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An Investigation into the Behavioural Characteristics of Orthodontic Elastomeric Modules

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Abstract. *The object of the study was to investigate the behavioural characteristics of orthodontic elastomeric modules with regard to their effect on frictional resistance and their failure load forces, and involoved the use of an experimental laboratory-based study.*

Six cohorts were assembled employing five types of module and two bracket types. Straight lengths of 0·018 × 0·025-inch stainless steel were pulled through the ligated brackets and frictional resistance was measured using an Instron® universal testing machine. Recordings were repeated over a 4-week period, during which time the cohorts were placed in a simulated oral environment. Failure load forces of new and used modules were also recorded, and frictional resistance and failure load forces.

Analysis of variance revealed that the Minitwin cohort exhibited significantly higher frictional resistance and that the clear modules demonstrated the lowest levels of friction. Time soaked in a simulated oral environment had a variable effect on frictional resistance. A wide range of failure load forces was seen for the five types of module and all types showed a reduction in failure load force following their soaking in the simulated oral environment.

There was variation in performance of the different modules both in friction testing and failure load testing.

Index words: Elastomerics, Failure Load, Friction.

Introduction

The success of the straightwire appliance depends to a large extent on the ability of orthodontic archwires to slide freely through brackets and tubes. Friction may be defined as a force tangential to the common boundary of two bodies in contact that resists the motion of one relative to the other; it is proportional to the force with which the two surfaces are pressed together and dependent on the nature of the surfaces in contact. If frictional forces are high, the efficiency of the system is affected and the treatment time may be extended or the outcome compromised (Drescher *et al.*, 1989).

Many factors which influence friction have been investigated; these include wire alloy composition and dimensions, bracket material and width, as well as the test conditions, including method of ligation. Wire alloy composition is significant with stainless steel showing the least friction increasing through cobalt-chromium, nickel-titanium and beta-titanium (Kusy and Whitley, 1990). Rectangular wires cause more friction than round wires (Frank and Nikolai, 1980) and there is more friction with large diameter wires than small wires (Ho and West, 1991). Second order angulation has been found to a critical factor in determining frictional resistance (Andreasen and Quevedo, 1970; Tidy, 1989).

Investigations into bracket material have found that both plastic and ceramic brackets consistently show higher frictional resistance than stainless steel brackets (Riley *et al.*, 1979; Angolkar *et al.*, 1990; Tselepis *et al.*, 1994). Studies on the influence of bracket width on friction give inconsistent results which may be due variation in levels of second order angulation (Frank and Nikolai, 1980; Andreasen and Quevedo, 1970; Peterson *et al.*, 1982; Tidy, 1989).

Differences between testing in dry and wet conditions have provided a confused picture with different studies showing that lubrication increased (Stannard *et al.*, 1986), decreased (Ireland *et al.*, 1991) and had no effect on friction (Andreasen and Quevedo, 1970). The difference between artificial saliva and water in friction testing is negligible (Baker *et al.*, 1987). The third law of friction which states that the coefficient of friction is independent of velocity is not always correct and may be modified by the surface characteristics of the various alloys. Cold-welding may occur with beta-titanium but for stainless steel the sliding velocity does not appear to affect the coefficient of friction (Kapila *et al.*, 1990).

The influence of the nature of ligation of the wire into the

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bracket slot on friction has received relatively little attention. Several studies on self-ligating systems have demonstrated lower levels of friction (Berger, 1990; Sims *et al.*, 1993), but ligation with elastomeric modules or steel ties remains more popular. Ligation with steel ties can lead to higher frictional forces as a range of ligating forces may be used by different operators (Riley *et al.*, 1979). Sims *et al.* (1993) studied two methods of ligation with elastomeric ligatures; regular and figure-of-eight pattern. They found the figure-of-eight pattern greatly increased the friction relative to the conventional ties. Tselepis *et al.* (1994) found no statistically significant difference on frictional forces when using different elastic ligature rings. In a pilot study on the effect of stretching the modules for 6 days, they found significantly lower frictional values compared to new modules.

