A Comparison of Self-ligating and Conventional Orthodontic Bracket Systems

G. E. READ-WARD, B.D.S., M.SC., F.D.S.R.C.S. (ENG. AND EDIN.), M.ORTH, R.C.S. (ENG.)
Department of Orthodontics, The Royal Bournemouth Hospital, Castle Lane East, Bournemouth BH7 7DW, U.K.

S. P. JONES, B.D.S., M.SC., F.D.S.R.C.S. (EDIN.), M.ORTH. R.C.S. (ENG.)

E. H. DAVIES†, M.I.SC.T.

Departments of *Orthodontics and †Materials Science, Eastman Dental Institute, 256 Gray's Inn Road, London. WC1X 8LD, U.K.

Abstract. *This* ex-vivo *study compared the static frictional resistance of three self-ligating brackets with a conventional steel-ligated Ultratrimm® bracket. The effects of archwire size (0·020, 0·019 × 0·025 and 0·021 × 0·025-inch), bracket/archwire angulation (0, 5 and 10 degrees) and the presence of unstimulated human saliva were investigated. The study demonstrated that both increases in wire size and bracket/archwire angulation resulted in increased static frictional resistance for all bracket types tested, with the presence of saliva having an inconsistent effect. Mobil-Lock Variable-Slot® had the least friction for all wires for 0 degrees angulation. However, with the introduction of angulation, the values were comparable to those of the other brackets. Activa® brackets had the second lowest frictional resistance, although high values were found with 0·019 × 0·025-inch wires.*

SPEED® brackets demonstrated low forces with round wires, although with rectangular wires or in the presence of angulation, friction was greatly increased.

Ultratrimm® brackets produced large individual variation, confirming the difficulty in standardizing ligation force, although under certain conditions, significantly larger frictional forces were observed.

In conclusion, self-ligating brackets showed reduced frictional resistance in comparison to steel ligated brackets only under certain conditions.

Index words: Archwires, Brackets, Friction, Saliva, Self-ligating.

Refereed Paper

Introduction

The increasing use of sliding mechanics in orthodontics has led to considerable research interest in the frictional forces developed between the archwire and bracket, which may inhibit tooth movement, require larger retraction forces and lead to anchorage taxation. Much of this research has led to the development of archwires of differing materials and properties, along with a plethora of brackets, differing in material, construction and design, appropriate to the technique with which they are to be used. This *ex-vivo* study compared the static frictional resistance of Activa® ('A' – Company, San Diego, California, U.S.A.), Mobil-Lock Variable-Slot® (Forestadent®, 5, rue Jacques Peirotes, Strasbourg, France, patented) and SPEED® (Strite Industries Ltd., Cambridge, Ontario, Canada; OREC Corporation, San Clemente, California, U.S.A.) self-ligating brackets with a conventional stainless steel ligated Ultratrimm® (Dentaurum – Hawley, Russell and Baker Ltd., Potters Bar, Herts) bracket, under conditions of increasing wire size and the influence of binding angulations.

Friction has been defined as 'the resisting force tangential to the common boundaries between two bodies when, under the action of an external force, one body moves or tends to move relative to the surface of the other' (Kajdas *et al*., 1990). It may be affected by:

(1) kinematics of the surfaces in contact (i.e. the direction and magnitude of the relative motion between the surfaces in contact);
(2) externally applied loads and/or displacements (including orthodontic ligation);
(3) environmental conditions such as temperature and lubricants;
(4) surface topography;
(5) material properties.

It may be divided into static friction, which is the force required to initiate tooth movement, and kinetic friction, the force that resists motion (Kajdas *et al*., 1990). The coefficient of static friction is always larger than kinetic friction (Jastrzebski, 1959). It is felt that the former is of more importance in tooth movement, for when a tooth slides along an archwire, tooth movement occurs in a series of short jumps as the archwire and biological resistance strive to upright the root through the alveolar bone, with the static frictional resistance needing to be overcome each time the tooth moves a little.

Orthodontic treatment with sliding mechanics involves a relative displacement of wire through bracket slots and whenever sliding occurs, frictional resistance is encountered. The magnitude, control and clinical significance of this frictional resistance is largely unknown (Stoner, 1960; Andreasen and Quevedo, 1970; Burstone and Koenig,

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1976; Frank and Nikolai, 1980; Tidy, 1989). Up to 60 per cent of the applied force is dissipated as friction (Drescher *et al*., 1989) which reduces the force available for tooth movement (Huffman and Way, 1983), such that an adequate translating force must be applied in order to overcome the frictional force. With increasing frictional resistance, proportionally greater forces will be required (Andreasen and Quevedo, 1970). However, as a result of appliance inefficiency and friction, it is difficult both to determine and control the magnitude of force that is being received by the individual tooth (Stoner, 1960; Proffit, 1993).

