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Evaluation of methods of archwire ligation on frictional resistance

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SUMMARY The aim of the study was to investigate the effect of elastomeric type and stainless steel (SS) ligation on frictional resistance using a validated method. To assess the validity of the new test system to measure mean frictional forces, SS and TMA wires, each with dimensions of 0.017×0.025 and 0.019×0.025 inches, were used in combination with a self-ligating Damon II bracket or a conventional preadjusted edgewise premolar SS bracket without ligation. Four types of elastomeric module, purple, grey, Alastik or SuperSlick, and a pre-formed 0.09 inch SS ligature were then assessed as methods of ligation using preadjusted edgewise premolar SS brackets. The specimens were tested on a Nene M3000 testing machine, with a crosshead speed of 5 mm/minute and each test run lasted for 4 minutes. Each bracket/wire combination with each method of ligation was tested 10 times in the presence of human saliva and the mean frictional force was recorded. The mean frictional forces were compared using three-way analysis of variance.

The Damon II self-ligating bracket and unligated conventional SS bracket produced negligible mean frictional forces with any of the wires tested. For the 0.017×0.025 SS, 0.019×0.025 SS or 0.019×0.025 inch TMA wires, SS ligatures produced the lowest mean frictional forces. With the 0.017×0.025 TMA wire, purple modules produced the lowest mean frictional force.

There was no consistent pattern in the mean frictional forces across the various combinations of wire type, size and ligation method. Under the conditions of this experiment, the use of passive self-ligating brackets is the only method of almost eliminating friction.

Introduction

The introduction of the preadjusted edgewise system reduced substantially the need for wire bending, but relies on sliding mechanics to move teeth, especially during space closure. Whenever sliding occurs, frictional resistance is encountered. Friction is the resistance to motion when one object moves tangentially against another (Benancon, 1985). The coefficient of friction for a given material surface is a constant, which may be dependent upon surface roughness, texture or hardness (Benancon, 1985). The frictional force is derived from the summation of the coefficient of friction and a force acting perpendicular to the contacting surfaces (Giancoli, 1980). In order for one object to slide against the other, the force applied needs to overcome the frictional resistance.

A number of factors have been suggested which are thought to influence frictional resistance. Most studies concentrate on the bracket/wire interaction. Bracket material, wear of the wire (Keith *et al.*, 1994), bracket width and interbracket distance (Frank and Nikolai, 1980) are believed to be of influence, along with the archwire material (Kapila *et al.*, 1990), diameter, cross-sectional shape (Peterson *et al.*, 1982; Tanne *et al.*, 1991), wire stiffness (Prososki *et al.*, 1991) and active torque (Tidy, 1989). Further contributing factors include bracket/wire angulation (Dickson *et al.*, 1994), the surface roughness of the wire (Kusy *et al.*, 1988), sliding velocity (Kusy and Whitely, 1989), saliva (Kusy *et al.*, 1991) and the method of ligation (Sims *et al.*, 1993).

Relatively few studies have investigated the means of archwire ligation on frictional forces. Edwards *et al.* (1995) compared the frictional forces produced when elastomeric modules, applied conventionally or in a figure of eight configuration, stainless steel (SS) ties or Teflon-coated SS ligatures were used for archwire ligation. The figure of eight modules appeared to create the highest friction. There was no significant difference in mean frictional force between the conventional module and the SS ligature, but the Teflon-coated ligature had the lowest mean frictional force. A further study investigated the mean frictional forces of differently coloured, shaped and manufactured modules when sliding a 0.018×0.025 inch SS wire through a premolar bracket (Dowling *et al.*, 1998). The clear modules exhibited significantly lower friction than the other module types. That study, however, was carried out in the absence of saliva and it is not clear whether there would be significantly different frictional values between modules of different colours. It is also not clear from either study whether attempts were made to ensure that the test wires were engaged passively in the bracket prior to module placement. This has important consequences, as the reported frictional resistance will be the sum of the friction produced by the module plus any wire/bracket binding produced as a result of the wire not seating passively in the bracket slot immediately prior to testing.

Both of the above investigations highlight the fact that the composition, or more specifically the surface characteristics, of the ligature may be another variable in determining the coefficient of friction. A new polymeric-coated ligature (SuperSlick™; TP Orthodontics, Inc., Indiana, USA) has recently been developed which is claimed to reduce friction significantly and could potentially shorten treatment time. The polymeric-coated module produces a four-fold reduction in friction compared with a control module, supposedly by rendering its surface slippery on contact with water or saliva (Devanathan, 2000). Other manufacturers (3M Unitek, Monrovia, California, USA) have produced a new range of modules (Alastik™ Easy-To-Tie) which incorporate a 45 degree bend to allow easier placement over the bracket tie wings, but the effect of this design modification on friction is currently unknown.