The aims of this study were to assess the influence of the elastomeric module on friction and to determine whether any differences occur between different types of module. In addition the influence of two different bracket types was examined and an evaluation of the effect of time dependent force degradation of elastomeric modules on friction was also studied. Finally, the failure load forces of the five types of module used in the study were measured both in their new state and following their participation in the friction testing which included immersion in a simulated oral environment for a 4-week period.

Materials and Methods

Five types of 0·011-inch diameter elastomeric module were selected (‘A’-Company®, Amersfort 3800, The Netherlands). Four types were produced by injection moulding and were round in cross-section (grey, clear, orange, and grey fluoride-impregnated). The fifth type was produced by die-punching and was rectangular in cross-section (grey).

Upper premolar brackets (‘A’-Company®, Amersfort 3800, The Netherlands) were chosen as these are typically brackets through which an archwire must slide during space closure. Fifty standard twin straightwire brackets were assembled with 0·022 x 0·028-inch slot dimensions. A further group of 10 upper premolar Minitwin brackets with similar slot dimensions were assembled. Six cohorts were then organised with ten bracket/module assemblies in each;

(A) Standard twin brackets/grey round modules.
(B) Standard twin brackets/clear round modules.
(C) Standard twin brackets/orange round modules.
(D) Standard twin brackets/grey round, fluoride-impregnated modules.
(E) Standard twin brackets/grey rectangular modules.
(F) Minitwin brackets/grey round modules.

Stainless steel strips measuring 3 × 1 × 0·0625 inches were used as mounting templates for the brackets. A jig was constructed to enable all the brackets to be mounted in identical fashion which consisted of two units of three stainless steel strips bonded together, separated by the length of one stainless steel strip (Fig. 1). The two units on either side were connected by two lengths of 0·021 × 0·025-inch stainless steel wire, one length along a scribe line which ran along the midline of the strips and the other length of wire was towards the edge of the assembly to provide stability (Fig. 1). A bracket was ligated to the middle 0·021 × 0·025-inch stainless steel wire, which was flush against the steel flats along its narrower dimension, one quarter inch from the left hand side. Epoxy-resin (Araldite®, Ciba-Geigy) was used as a water-proof adhesive and was applied to the bracket base. A blank stainless steel strip was introduced between the ends of the jig and the bracket was slowly lowered to enable the adhesive to contact the strip. The mounting jig was then placed against a steel block to ensure the assembly was parallel. The resin was allowed to set for 1 hour. The effect of this mounting procedure was that all specimens were mounted in a similar manner with zero degrees of tip and torque.

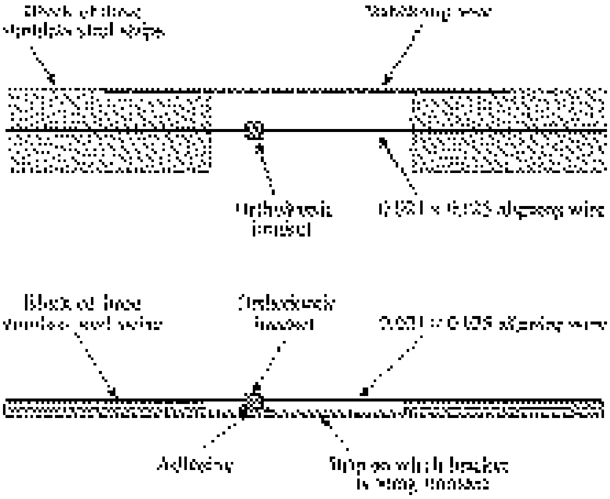

FIG. 1 Schematic representation of bracket mounting apparatus.

Twenty-centimetre long straight lengths of 0·018 × 0·025-inch stainless steel were placed in the brackets approximately 4 cm along their lengths. An Orthopli® 018 R forceps was used to place the modules over the brackets and engage the archwires. The first friction test was carried out in the dry state immediately following their ligation (T1).

