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Original Article

Frictional resistance to sliding archwires with repeated displacement

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Frictional resistance between a length of stainless steel archwire and a single bracket was calculated, and the effects of cyclical displacement forces on frictional resistance were tested. With the application of repeated displacement forces to the archwire, the force required to slide the wire through the bracket was substantially reduced. The percentage reduction in the force required to slide the wire was dependent on the size of the displacement force applied to the archwire. Frictional resistance in the mouth may not be satisfactorily reflected by steady mode laboratory models. The clinical implications for different types of orthodontic brackets remain unresolved.
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Introduction

A great deal has been written about frictional resistance to tooth movement both in the early stages of bracket alignment and in the definitive movement of teeth using sliding mechanics.[1,2] The overall resistance to sliding is partitioned into three components: classic friction, elastic binding and physical notching.[3] Elastic binding occurs when the angle of contact between an archwire and a bracket slot exceeds a critical value determined by the cross section of the slot and the dimensions of the wire. Elastic binding may progress to physical notching of either the wire or the bracket.

These problems have become more salient with the introduction of low modulus archwire alloys that allow very significant flexible deformation of archwires in brackets that are markedly displaced from each other in the first, second or third orders. With large relative displacements of brackets, an archwire is likely to bind after engagement, thereby limiting sliding adjustment of the archwire as the teeth begin to align and level. The forces applied by the ligating mechanism (wire or elastomeric) have also been implicated in determining the binding action, and it is often stated that loose stainless steel ligatures offer a better solution to these problems than elastomerics.

Most experimental models used to study friction associated with orthodontic brackets have been based on the assumption that the wire–bracket interface alone generates the most significant determinants of the loads that must be applied to a tooth to overcome resistance to sliding. Factors studied in this regard have included composition of the wire and/or bracket, surface modification, lubrication and design of the bracket.[4]

Only one published study has examined the changes in frictional resistance occurring with the application of secondary forces such as those resulting from mastication or inter-occlusal contacts.[5] Braun and co-workers studied the effects of low-order random perturbations (finger pressure: from 20 to 200 grams) applied to the bracket and the archwire.[5] They noted that frictional resistance momentarily fell to zero, and that the reduction seemed to be independent of the size of the archwire, the type of ligature wire or the elastomeric. They observed that "there is no real evidence to lead the investigators to believe that the method of tying would make an important difference". They further noted that "relative arch wire stiffness, and consequently the related response to random perturbations, is affected significantly by the arch wire length defined by the location of the end supports". It was also cautioned that the performance of wires engaged in adjacent displaced brackets may be different from the single bracket model, but this point is yet to be tested rigorously.

The importance of these findings has been highlighted with the increasing use of a range of self-ligating brackets that are variously described as "active" or "passive". Active brackets rely on the application of pressure to the archwire by the locking mechanism. Passive brackets employ an inactive closing latch that exerts no inherent force once closure is achieved. Self-ligating brackets may have several advantages, the most obvious of which may be a reduction in the time required to secure an archwire, as well as elimination of the supposedly high friction rates resulting from conventional ties. Some of the manufacturers of self-ligating brackets claim that a significant reduction in bracket–wire friction leads to more efficient practice management because the properties of highly flexible archwires can be maximised and the time intervals between patient appointments increased. Studies of these self-ligating brackets using laboratory bracket-wire models do indicate a reduction of friction.[6,7] However, comparisons between brackets may need to be re-examined using a model that simulates the clinical environment and, in particular, the cyclical application of occlusal or masticatory forces. In addition, there is a need to employ multi-bracketed laboratory models as opposed to single-bracket models.

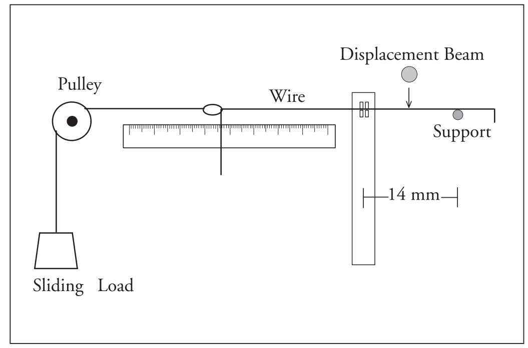

Figure 1. Diagram of the test apparatus (not to scale).

Materials and methods

The aim of this study was to determine the significance of the changes in frictional resistance occurring with the application of a displacement force to a sliding wire.

Frictional resistance was assessed by measurement of the minimum force (F-m) required to produce continuous sliding of the archwire through the bracket. This parameter is adequate for evaluation of the effects of vertical displacement on frictional resistance to sliding between the wire and bracket.[1,8]

The experiment consisted of two parts.

Part A: to determine the rate of wire movement through a bracket when the wire was subjected to varying displacement loads (from 25 to 400 grams) at the same time as the application of decreasing sliding loads as a percentage of the frictional resistance value (F-m).