An alternative to elastomeric or SS ligation is the self-ligating bracket. One type has a spring clip which pushes the wire into the bracket slot (Hanson SPEED and Adenta Time brackets) and the other a passive clip which does not press on the wire (Activa and Damon II brackets). Brackets with a passive clip have been shown to generate negligible friction (Sims *et al.*, 1993, 1994; Thomas *et al.*, 1998).

A recent study (Loftus and Årtun, 2001) evaluated an *in vitro* model system for measuring orthodontic friction. They concluded that a device should be manufactured that allows adjustment of the bracket slot in all three planes of space during mounting in the test machine, in order to eliminate any binding of the bracket slot and archwire.

No study has compared the frictional resistance of the newly marketed elastomerics with that of conventional elastomerics or SS ligation using a validated model. The aims of the study were to investigate the validity of a new test system and then to assess the effect of elastomeric type and SS ligation on frictional resistance.

Materials and methods

Validation of the method used to assess friction

Self-ligating, Damon II brackets (Ormco, Orange, USA) with 0 degrees tip and torque and maxillary preadjusted edgewise premolar SS brackets with a 0.022 inch slot dimension and 0 degrees tip and torque were used in this investigation. Straight lengths of SS and TMA wires (3M Unitek), each of dimensions 0.017×0.025 and 0.019×0.025 inches, were tested in combination with each of the bracket types. The wires were not ligated into the preadjusted edgewise SS brackets.

A testing machine (Nene M3000, Wellingborough, UK) with a 5 kg load cell was used in this study. Each bracket was mounted on a Perspex block with epoxy resin (Araldite, Bostik Ltd, Leicester, UK). Each bracket was orientated with the long axis of the slot vertical and in line with the direction of measurement of the load cell. The Perspex block was then secured to the load cell using the clamps provided by the manufacturer. A straight 60 mm length of test wire was taken and a right angle bend placed 10 mm from the end of the wire. The wire was examined to ensure that this procedure had not introduced any torque in the wire. Wire in which torque was introduced was discarded.

A rack and pinion mechanism which allowed accurate positioning of the wire into the bracket slot was secured on to the lower fixed clamp of the Nene machine. The Perspex block was then secured to the top of this mechanism, so that turning the dial would move the block in a sagittal direction. A 20 mm length of orthodontic tubing, with a 0.8 mm internal diameter, was secured to the block with self-cure acrylic resin (Orthoresin, Dentsply Ltd, Surrey, UK). The short end of the test wire (10 mm) was inserted into the tubing and the dial turned to allow the now vertical portion of wire to engage the bracket slot passively. The passivity of the wire–bracket engagement was checked by gently rotating the dial backwards and forwards to ensure that the wire moved freely within the bracket slot. Any adjustments to the block carrying the bracket or the wire could be made to remove any binding (Figure 1a, b). All archwires and brackets were washed in 95 per cent ethanol and air dried prior to testing. The tests were conducted in the presence of fresh, whole human saliva which was obtained without stimulation. Saliva was dripped into the bracket–wire junction at a rate of 1 ml/minute from a syringe (Plastipak, Ireland). The crosshead speed was set to 5 mm/minute and each test run lasted for 4 minutes. Each bracket and archwire combination was only tested once to eliminate the influence of wear. The load cell recorded the force values needed to move the wire through the bracket, i.e. the resistance to sliding. The direct current produced was passed through a data acquisition board and interpreted by software (Nene) on a personal computer (Elonex, London, UK). The data were stored, exported as an ASCII file and then imported into Microsoft Excel for analysis.

The Damon II self-ligating bracket and the preadjusted edgewise premolar SS bracket without ligation both produced negligible mean frictional forces (0.05 ± 0.02 N) with any wire type used in the study.