An Instron® 1011 universal testing machine was used to measure frictional resistance. A 50 N transducer was used as the force values were so low. A cross-head speed of 1 mm/min was used. Following a calibration procedure, the specimens were loaded into the Instron® machine and testing in the tension mode was initiated (Fig. 2). Tension values were recorded digitally and graphically. Once a peak had been observed, the test was continued for a further ten seconds. The value of interest was the static coefficient of friction which was represented by the peak value. Following the initial test, the specimens were placed flat on a perforated shelf in a water bath at 37°C and subsequent tests were carried out in the wet state at weekly intervals (T2–T5).

In order to demonstrate the difference between the Standard and Minitwin brackets with regard to the nature of ligation, scanning electron microscopy was carried out on one specimen of each type along the length of the wire.

The second test carried out on the modules involved

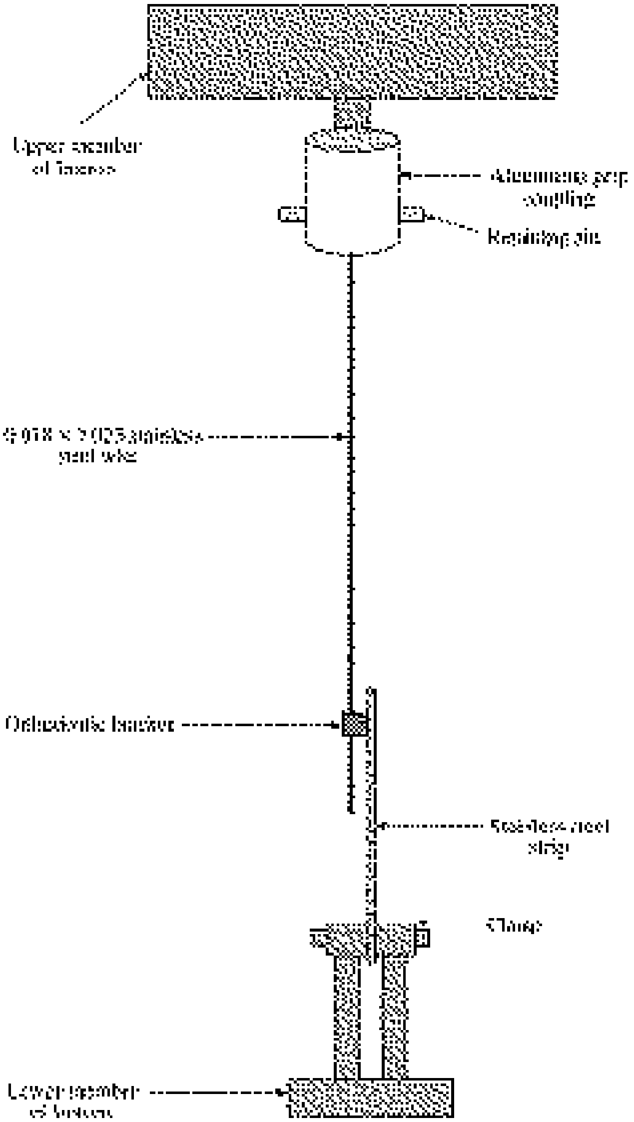

FIG. 2 Schematic representation of friction testing apparatus.

stretching the modules on the Instron® testing machine until they broke. Lengths of 0·020-inch round stainless steel were used to form U-shaped loops from which the elastomeric modules could be stretched on the Instron® testing machine. This was carried out using a cross-head speed of 50 mm/min. The peak force level was recorded digitally and graphically. Ten elastomeric modules of each of the five types were tested in the 'as new' state. Following the final friction tests the used modules which had been in a humid environment for 4 weeks at 37°C were removed from the specimens and transferred to the failure testing apparatus.

