	0·028	0·375	1·248	0·046	0·687	1·063	0·041	0·813	0·670	0·023	0·535
·25 mm	0·782	0·028	0·627	1·295	0·046	0·975	0·618	0·041	0·655	0·613	0·023	0·365
·5 mm	0·557	0·028	0·565	1·134	0·046	0·625	0·388	0·041	0·700	0·566	0·023	0·435
mm	0·174	0·028	0·250	0·906	0·046	0·563	0·159	0·041	0·420	0·544	0·023	0·370

ABLE 2 *Tukey–Kramer HSD comparison (T50) for each archwire*

isplacement	0·019 × 0·025 stainless steel (mm)				0·019 × 0·025 beta-titanium (mm)				0·021 × 0·025 stainless steel (mm)				0·016 stainless steel (mm)			
	0	0·25	0·5	1	0	0·25	0·5	1	0	0·25	0·5	1	0	0·25	0·5	1
mm	–	NS	S	S	–	NS	NS	S	–	S	S	S	–	NS	S	S
·25 mm	NS	–	S	S	NS	–	NS	S	S	–	S	S	NS	–	NS	NS
·5 mm	S	S	–	S	NS	NS	–	S	S	S	–	S	S	NS	–	NS
mm	S	S	S	–	S	S	S	–	S	S	S	–	S	NS	NS	–

ollowed by 0·021 × 0·025-inch stainless steel, 0·019 × ·025-inch stainless steel and 0·016-inch stainless steel, vhich had the lowest levels of resistance.

For the four wires tested, a summary of the means and tandard errors is shown in Table 1. For each wire type, the esults of the multiple pairwise comparisons are shown in able 2 with significance at the 5 per cent level. With regard o 0·019 × 0·025- and 0·016-inch stainless steel, a displacement of 0·5 mm was required before a significant reduction n frictional forces was observed ($P < 0·05$). For the 0·021 × ·025-inch stainless steel wire a significant reduction was noted at a displacement of 0·25 mm ($P < 0·05$), while for the ·019 × 0·025-inch beta-titanium a significant reduction vas only noted at a displacement of 1 mm.

The reduction in sliding resistance noted with displacement depended on the archwire. Over the range of displacements tested, there was an 85 and 80 per cent eduction associated with 0·021 × 0·025-inch and 0·019 × ·025-inch stainless steel, respectively. For 0·019 × 0·025-nch beta-titanium and 0·016-inch stainless steel, these eductions were 27 and 19 per cent, respectively.

Discussion

Vhen attempting to translate a tooth along an archwire here is always some degree of tipping in our imperfect ystem of mechanics. The crown moves before the root pex resulting in tipping of the tooth and the bracket elative to the archwire. This tipping proceeds until the riction or binding at the bracket archwire interface ecomes so great that crown movement stops. The couple reated by the bracket/archwire interaction works to upright the tooth, and the cycle of tipping and uprighting epeats itself (Drescher *et al.*, 1989). This study sought to imulate the clinical situation in which some tooth tipping ccurs during a resultant translation along an archwire by uspending a weight from a counter-arm.

The effect that mastication and tooth mobility have on this process was simulated by repeated displacement of the counter-arm. This repeated displacement produced an angular change between the bracket and archwire that results in a releasing of the binding. If one considers that the average distance between the centre of rotation of a maxillary canine and the centre of its crown is 16 mm (Nikolai, 1975), then an angular change between the bracket and archwire, similar in magnitude to that observed during the present investigation, would occur with a mesio-distal crown movement in the range 0–0·16 mm. This means that a 1-mm displacement at the end of the 10-cm long counter-arm will produce the same angular change at the bracket/archwire interface as a 0·16-mm displacement applied 16 mm from the central axis. One can conclude therefore, that 0·25-, 0·5-, and 1-mm displacements at the end of the counter-arm are equivalent to 0·04-, 0·08-, and 0·16-mm mesio-distal crown movements.

Tooth mobility prior to and during orthodontic treatment has been investigated by several authors (Muhlemann, 1954; Inoue, 1989; Tanne *et al.*, 1995). Muhlemann (1954) found that, over a 4-week period, tooth mobility increased from 0·07 to 0·4 mm per 500 g force, while Inoue (1989) found similar results using a 200-g force. More recently, Tanne *et al.* (1995) examined a range of applied forces and compared the mobility observed prior to treatment and after 24 days of canine retraction. In the latter study, they found that, before treatment, tooth mobility measured 41·3 and 101·5 µm, on average, when 100- and 500-g forces were applied, respectively. After 24 days of orthodontic movement, these measured 73·1 and 157·6 µm, respectively. Furthermore, if one considers that the forces noted during normal mastication are in the range 3–9 kg (Anderson, 1956), then it is not unreasonable to expect the magnitude of tooth mobility to be at least similar to those mentioned above.

The values recorded for the sliding resistance are similar in magnitude to those reported in other studies for stainless steel brackets (Garner *et al.*, 1986; Tidy, 1989; Omana *et al.*, 1992). However, they are lower than those reported by

)rescher *et al.* (1989). The sliding resistance recorded for he beta-titanium archwire was significantly greater (p : 0·05) than the stainless steel archwires and this concurs vith previous studies (Drescher *et al.*, 1989; Tidy, 1989; \ngolkar *et al.*, 1990; Kaplia *et al.*, 1990; Kusy and Whitley, 988, 1989, 1990a,b; Kusy *et al.*, 1990, 1991). It is apparent rom the results that the sliding resistance increases ignificantly as the wire size increases ($P < 0·05$) and this gain agrees with previous studies (Andreasen and)uevedo, 1970; Drescher *et al.*, 1989; Angolkar *et al*, 1990; 'anne *et al.*, 1991; Sims *et al.*, 1993; Downing *et al.*, 1994;)gata *et al.*, 1996).