Main study

Maxillary preadjusted edgewise premolar SS brackets with a 0.022 inch slot dimension and 0 degrees tip and torque were also used in the main investigation. Wires of the same type and size as those used in the validation study were also used in this experiment. The bracket and wire were held together with either one of four

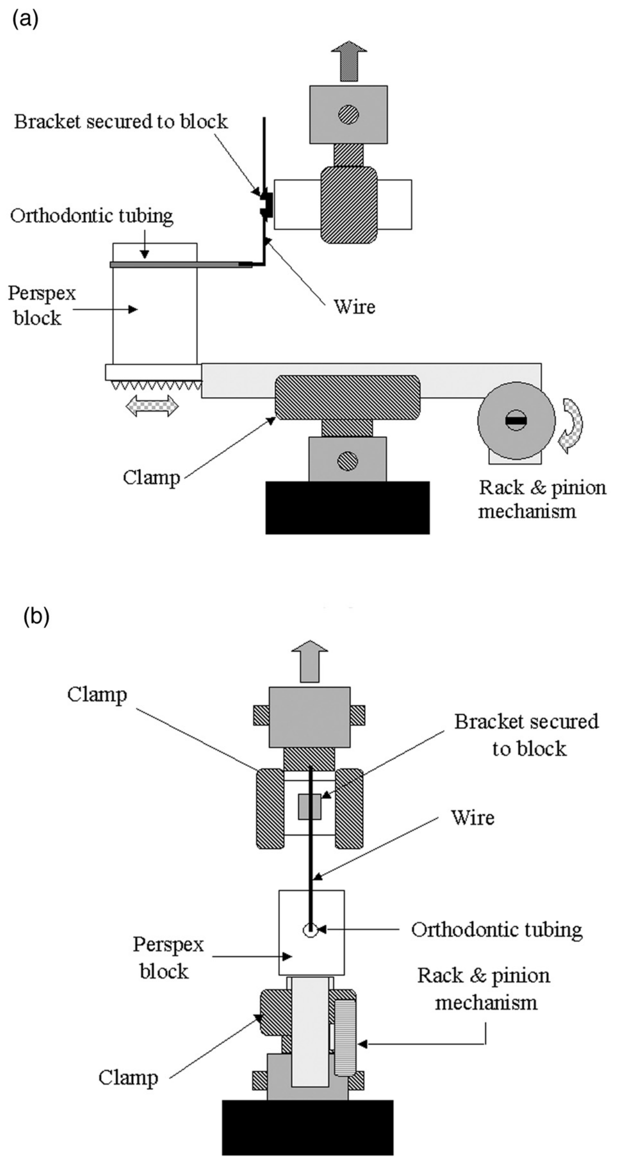

Figure 1 (a) Diagrammatic representation of the experimental set-up (syringe not shown). (b) Diagrammatic representation of the experimental set-up (syringe not shown)—90 degree view.

types of elastomeric module (purple, grey, Alastik or SuperSlick) or by a pre-formed 0.09 inch SS ligature. The elastomeric modules were placed over the tie wings of the brackets with a ligature gun (Straight-shooter, TP Orthodontics). Prior to Alastik placement, the position of the 45 degree bend was marked with a fine black permanent marker (Lumocolor, Staedtler, Germany) to ensure the correct orientation of the module to the wire. In an attempt to standardize SS ligature placement, each short ligature was given seven full turns of the Spencer-Wells clips after it was placed ready for tightening (Bazakidou *et al.*, 1997). The clip was then removed and the ligature wire left vertical and parallel to the test wire. Testing for all specimens was undertaken in similar conditions and in a manner identical to that used for the validation study. Each bracket and archwire combination was tested 10 times with each module type; in total 200 specimens were tested.

Data analysis

The three factors considered in the main data analysis were wire type (SS or TMA), wire size (0.017×0.025 or 0.019×0.025 inch) and ligation method (purple, grey, Alastik, SuperSlick and SS ligature). The Damon II bracket was not included in the main study.

After checking that the data were suitable, a three-way analysis of variance was used to examine the combination of these three factors on the mean frictional forces, in particular the three-way interaction of wire type, size and ligation method. To interpret the results of the three-way analysis of variance, the mean frictional forces of the five different ligation groups were then compared within each of the four combinations of wire type and size, using suitably adjusted follow-up multiple comparisons.

Results

Figure 2 presents box plots for each of the five ligations for each of the wire type and wire size combinations. One of the key points to note was the large variability across the combinations of the three factors. In particular, there was large variability of the 0.017×0.025 TMA wire with a SS ligature, relative to the other combinations involving SS ligatures. In contrast, there was a small range of values for the 0.019×0.025 TMA secured with a grey module in relation to the other three grey module combinations. This large variability makes it more difficult to identify any potential significant differences.

The three-way interaction of wire type, size and ligation method was highly significant ($P < 0.001$). To interpret this interaction, the mean frictional forces of the five ligation methods, for each of the four combinations of wire type and size, were calculated and are given in Table 1. Follow-up multiple comparisons were used to identify between which of the ligations there were significant differences in terms of the mean frictional force.

0.017×0.025 inch SS

SS ligatures showed the smallest mean frictional force, which was significantly lower than that for the grey, SuperSlick or Alastik modules but not significantly different from the purple module. The mean force for the Alastik module was significantly higher than three out of the other four methods of ligation.