Within each week the effects of different modules on friction could be observed. A one-way analysis of variance (ANOVA) was used to determine differences for the means of the different cohorts. This analysis of variance was repeated each week. At T4 and T5, some of the distributions departed from normal and the Kruskal–Wallis test was then used as it is more appropriate on non-parametric data. The Tukey–Kramer HSD (honestly significant difference) test was used as a *post hoc* analysis to compare all pairs on a weekly basis. A repeated measures analysis of variance was used to determine differences in frictional values over time. A one-way analysis of variance (ANOVA) was carried out on both the new and used cohorts in the failure test. Paired *t*-tests were used to study differences between the new and used states for each module type.

Results

The results of these analyses indicated that there were highly significant differences ($P < 0{\cdot}001$) between the cohort means each week of the friction testing. The last cohort in all but the initial test showed the greatest differences and therefore in order to evaluate whether significant differences existed for other cohorts, a *post hoc* analysis was carried out which compared all pairs on a weekly basis. The Tukey–Kramer HSD (honestly significant difference) test was used which assumes that the sample sizes are all the same and tests at the exact 5 per cent level. In most cases, cohort F had strongly positive values indicating that it was significantly different from the other cohorts each week. The other cohort which most often had positive values was cohort B, the clear modules. Thus, it can be stated that the Minitwin cohort showed frictional values which were significantly higher ($P < 0{\cdot}05$) than the other cohorts and equally the clear module cohort had frictional values which were significantly lower ($P < 0{\cdot}05$).

The influence of time soaked in a simulated oral environment was evaluated on a week to week basis (Table 1). A repeated measures analysis of variance was carried out to determine differences in frictional values over time. Two assessments were made: the effect of time soaked irrespective of cohort and the differences between types over time. The repeated measures analysis of variance indicates that significant differences exist between the cohorts when soaked in a simulated oral environment over time and also that time soaked had a significant effect on the frictional forces for each cohort.

The failure load test results were analysed to determine if there were differences between the module types and to see if immersion in a simulated oral environment affected all types equally. A one-way analysis of variance of the 'as new' group revealed that there were highly significant differences between the means of the cohorts tested. The rectangular grey modules produced by die-punching were 50–80 per cent stronger than other cohorts tested. The clear modules demonstrated the lowest failure forces. A similar analysis of the 'used' group revealed that the clear and the fluoride-impregnated modules had the lowest failure load forces. The effect of 4 weeks immersion on the failure loads for each type of module can be seen in Table 2. All the cohorts showed a reduction in failure load force of approximately 10–20 per cent with the exception of the rectangular modules which suffered a reduction of 35 per cent. However, the rectangular modules still compared favourably with the other cohorts at the end of the 4 weeks.

Discussion

The actual friction values found for various combinations were similar to figures quoted in other papers (Downing *et*

TABLE 1 *Frictional resistance for all cohorts weeks 1–5*

	T1 Mean (SD) Newtons	T2 Mean (SD) Newtons	T3 Mean (SD) Newtons	T4 Mean (SD) Newtons	T5 Mean (SD) Newtons
A	1·05 (0·09)	1·28 (0·11)	1·32 (0·14)	1·21 (0·24)	1·15 (0·13)
B	1·06 (0·12)	0·91 (0·13)	0·85 (0·08)	0·83 (0·14)	0·70 (0·12)
C	0·91 (0·10)	1·25 (0·10)	1·21 (0·12)	1·26 (0·08)	1·18 (0·06)
D	1·16 (0·17)	1·19 (0·15)	1·13 (0·16)	1·11 (0·12)	0·96 (0·11)
E	1·46 (0·19)	1·32 (0·14)	1·15 (0·12)	0·97 (0·23)	0·93 (0·14)
F	1·32 (0·15)	2·54 (0·13)	1·88 (0·23)	1·77 (0·07)	1·65 (0·12)

(A) Standard twin brackets/grey round modules.
(B) Standard twin brackets/clear round modules.
(C) Standard twin brackets/orange round modules.
(D) Standard twin brackets/grey round, fluoride-impregnated modules.
(E) Standard twin brackets/grey rectangular modules.
(F) Minitwin brackets/grey round modules.