Part B: to determine the rate of wire movement through a bracket when the wire was subjected to varying displacement loads (from 50 to 450 grams) and the sliding force was set at 80 per cent of the frictional resistance value (F-m).

Simple experimental equipment consisted of straight lengths of 0.016 x 0.022 inch stainless steel wire (Ormco, USA) ligated to a 0.018 x 0.025 inch upper cuspid bracket (Ormco, USA) using an elastomeric module (3M Unitek, USA). The bracket was fixed to a single brass rod representing the canine, and the wire was aligned so that there was no perceptible angle between the wire and the bracket slot. The wire was drawn through the bracket slot by means of various weights attached to a cord that passed over a low-friction pulley (Figure 1).

In addition, by means of an offset circular cam rotating at 91 rpm and a low friction beam, various displacing forces were applied to the wire

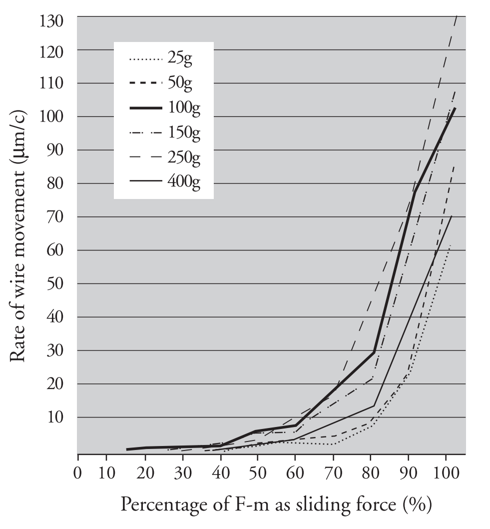

Figure 2. The rate of wire movement (μm/cycle) plotted against the percentage of F-m as sliding force for the different displacement loads used.

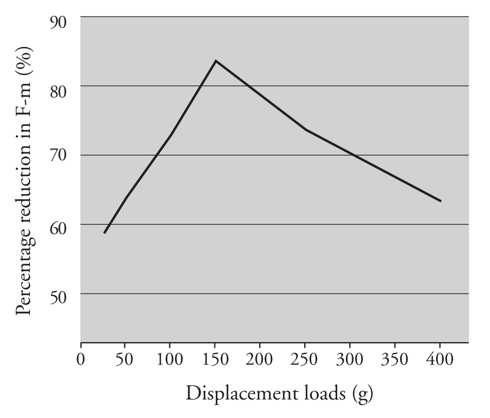

Figure 3. The percentage reduction in F-m plotted against the displacement loads used.

during each test phase. Displacement loads were applied to the top of the wire of the experimental model of a 14 mm "extraction" space by means of a contact brass rod (4.2 mm diameter) on the underside of the beam. Downward forces exerted by the beam were measured to 0.01 gram. The rate of wire movement was measured in μm per cycle of the displacing force.

Frictional resistance was determined as the smallest sliding force at the end of the cord that would cause the wire to slide through the bracket without stopping, the value then being slightly higher than the true value for static friction.

Regular procedures of ligature application and cleaning the apparatus were established to achieve reliable data. F-m was established prior to each phase of testing.

Part A

Having determined F-m for the wire, the initial sliding load applied on the pulley was set at 100 per cent of F-m and the rate of wire progress through the bracket was measured at the same time as the cyclical displacement load was applied to the top of the wire by the rod on the beam. Displacement loads applied were 25, 50, 100, 150, 250 and 400 grams. With each new beam load, new elastic modules were used. This whole procedure was repeated with a decreasing sliding force (as a percentage of F-m) on the pulley until no further wire movement occurred. The rate of wire movement was plotted against the sliding load (as a percentage of F-m) at each of the beam displacement loads (Figure 2). In addition, the percentage reduction in F-m, at different displacement loads, was plotted against the displacement load used (Figure 3).

Part B

With the sliding load set at 80 per cent of F-m, increasing displacement loads (from 50 to 450 grams) were applied by the beam and the rate of wire movement measured for each displacement load (Figure 4).