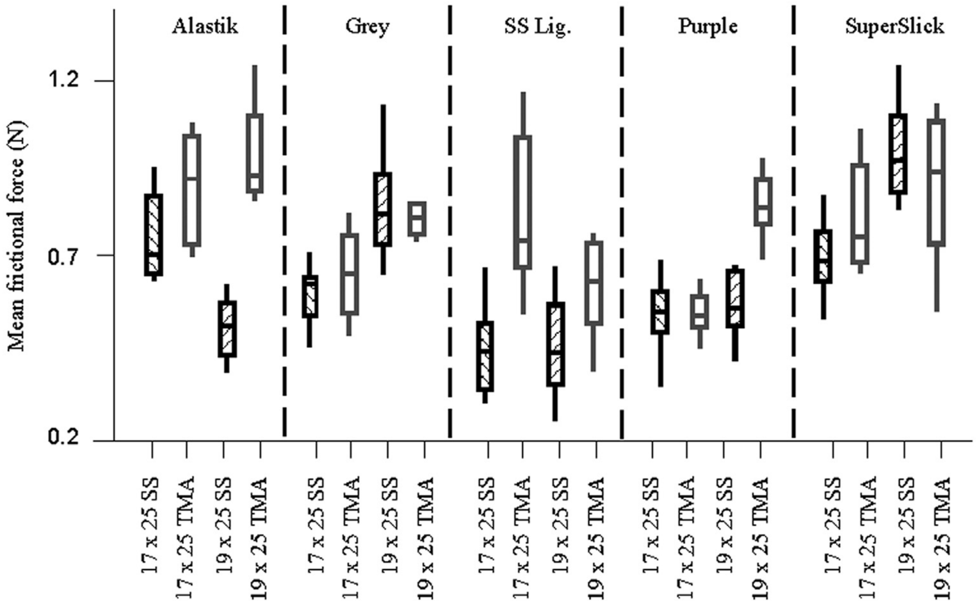

Figure 2 Boxplots for mean frictional force by method of ligation, wire size and type.

Table 1 Mean frictional forces for each wire size and type combination.

Wire size	Wire type	Order of ligation in terms of mean (standard deviation) force (N) (smallest→largest force)				
0.017 × 0.025	SS	SS Lig[a] 0.43 (0.11)	Purple[ab] 0.53 (0.10)	Grey[bc] 0.59 (0.08)	SuperSlick[cd] 0.68 (0.11)	Alastik[d] 0.75 (0.12)
0.017 × 0.025	TMA	Purple[a] 0.53 (0.06)	Grey[ab] 0.65 (0.12)	SuperSlick[bc] 0.79 (0.14)	SS Lig[bcd] 0.82 (0.22)	Alastik[cd] 0.90 (0.15)
0.019 × 0.025	SS	SS Lig[a] 0.45 (0.14)	Alastik[ab] 0.50 (0.09)	Purple[ab] 0.56 (0.09)	Grey[c] 0.84 (0.15)	SuperSlick[c] 0.98 (0.13)
0.019 × 0.025	TMA	SS Lig[a] 0.60 (0.14)	Grey[b] 0.80 (0.05)	Purple[bc] 0.84 (0.08)	SuperSlick[bcd] 0.88 (0.20)	Alastik[cd] 0.98 (0.13)

Common symbol, no significant difference between methods of ligation; different symbol, significant difference between methods of ligation.
SS, stainless steel.

0.017 × 0.025 inch TMA

The lowest mean frictional force was found with the purple module, which was significantly lower than the mean force for the SuperSlick module, Alastik module or SS ligature but not significantly different from the mean frictional force for the grey module. There were no significant differences between the mean frictional forces for the grey module, SuperSlick module or SS ligature.

0.019 × 0.025 inch SS

The lowest mean frictional force was for the SS ligature, which was significantly lower than that of the grey and SuperSlick modules, but not significantly different from the mean frictional forces of the Alastik and purple modules. An interesting point to note for this wire type was the low mean frictional force when using the Alastik module.

0.019 × 0.025 inch TMA

Once again, the lowest mean frictional force was with the SS ligature, which was also significantly different from each of the other four methods of ligation. There was no significant difference between the mean frictional forces of the grey, purple and SuperSlick modules. The Alastik module had a significantly higher mean frictional force than the grey module, but not significantly higher than the purple and SuperSlick modules.