TABLE 2 *Mean failure loads of modules in new and used states*

	A Mean (SD) Newtons	B Mean (SD) Newtons	C Mean (SD) Newtons	D Mean (SD) Newtons	E Mean (SD) Newtons	F Mean (SD) Newtons
New	18·68 (0·78)	15·22 (0·34)	19·79 (1·10)	17·31 (0·64)	27·85 (2·29)	18·68 (0·78)
Used	17·00 (1·76)	12·10 (0·82)	16·75 (1·16)	11·61 (1·64)	17·97 (3·47)	16·35 (1·58)

(A) Standard twin brackets/grey round modules.
(B) Standard twin brackets/clear round modules.
(C) Standard twin brackets/orange round modules.
(D) Standard twin brackets/grey round, fluoride-impregnated modules.
(E) Standard twin brackets/grey rectangular modules.
(F) Minitwin brackets/grey round modules.

al., 1995; Sims *et al.*, 1993). As it is impossible to simulate accurately all the variables of the intra-oral environment, it is the relative rankings of the cohorts which is more meaningful than the actual frictional force values.

In week 1, the grey rectangular module produced by die-punching produced frictional forces significantly higher than other cohorts. This trend was not sustained during the subsequent 4 weeks with the levels for this group gradually diminishing to levels comparable with the other cohorts. Over the period of testing, the clear round module deviated markedly from the other types of module, producing the lowest frictional forces. The fluoride-impregnated module did not appear to degrade more significantly than other modules; the leaching out of fluoride may have been expected to cause rapid deterioration of performance but this was not reflected in frictional values. The standard deviations give an indication of the consistency of the performance of the various elastomeric modules. For the five types of module tested, there was reasonable consistency of frictional forces.

The most striking feature of the results was the difference in frictional forces between the standard twin and Minitwin assemblies which used the same type of module (cohorts A and F). For all weeks cohort F demonstrated frictional values approximately 30–40 per cent higher than cohort A, the exception being week two where the Minitwin group showed an enormous rise in frictional levels. Differences between cohorts A and F were highly significant each week ($P < 0{\cdot}001$). It is difficult to explain why the difference in bracket type produces such significant frictional differences. Examination of the ligated archwires along the long axis of the wire shows how the module rises more acutely in the Minitwin bracket (Fig. 5). Kuroe *et al.* (1994) studied the Friction-free bracket and claimed the absence of vertical load resulted in low frictional forces. The more acute rise in the module for the Minitwin bracket may result in an increased vertical load when compared to the standard twin bracket. This disagrees with Kapila *et al.* (1990) who found lower level of friction in narrower brackets than wide brackets which they attributed to greater stretching of the elastomeric module over the wider bracket. In our test, the Minitwin bracket was narrower than the standard twin bracket and yet it showed higher levels of friction. The origin of the steep rise in frictional forces found in week 2 is obscure.

Previous studies on force degradation of elastomerics have shown force reductions of 50 per cent (Rock *et al.*, 1986) to 73 per cent (Wong, 1976) over a 4-week period. This degradation was not mirrored by a concomitant reduction in frictional forces. Time soaked in a simulated oral environment produced a variable response in terms of frictional resistance as can be seen in Table 1. Some cohorts showed increases in frictional levels, some remained fairly constant and others showed decreases. This implies that it is possible that factors other than the vertical force may be involved in frictional resistance.

