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Effect of bracket and wire composition on frictional forces

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SUMMARY Previous work on friction has considered movement of single teeth along an archwire. The aim of this investigation was to consider friction in buccal segment attachments during overjet reduction involving sliding mechanics. A buccal segment model was constructed to compare friction in steel and ceramic brackets, using steel and nickel titanium wires of two sizes along with a new experimental polymeric wire.

The results indicate that friction during overjet reduction is minimized by using larger dimension rectangular wires and by using steel rather than nickel titanium. Comparing steel with ceramic brackets in series, the latter show greater frictional resistance, but only when used with the smaller rectangular wires. The combined effect of environment, ligation, bracket, and archwire significantly reduced the difference. Clinically, there may, therefore, be little to choose between steel and ceramic brackets in the buccal segments, with wire choice as determined by tooth displacement being more important. Comparison of the results with those obtained using single brackets illustrates the problems of interpreting results from friction experiments. The polymeric archwire in its present form was found to be unsuitable for use in orthodontics.

Introduction

Much work has been done in recent years on the retraction of single teeth along archwires and the frictional forces involved in the process (Riley *et al.*, 1979; Frank and Nikolai, 1980). Classically, friction occurs at a tangent to the contact area between two materials and can be divided into static and dynamic modes (Nikolai, 1985). In orthodontics friction will vary between the two modes as the teeth being moved alternately tip and upright during movement of the wire through the attachments (Moore, 1987). Movement of the teeth during mastication will also alter the frictional mode at a given time. A further complication is that as teeth tip towards each other in the vertical plane, rotations will occur around their vertical axes. Thus, the contact area of the wire and bracket is altered, and frictional mode and force will be affected. In view of the very complex nature of the tooth movements which may occur it was decided to use a model of the buccal segment anchor teeth to simulate the frictional effects which may arise as the upper labial segment teeth are retracted with a pre-adjusted appliance. This permits a relatively simple experimental technique involving immovable brackets, on the assumption that the anchor teeth, as a block, will undergo minimal tipping and rotation during overjet reduction. This is almost certainly the case during overjet reduction where a mesially directed force is not being applied to the buccal segment teeth, as, for example, if sliding is produced by the effect of class II elastics or headgear to the upper labial segment. In the case of intramaxillary traction, however, some mesial tipping of the buccal segment teeth would occur which would obviously alter the friction in these attachments, although this may be minimized during periods when extra-oral anchorage is being applied directly to the first permanent molars.

The aim of this experiment was to determine the effect of wire and bracket composition on the frictional forces, and how these will further be modified by the environment. In particular, the effect on frictional forces of change of bracket material was investigated. Previous work has focused on changing wire size and composition, but has been limited to stainless steel and plastic brackets (Frank and Nikolai, 1980; Tidy, 1989; Peterson *et al.*, 1982). In view of the decline in the use of plastic brackets and the increased popularity of ceramic brackets it was decided to compare the latter with stainless steel brackets, ceramic tubes bonded onto first molars being rarely used. In addition, a new polymeric aesthetic archwire material was tested.

Materials and methods

The wires used in this experiment were stainless steel (Ormco) and nickel titanium alloy (Nitinol) of two sizes, 0.017″ × 0.025″ and 0.019″ × 0.025″. The brackets under test were stainless steel 0.022″ pre-adjusted ('A' Company) and polycrystalline ceramic 0.022″ pre-adjusted (Unitek Transcend). The mesiodistal widths of the brackets were 3 and 3.5 mm, respectively.

Testing was performed on an Instron Universal Testing Machine set with a cross-head speed of 5 mm/min. A pilot study examined standardized arrangements of brackets and archwires at cross-head speeds of 50, 20, 10, 5, 1, and 0.5 mm/min. The results showed no significant differences between the 0.5, 1, and 5 mm/min groups no matter what combination of tube and archwire was used. There was no tendency for the median values to increase or decrease at these cross-head speeds. It was decided that 10, 20, and 50 mm/min did not represent a true clinical situation and so 5 mm/min was chosen as a standard. The brackets were tested singly and, in order to simulate a wire moving through the attachments on anchor teeth during overjet reduction, as a unit of two brackets and one buccal tube (Fig. 1). Alignment of the slots was achieved by tying these attachments to a straight piece of 0.0215″ × 0.028″ stainless steel prior to mounting in acrylic. In the case of the buccal segment model the wires were tested with and without ligation using elastic ligature rings (Elast-o-loop, Lancer Pacific). Tests were performed on the ligated specimens, dry or after the elastomeric rings had been pre-soaked for 24 hours in a water bath at 37°C. In the latter case the same water was poured over the brackets during testing on the Instron. With the single bracket, also mounted in acrylic, testing was performed with and without elastomeric ligation. Elastic ligatures were used in preference to steel because of the difficulty in obtaining reproducible ligation with the latter. Testing was carried out immediately after ligation in all cases.