Discussion

Optimal tooth movement with a fixed appliance requires the use of optimal forces, but these forces need to overcome initially the frictional resistance that is present between the wire, the bracket and the means of ligation. As a result, the resistance to sliding needs to be quantified and compensated for by increasing the force applied to the tooth.

From a clinical perspective, the aim is to keep the frictional forces as low as possible and ideally to eliminate them altogether. Sliding mechanics occur predominantly during space closure and this needs to be carried out on a wire that has sufficient stiffness to prevent its distortion and subsequent tilting of the adjacent teeth into the space. For this reason, space closure is usually undertaken on SS and possibly TMA wire. TMA wire is usually used in the finishing phase of treatment, but the frictional properties of TMA have been investigated in other friction studies (Downing *et al.*, 1994; Michelberger *et al.*, 2000) and were also tested in the present study. It is generally accepted that space should not be closed on nickel titanium wire, as it has low stiffness and hence this wire type was not included in this investigation (McLaughlin and Bennett, 1989).

Previous studies have focused on the effect of changes in wire type or dimension as a means of reducing friction (Kusy *et al.*, 1988; Kapila *et al.*, 1990; Keith *et al.*, 1994). The present research addressed the effect of the method of wire ligation, by module or SS, on frictional resistance and used a validated testing system to eliminate binding between the wire and bracket during the test phase. The sample size and crosshead speed chosen were in accordance with those used in previous studies (Downing *et al.*, 1995; Taylor and Ison, 1996). In addition, the method of ligature placement allowed a standardized method of ligation for the SS ligatures, while the use of the ligature gun (Straight-shooter) allowed the elastomeric modules to be stretched by a standard amount prior to placement regardless of the internal or external dimensions of the module. Furthermore, all tests were carried out in the presence of whole unstimulated saliva to replicate the clinical environment, in line with the recommendations of Kusy *et al.* (1991). Artificial saliva has been shown to be an inadequate substitute for human saliva in friction studies (Downing *et al.*, 1995).

Negligible frictional force was produced by the Damon II bracket, confirming the results of previous studies (Sims *et al.*, 1993; Shivapuja and Berger, 1994; Thomas *et al.*, 1998). This bracket does not produce a force acting perpendicular to the contacting surface and, therefore, appears to be friction-free in this form of experimentation. The preadjusted edgewise bracket with 0 degrees tip and torque also exhibited negligible friction without ligation of any of the wires tested. The validity of the new testing method was, therefore, confirmed before proceeding to assess friction with different combinations of wire and means of ligation.

The use of metal ligatures with seven turns produced the lowest friction, confirming the findings of Bazakidou *et al.* (1997). This is most probably related to the wire, bracket and mode of ligation all being made of SS and thus all having the same coefficient of friction. The values of mean frictional forces generated by the elastomeric modules were also in a similar range to those found by other investigators (Angolkar *et al.*, 1990; Kapila *et al.*, 1990; Downing *et al.*, 1995; Taylor and Ison, 1996). It is impossible to make comparisons between studies because the experimental method was not constant and some of the experiments were conducted in the absence of saliva (Angolkar *et al.*, 1990; Kapila *et al.*, 1990).

For the SuperSlick module, the results indicate that the mean frictional forces with all the archwire combinations tested were too great to make it a viable alternative to any current module. For this type of module to be effective in reducing friction, the manufacturers state that the module needs to be in a wet environment to aid lubrication. This would require a film of saliva to be present constantly between the module and the wire. A possible explanation for the higher than expected mean frictional force with this type of module is that it removes the saliva film as the wire translates beneath it during sliding.

The Alastik module also produced high mean frictional forces, except when used in conjunction with a 0.019×0.025 inch SS wire with a bracket with a 0.022 slot. Fortunately, this wire is favoured by many clinicians for space closure. There were no significant differences in mean frictional forces between the metal ligature, the Alastik module and the purple elastomeric module when used with this wire. A possible explanation for the Alastik module performing so well with a 0.019×0.025 SS is that the bend in the module prevents all of the module contacting the wire. If this hypothesis is correct, then one would expect a similar result with the 0.019×0.025 inch TMA wire, but the mean frictional force was doubled with this module. This may be explained by the change in wire type and could indicate that the surface characteristics of the module and the wire are more important than the size of the wire in generating friction.

Conclusions

There was no consistent pattern in the mean frictional forces across the various combinations of wire type, size and ligation method. The polymeric-coated module did not produce the lowest mean frictional force with the wires assessed. The introduction of a 45 degree bend into the module reduced mean frictional forces to that of a SS ligature when using a 0.019×0.025 inch SS wire. Under the conditions of this experiment, the use of passive self-ligating brackets is the only current method of almost eliminating friction.

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