Failure load testing reveals another physical characteristic of the elastomeric modules used in this study, namely, the likelihood that the module will break during use with a subsequent loss of tooth control. In the new state, the rectangular grey module produced by die-punching demonstrated the highest failure load forces. Participation

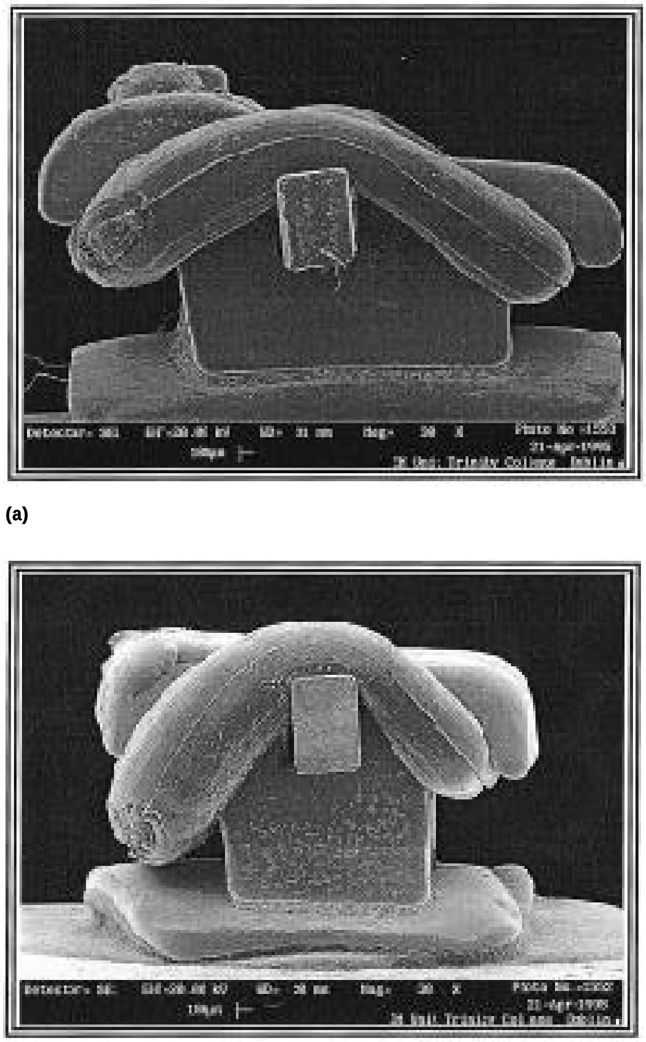

FIG. 3 Scanning electron micrograph of (a) standard and (b) Minitwin assemblies along the length of the archwire.

in the friction test including soaking resulted in a reduction of failure load force for all types of module. Following immersion, the clear and fluoride-impregnated modules had the lowest failure load forces. Therefore, the advantage of low friction levels for the clear modules must be carefully balanced against the likelihood of failure which could result in loss of tooth control.

Ex vivo studies tend to focus on individual factors under controlled conditions. *In vivo* conditions may differ markedly due to such variables as wide temperature changes, masticatory forces and parafunctional oral behaviour. Thus, although *ex vivo* findings are a useful guide to anticipated clinical behaviour, the observed clinical performance may be quite different. Caution must be exercised in extrapolating *ex vivo* findings to *in vivo* behaviour.

Conclusions

1. Significant differences ($P < 0{\cdot}001$) exist with regard to friction between the five types of elastomeric module tested using 0·018 × 0·025-inch stainless steel archwires through 0·022 × 0·028-inch slots at zero degrees tip and torque. The clear round modules exhibited the lowest frictional values.
2. Highly significant differences ($P < 0{\cdot}001$) occur between standard twin and Minitwin brackets with 0·018 × 0·025-inch stainless steel archwires through 0·022 × 0·028-inch slots at zero degrees tip and torque when the grey round elastomeric module is used for ligation. The difference varied from week to week between 30 and 100 per cent.
3. Time immersed in a simulated oral environment affected different modules in different ways with regard to friction. For some, the frictional forces increased, while for others the forces decreased or remained fairly constant. The dramatic force degradation seen for elastomeric chains in previous experimental work was not reflected in changes in frictional forces.
4. Immersion in a simulated oral environment resulted in a reduction in failure load strengths for all the types of module tested of between 10 and 35 per cent. It is therefore recommended that all modules be replaced at each visit for routine appliance adjustment.

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