A new material for use as an aesthetic wire, namely Super-drawn Polyacetal (Asahi Chemical Ind. Co. Ltd. 1988), was tested in 0.020″ round form and was tested only with the buccal segment model using steel brackets and a buccal tube.

A total of 410 observations were recorded, with each being made as 10 mm of wire passed through the brackets. Scanning electron micrographs (SEM) were taken of new and used wires, and brackets using a Hitachi S-405A Scanning electron microscope.

Results

Data were analysed using the SAS PC statistical package version 6.03. A one-way analysis of variance was performed, and Bonferroni's test was used to compare effects at a probability level of 0.05. This test was chosen because it is a conservative test controlling the comparison-wise and experiment-wise error rate. *t*-Tests were used for environmental effects. Figures 4 and 5 are three-dimensional histograms of the results.

The effect of bracket material

Consideration of single brackets showed polycrystalline ceramic brackets to exhibit significantly less friction with all types and sizes of wire than did the single stainless steel brackets. Single brackets were tested only under dry conditions.

However, when frictional forces were compared between the buccal segment models of two ceramic brackets and one steel tube, and two steel brackets and one steel tube, there was no significant difference between their values under dry conditions with 0.019″ × 0.025″ wires, although with 0.017″ × 0.025″ wire the ceramic model showed significantly more friction.

The effect of wire composition and dimension

With each of the single brackets and the buccal segment models there were no significant differ-

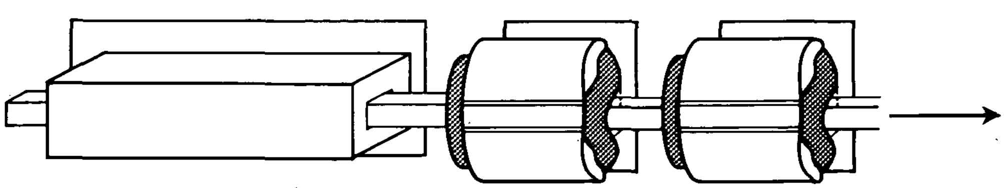


Figure 1 Diagrammatic representation of buccal segment anchor model.

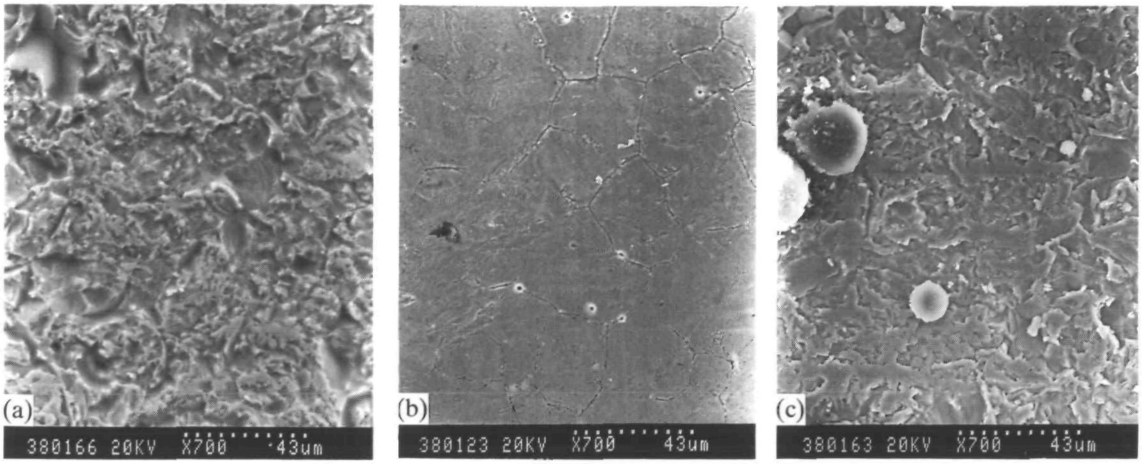


Figure 2 (a) SEM of new ceramic bracket slot (× 700). (b) SEM of new steel bracket slot (× 700). (c) Used ceramic bracket showing Nitinol wire debris in the slot (× 700).