Results

F-m by definition is the minimum force required to produce continuous sliding of the wire through the bracket. When the sliding force is below F-m no sliding occurs. In the present study however, with the application of repeated displacement forces to the wire, the sliding force required to slide the wire was less than F-m. Figure 2 shows the plots of the rates of wire movement against the percentage of F-m for different displacement loads. They all showed the same exponential type of relationship of the rate of wire movement to percentage of F-m. There was a rapid decrease in the rate of wire movement, with decreasing percentages of F-m until the curves approached the horizontal axis, where the rate of decrease slowed down. The coefficients of linear regression

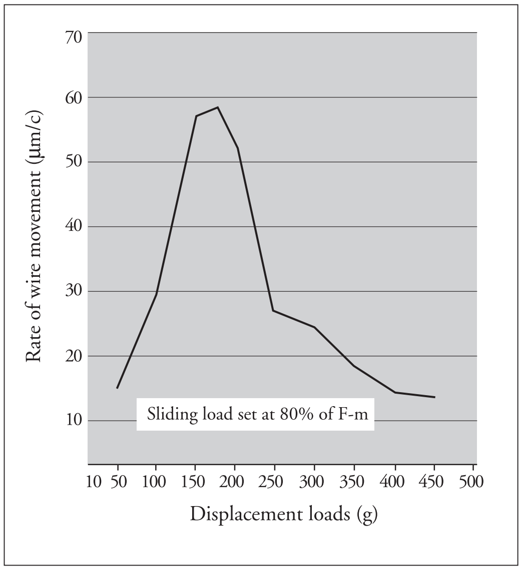

Figure 4. The rate of wire movement plotted against the displacement loads used.

were high at over 0.9 for the different displacement loads. Where the curves intercepted the horizontal axis, the percentage of F-m as the sliding force corresponded to the minimum force needed to produce continuous sliding with cyclical displacement of the wire. In practical terms, these were the load values at which movement was effectively zero.

The percentage reduction in F-m was dependent on the displacement loads used. The range of the percentage reduction of F-m was from 60 to 85 per cent for displacement loads between 25 and 400 grams. There was a maximum reduction of 85 per cent at the displacement load of 150 grams. Displacement loads as low as 25 grams could decrease effective friction by 60 per cent (Figure 3).

When the sliding load was set at 80 per cent of F-m, the amount of displacement load had an effect on the rate of wire movement, with an effective reduction in friction. Beginning at low displacement loads, the rate of wire movement increased as the displacement load increased, until a maximum rate of movement was reached at a displacement load of 175 grams. Beyond this optimal load, the rate of wire movement decreased with increasing loads. The optimal range for a reduction in friction was from 100 to 250 grams of displacement load (Figure 4).

Discussion

In this study, the value of F-m is considered to be similar to the value of static and dynamic friction determined by other workers. This approximation is considered adequate to determine the comparative effects of different vertical displacement loads on the effective friction of the wire in the bracket. In this study, only one bracket and one type of wire were used, but it is expected that other parameters may apply. These would include dental mobility, the relative displacements of brackets on adjacent teeth and bracket type.

Masticatory forces are quasistatic and they can reach a peak of 150 grams within a few tenths of a second.[9] They are generally lower than maximal bite forces. Forces vary with the state of the dentition, consistency and viscosity of food, bite strength and times of recording.[10,11] Chewing frequency may vary between 32 and 146 cycles per minute.[12,13] In the present study, the rate of 91 cycles per minute was deemed to be a reasonable compromise for the purposes of investigation.

The results of this study support the conclusions of Braun *et al*.[5] that laboratory tests of the friction between archwires and brackets do not reflect the mode of sliding in the mouth, and that effective frictional resistance is greatly reduced in the mouth because of the intermittent displacements of the wire by occlusal and masticatory forces. The results of this research also support the hypothesis that laboratory tests of the friction between sliding archwires and brackets do not reflect the mode of sliding in the mouth. Repeated and intermittent relative displacements between the wire and the bracket decreased the effect of friction and this is likely to apply in the mouth. Frictional resistance values recorded in a steady mode experiment are higher than the force required to move a tooth in the mouth.[14] The present study has shown a reduction in friction between 60 and 85 per cent when the wire is subject to repeated vertical displacement with loads between 25 and 400 grams. There was an optimum reduction in friction with loads of 100 to 250 grams. Forces as light as 25 grams could reduce friction by 60 per cent.

In the mouth, the biomechanical system is more complicated and for translation of a single tooth along a continuous wire, the possible factors affecting relative displacement of the archwire are wire flexibility, bracket design, tooth mobility and mastication. The flexibility of the archwire is directly dependent on the length cubed and inversely proportional to the moment of inertia and the modulus of elasticity of the wire. In theory, archwires with greater flexibility would be expected to facilitate relative bracket-wire movement and thereby reduce friction. Small forces, well within the range exerted in the mouth, are sufficient to produce this effect. The effects of cyclical archwire displacement on a multi-bracketed system are not known. However, Braun *et al*,[5] who tested brackets at angulations up to 25 degrees, showed similar reductions in frictional resistance with angulated brackets.

Conclusions

The resistance to an archwire sliding through an orthodontic bracket is decreased by repeated vertical displacements of the wire. These displacements can reduce resistance by up to 85 per cent. While maximum reduction in frictional resistance occurs with forces ranging from 100 to 250 grams, forces as low as 25 grams can reduce friction by more than 50 per cent. Friction between an archwire and brackets in the mouth may not be correctly represented by steady mode laboratory models.

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