Analysis of the data shows that repeated displacement of he bracket has a significant effect on the resistance to rchwire sliding. This relationship appears to be linear in iature, indicating that increased tooth mobility enhances he release of binding. On closer examination it appears hat the expected reduction in sliding resistance for a given legree of tooth mobility varies with the wire tested. Over he range of displacements tested (0–0·16-mm crown movenent), the reduction in sliding resistance for the 0·016-inch tainless steel wire was 19 per cent, while the reduction for he 0·019 × 0·025-inch beta-titanium wire, over the same ange was slightly greater at 27 per cent. For the 0·019 × ·025 and 0·021 × 0·025-inch stainless wires tested the eduction was 80 and 85 per cent, respectively. The impliation is that displacements, with an amplitude equivalent o 0·16 mm of mesio-distal crown movement, can release inding, and significantly reduce sliding resistance. Howver, the degree to which bracket displacement affects the esistance to sliding also depends on the wire size and alloy.

In comparing the stainless steel wires, there was relaively little reduction in resistance, with displacement, in he 0·016 stainless steel wire, whereas with larger stainless teel wires greater reductions were demonstrated with racket displacement. One assumption might be that the naximum displacement used in this test (0·16 mm) was less han the difference in freedom between wire and slot and hus insufficient bracket displacement to permit releasing 0·022–0·016 inch = 0·006 inch or 0·15 mm freedom, ssuming zero manufacturing tolerances).

Previous studies have suggested that beta-titanium archvires have greater resistance to sliding than a similar size tainless steel wire (Kusy and Whitley, 1988, 1989, 1990a,b;)rescher *et al.*, 1989; Angolkar *et al.*, 1990; Kapila *et al.*, 990; Kusy *et al.*, 1990, 1991). This difference was again lemonstrated in this investigation however, not to the ame magnitude. A comparison of the resistance to sliding etween 0·019 × 0·025-inch stainless steel and the same size eta-titanium wire indicates that the wire to bracket interctions are more complex than either a simple friction nodel, or a binding and releasing model can fully explain.)ne possible explanation might arise from the significant lifferences in their relative wire stiffness. The beta-itanium wire, at 42 per cent the stiffness of the stainless teel wire, may be flexing with the bracket displacement nd thus might require greater displacement to demonstrate proportionately larger reduction in the sliding resistance. 'uture testing with ion impregnated beta-titanium wire, vith a coefficient of friction similar to stainless steel, may ielp define the contributions of surface roughness, friction nd dissimilar alloys to the resistance to sliding.

It should be noted that, in this investigation, there was no intentional displacement of the archwire. It is possible that, in the clinical situation, direct or indirect displacement of the archwire could occur, and that this may further reduce the sliding resistance. Since the degree of wire displacement is dependent upon wire resilience, greater movement of the 0·016-inch stainless steel and 0·019 × 0·025-inch beta-titanium wires would be expected during mastication. Hence, this movement may be sufficient to reduce the sliding resistance associated with these wires, to levels similar to those observed with the two rectangular stainless steel wires.

If one considers the clinical situation, where there is intermittent movement between the bracket and archwire, then clinically we may not be looking at true friction, but rather a binding and releasing phenomenon. In the present study, it was found that repeated displacement of a bracket, equivalent to as little as 0·16 mm of mesio-distal crown movement, could reduce the sliding resistance by as much as 85 per cent. Assuming this fact, it is not unreasonable to conclude that the reduced sliding resistance observed *in vivo* may be a result of this intermittent movement between the bracket and archwire.

Conclusions

If the resistance to sliding is reduced with larger rectangular wires by bracket displacement, then the use of small diameter wires, in the belief of generating less friction, is unjustified. The use of bi-dimensional wires or dual slot sizes, to reduce sliding resistance, may likewise be unfounded. Selecting materials (archwires or bracket type) based upon measurements of coefficients of friction may not be valid.

The present research suggests that the effective sliding resistance between orthodontic brackets and archwires is substantially reduced by repeated displacement equivalent to 0·16 mm of crown movement, which is within the range of normal tooth mobility. Repeated bracket displacement has a highly significant effect on the sliding resistance at the bracket-archwire interface ($P < 0·001$). Within the no displacement (control group) significant differences were noted between all the wires tested ($P < 0·05$). The wires were ranked, according to sliding resistance, in the following order: 0·019 × 0·025-inch beta-titanium (highest), 0·021 × 0·025-inch stainless steel, 0·019 × 0·025-inch stainless steel, and 0·016-inch stainless steel (lowest).

The reduction in sliding resistance noted with displacement, depended on the archwire. Over the range of displacements tested, there was an 85 and 80 per cent reduction associated with 0·021 × 0·025 and 0·019 × 0·025-inch stainless steel, respectively. For 0·019 × 0·025-inch beta-titanium and 0·016-inch stainless steel, these reductions were 27 and 19 per cent, respectively.

The influence of friction, given the likelihood of bracket and/or archwire displacements *in vivo*, is thought to be small and may have significantly less clinical importance than previously stressed.

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