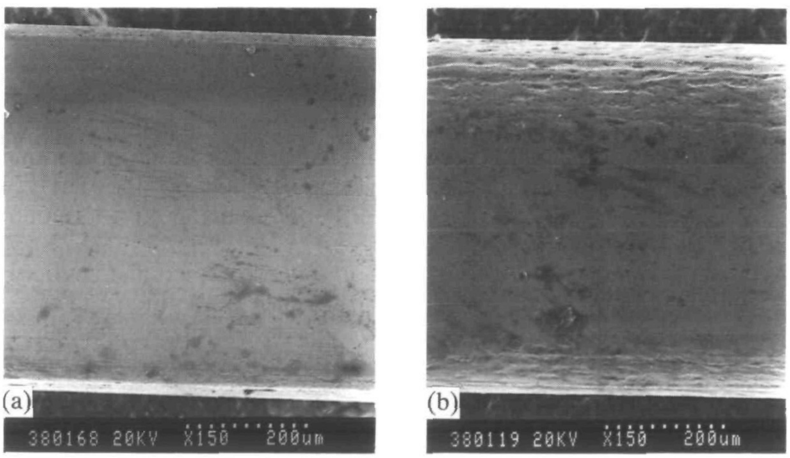


Figure 3 (a) Unused 0.017″ × 0.025″ steel wire (× 150). (b) Unused 0.017″ × 0.025″ Nitinol wire (× 150).

ences in frictional values between the two sizes of steel wire, except with the ceramic buccal segment model. Here the smaller wire gave the greater frictional value.

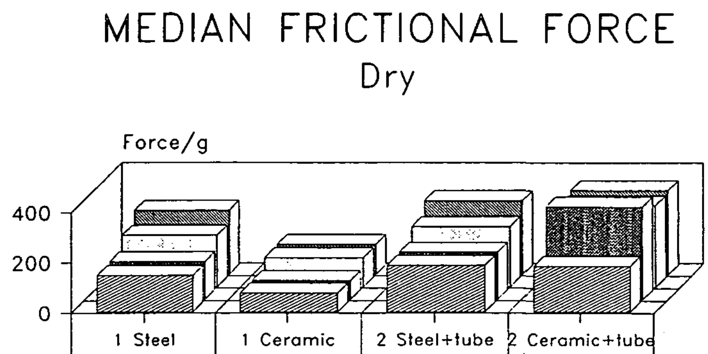
Moving on to Nitinol, with ceramic brackets, there was no significant difference between the two wire sizes. With steel brackets though, singly and in combination with a tube, there was a significant increase in friction as wire size increased.

Comparing stainless steel with Nitinol wires, within each bracket type under dry conditions, Nitinol gave significantly higher values, except for 0.017″ × 0.025″ steel in the ceramic buccal segment model which did not display significantly different results from that of the same size Nitinol wire. It was because of the unexpectedly high values obtained with this smaller dimension steel wire that it was retested in the ceramic buccal segment model. Although the results were slightly lower in the retest, there was still no significant difference between this small dimension steel wire and the equivalent Nitinol ($t = 1.95$, probability $= 0.07$).

Environment

The influence of dry versus wet conditions was investigated using only the bracket and tube combinations.

With stainless steel brackets there was no

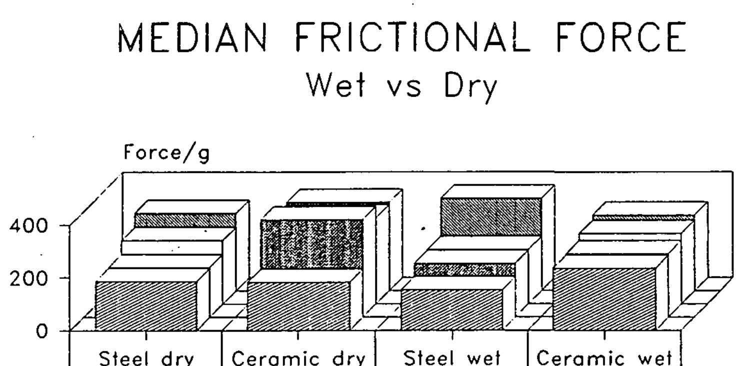


	1 Steel	1 Ceramic	2 Steel+tube	2 Ceramic+tube
0.019" x 0.025" Ni	255	120	295	335
0.017" x 0.025" Ni	205	115	240	325
0.017" x 0.025" ssw	150	75	187.5	370
0.019" x 0.025" ssw	145	75	185	182.5

System

0.019" x 0.025" ssw
0.017" x 0.025" ssw
0.017" x 0.025" Ni
0.019" x 0.025" Ni

Figure 4 Three-dimensional histogram of results (dry).