Schumacher *et al*. (1990), stated that friction was determined mostly by the nature of ligation and not by the dimensions of the different archwires. Friction is related to the applied normal force, which is influenced by the degree of tension of the ligature engaging the archwire into the slot (Nicolls, 1968; Paulson *et al*., 1970; Farrant, 1976) and the coefficient of friction between the ligature and the archwire material (Frank and Nikolai, 1980).

Self-ligating brackets were first introduced in the mid-1930s in the form of the Russell attachment whose main aims were a reduction in ligation time (claims were made of up to 50 per cent reduction in chairside time) and improved operator efficiency (Stolzenberg, 1935, 1946). From the patient's perspective self-ligating brackets are generally smoother, more comfortable and easier to clean due to the absence of wire ligatures (Shivapuja and Berger, 1994).

Three self-ligating brackets were investigated in this study.

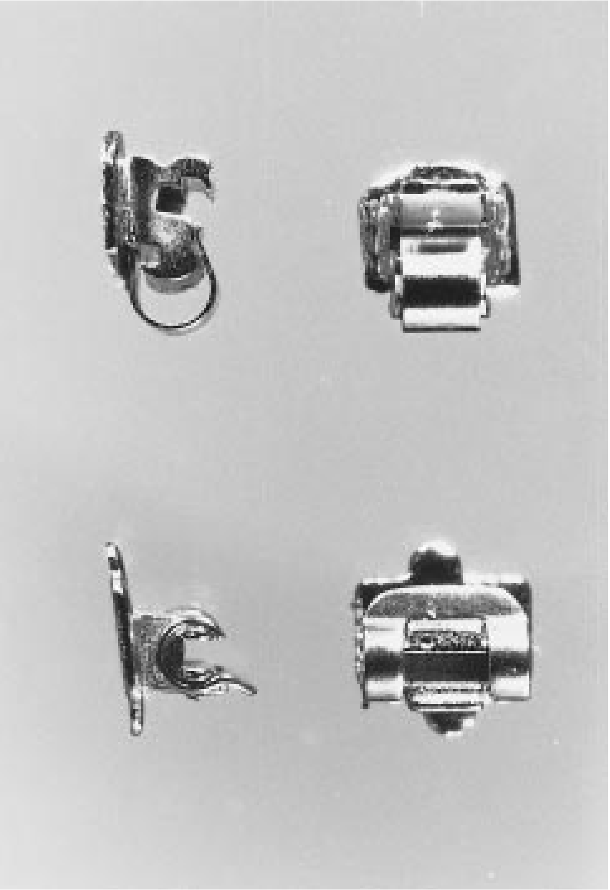

FIG. 1 ACTIVA® and SPEED® brackets: superior and lateral view.

(a) Activa® brackets ('A'-Company) (Fig. 1)

1. Introduced in 1986 and relaunched in 1991 with minor modifications.
2. Hinged cover, which when locked, converts the slot into a rigid tube of 0·022 × 0·028-inch.
3. Vertical slots for the incorporation of auxiliaries.
4. Relatively large slot length (3·45 mm).

(b) SPEED® brackets (Strite Industries) (Fig. 1)

1. Prototypes developed in 1971, design optimization being carried out in collaboration with Strite Industries and OREC Corporation from 1976 (Hanson, 1986).
2. SPEED®, an acronym, is derived from the descriptive terms; Spring-loaded, Precision, Edgewise, Energy, Delivery.
3. Multi-slotted bracket body with auxiliary slot.
4. Pretorqued archwire slot, which may take round, rectangular or the special SPEED® shaped (bevelled) archwires which optimize bracket archwire engagement.
5. Spring retainer slot, which has been incorporated into the design to house the recurved tip of the spring clip and prevent accidental archwire release (Berger, 1994).
6. Resilient spring clip which converts the archwire slot into a trapezoidal tube with three rigid walls and an elastic, inclined labial wall. Its functions are to: (i) reduce sliding friction; (ii) produce optimal three-dimensional control due to the elastic strain of the spring setting up restoring forces automatically which, as well as assisting in the initial stages of alignment, may help to extend the range over which light corrective forces remain active, even when very stiff archwires are used. It may also permit the insertion of rigid wires earlier in treatment.