	Steel dry	Ceramic dry	Steel wet	Ceramic wet
0.019"x0.025"Ni	295	335	350	287.5
0.017"x0.025"Ni	240	325	205	267.5
0.017"x0.025"ssw	187.5	370	202.5	240
0.019"x0.025"ssw	185	182.5	152.5	235

System

0.019"x0.025"ssw
0.017"x0.025"ssw
0.017"x0.025"Ni
0.019"x0.025"Ni

Figure 5 Three-dimensional histogram of results (wet versus dry).

significant difference within each wire size between wet and dry. However, Nitinol wires still displayed greater frictional values than steel.

With the ceramic buccal segment model and with both wires of 0.019″ × 0.025″ dimension there was no significant difference between wet and dry conditions. Wet conditions led to a significant reduction in friction values for both types of 0.017″ × 0.025″ wire.

Ligation

In the case of both the single and the multibracket specimens, testing was performed with and without elastomeric ligation, and in each case ligation led to significantly higher values as might be expected. In fact, no force values were registerable without ligation.

Binding was not found to automatically increase with increase in archwire size when using elastomeric modules for ligation.

Super-drawn Polyacetal 'aesthetic wire'

The wire substitute did not slide through the brackets in testing, but merely underwent considerable plastic deformation before finally breaking.

Discussion

With single brackets it was interesting that ceramic appears to offer less frictional resistance than steel, and yet when placed in series with a buccal tube, and with the exception of the smaller dimension wires, there was little difference between the ceramic and steel multibracket systems under dry conditions. It would seem from this work, that with steel attachments friction is not additive, whilst with ceramic it is. In other words, friction will increase as the number of ceramic attachments is increased, but this is not the case with steel attachments. This phenomenon is difficult to explain. Classically, friction is dependent upon the normal force and the nature of the materials in contact. The ceramic brackets were larger mesiodistally than the steel brackets, and although friction is independent of area of contact, the elastomeric modules used for ligation would undergo greater stretching. Thus, they would be expected to apply a greater force to the archwire in the case of the larger bracket. Indeed, Stannard *et al.* (1986) testing wires gripped between steel plates under differing loads showed a marked increase in coefficients of friction with applied normal load, in agreement with the second law of friction (Bowden and Tabor, 1956). However, if bracket size and consequent ligational stretch were the only factors operating, the single ceramic brackets should show greater frictional resistance than the single steel brackets. This was not the case. It also does not explain why friction was only found to be additive with the ceramic brackets.

Friction is not only dependent upon normal force, but also on the materials in contact. The answer to the conflicting single and multibracket results between steel and ceramic attachments must, therefore, lie somewhere in the complex interplay of bracket material, wire material, surface topography of each, the number of attachments through which the wire is passing, the ligational forces and the ligature material. In addition, environment was also found to have an affect. In the clinical situation any bracket malalignment and additional torque applied to the wire would also be important, though these effects were minimized in this experiment.

Previous work with friction in single brackets has shown that altering wire size and material can give variable results. Kapila *et al.* (1990) by using wide 0.022″ brackets found that, in general, increasing wire size increases frictional force, although small increases in size may not significantly affect friction. It was also stated that with the larger 0.019″ × 0.025″ wires there was little difference between steel and Nitinol. Tidy (1989), however, states that within a bracket size, changing wire dimension has no effect on frictional force, although Nitinol gives greater values than steel wire. Garner *et al.* (1986) using a combination of the above showed an increase in friction with wire size and in changing from steel to Nitinol. Our experimental observations simply confirm the unpredictable nature of the results of work on friction. Wire dimension was not significant with steel wires in single or multibracket systems, with the exception of the ceramic multibracket system. In this case the smaller dimension wire actually gave the greater friction. This contradicts most other works on friction, and although Baker *et al.* (1987) found such results, their work used only single brackets, and of the wires only one was rectangular. Also they explained the results as being due to the greater likelihood of distortion and, thus, binding of the smaller dimension wire within the bracket, which is likely since it seems that the wire was pushed rather than pulled through the brackets during testing.

Nitinol gave significantly greater friction with most bracket types and combinations, which agrees with the works of Tidy (1989), Garner *et al.* (1986), and Drescher *et al.* (1989) where only single brackets were tested. The unexpected result was for the smaller, 0.017″ × 0.025″ steel wire in the ceramic multibracket combination which gave friction values similar to the same size of Nitinol.

The SEM pictures (Fig. 3a and 3b) confirm previous reports that Nitinol wires have greater surface roughness than stainless steel wire (Drescher *et al.*, 1989). In addition, Fig. 2a, b show ceramic brackets to have a much greater degree of surface roughness within the slot than do steel brackets. The SEM (Fig. 2c) of the used ceramic bracket after testing with Nitinol wire shows a large degree of surface debris in the used slot. Indeed, the effect of such debris could be seen macroscopically quite easily as a grey colouration in the slot. It is possible that such material, only seen with the ceramic brackets, could act to modify the sliding of the wires through the bracket slot. Exactly how such sliding asperities might affect frictional values is unclear from this experiment. Surface roughness has been postulated to increase friction by Garner *et al.* (1986), but our results once again indicate that the degree of surface roughness does not correspond directly with measured friction, since with the single brackets the rougher ceramic shows less friction than the smoother steel bracket. Similarly, with the ceramic multibracket model there was no significant difference between the steel wire and the rougher Nitinol wire in the smaller size.

The influence of environment, wet and dry, was found to be minimal with both bracket types using the larger dimension wires after 24 hours immersion of the ligatures in water. With the smaller wires, however, the environmental effect led to a significant reduction in frictional values with the ceramic buccal segment model, such that no significant difference was seen between the two wire materials. Stannard *et al.* (1986) working with artificial saliva found coefficients of friction to increase when compared with the results obtained under dry conditions. Baker *et al.* (1987), on the other hand, found friction to significantly reduce when a different saliva substitute was used, compared with dry testing. Once again our results contradict the results of both the above works, probably because no one factor alone dictates entirely the measured friction within a system. Friction is dependent upon the interaction of many factors of which environment is but one.

The results of both the single and multibracket experiments without ligation, where no frictional force values were registerable, indicated that bracket malalignment was not a contributory factor in any of the results obtained with the ligated specimens. Also with the latter specimens, increased archwire binding with increase in wire dimension due to elastomeric ligation, as suggested by Echols (1975), was not found to be the case.

Finally, the aesthetic wire proved inadequate as an orthodontic wire substitute since not only did binding prevent it from moving through the slot, but also led to considerable plastic deformation and eventual failure at relatively low force values. Superdrawn Polyacetal is produced from polyacetal resin which has been drawn several times. Altering the draw ratio alters properties such as Young's modulus and tensile strength. The sample used in this experiment seemed to have a low stiffness and may have been produced with a low draw ratio. Further work needs to be performed on samples of high draw ratio before its suitability for orthodontic use can be determined. A further disadvantage of Super-drawn Polyacetal at the present time is that it is available only in gauges of 0.5–2.5 mm diameter and in round form.

Conclusions

Under the conditions of the experiment, the following conclusions were reached.

1. Sliding mechanics are best performed using stainless steel wire rather than Nitinol if frictional forces are to be minimized.
2. Significant differences were seen between the two buccal segment models when smaller dimension wires were tested under dry conditions. The ceramic brackets displayed greater friction.
3. With the larger 0.019″ × 0.025″ wires no significant difference was detectable when using the two buccal segment models.

4. Friction is additive in the case of ceramic brackets, but not with steel brackets.
5. Environment had its greatest effect on 0.017″ × 0.025″ wires used with the ceramic model. Indeed, there was no significant difference between any of the wires with these brackets following environmental exposure and, in fact, little difference between the two buccal segment models. It is possible that clinically, during overjet reduction with sliding mechanics, friction will not be greatly influenced by the bracket material.
6. The frictional effects observed during movement of wire through buccal segment models, as would occur during overjet reduction with a pre-adjusted Edgewise appliance, are influenced by the complex inter-relationship of archwire size and dimension, bracket material, ligation, and environment.
7. Super-drawn Polyacetal in 0.020″ size is unsatisfactory as an aesthetic orthodontic wire substitute. The properties of the wire are greatly influenced by the drawing process during manufacture, and with further development a satisfactory aesthetic polymeric archwire may eventually be produced.

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