(c) Mobil-Lock Variable Slot Lock® brackets (Forestadent) (Fig. 2)

1. Developed by the University of Bonn Orthodontics Department.
2. Clockwise rotating, eccentric cam, resulting in the variable slot (0·016–0·022-inch in the occlusogingival direction), which may be adjusted by the use of a key which is constructed with a 'ratchet' system such that the archwire is engaged only up to a certain pressure, after which the ratchet will slide (Alst, 1983).
3. Three main positions for the lock. (i) Open position. (ii) Free-sliding, where the depth of the slot is 0·022-inch and permits maximum play of the archwire. (iii) Further turning of the cam leads to gradual engagement of the archwire up to the point of locking the archwire, it is

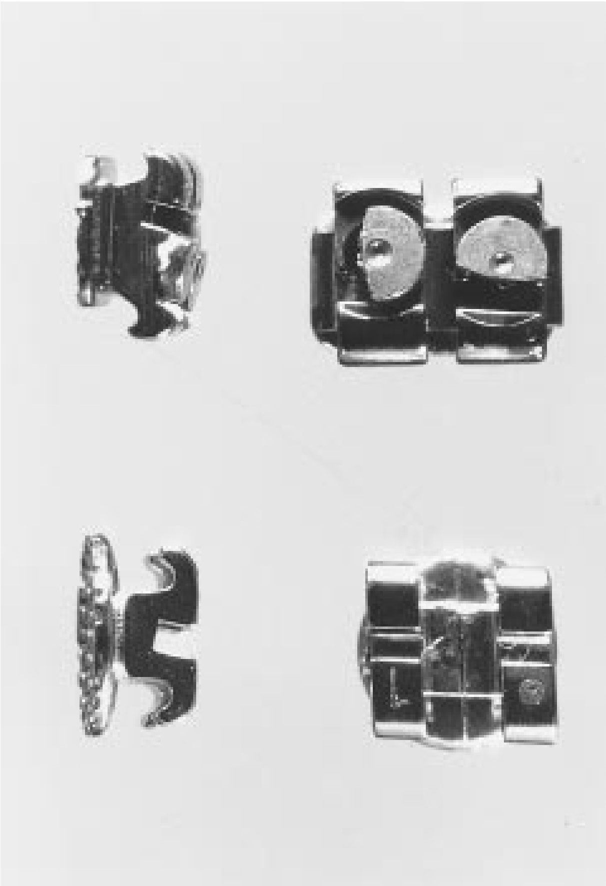

FIG. 2 Mobil-Lock® and Ultratrimm® brackets: superior and lateral view.

possible to regulate the amount of torque and tip transmission to the tooth (Forestadent, 1981).

Frictional considerations

Previous investigations have shown a reduction in friction in comparison to conventional bracket types for SPEED® brackets (Berger, 1990; Sims *et al*., 1993; Taylor, 1993) and Activa® brackets (Griffies *et al*., 1993; Sims *et al*., 1993; N. G. Taylor, personal communication). In fact, Sims *et al.* (1993), found that at times the friction of Activa® brackets was negligible, obtaining such low values of the order of 0·03 N, that there was concern regarding the sensitivity of the load cell being adequate. Another study found no statistical difference between Activa®, SPEED®, Edgelok® (ORMCO, Glendora, Calif., U.S.A.) and a conventionally ligated twin bracket (Shivapuja and Berger, 1994). Bednar *et al.* (1991), found that in a comparison of SPEED® brackets and a conventional bracket system, the former exhibited similar or greater friction than the latter. They felt that despite the self-ligating clip design inherently decreasing friction, once the tooth tipped during translation, it was the reduced width of the SPEED® bracket that determined the increased frictional resistance.

The frictional forces associated with SPEED® brackets, increased in a stepwise progression through the increasing wire sizes (Berger, 1990). Sims *et al.* (1993) confirmed this, with the exception of the largest (0·019" × 0·025") archwire, which tended to suggest that friction in SPEED® brackets may not necessarily be a function of archwire width, but possibly related to the occupation of the slot depth. The Activa® brackets, however, showed no (Sims *et al*., 1993) or minimal (N. G. Taylor, personal communication), stepwise progression of increased resistance to sliding movement through the brackets with increasing archwire dimensions. N. G. Taylor (personal communication) in sliding round and rectangular stainless steel archwires through simulated buccal segment attachments, found that with round wires both SPEED® and Activa® brackets, frictional forces below 10 g force were recorded. However, for rectangular wires, much greater forces were recorded for both the standard pre-adjusted stainless steel and SPEED® brackets.

Berger (1990) in examining both static and kinetic friction, found that SPEED® brackets showed dramatically lower initial force levels, followed by an almost constant low level of force during continuous translation as compared with other orthodontic bracket-wire systems, irrespective of the means of ligation. These lower force values, in combination with the absence of the erratic pen charting observed on flow charts with other ligated bracket systems, he felt, were suggestive of an almost frictionless system.

Little work has been carried out on the frictional characteristics of the Mobil-Lock® system.

The effect of salivary lubrication is a controversial subject, with investigations carried out under dry conditions or with the addition of human, artificial saliva or water, producing conflicting results. Kusy (1991) stated that experiments conducted in artificial saliva were invalid, and that it was no replacement for human saliva. A similar conclusion was drawn following the evaluation of the efficacy of five different artificial salivas, in comparison with deionized water, normal human saliva and the dry state (Kusy and Whitley, 1992). A number of studies have found that friction is increased by human saliva (Koran *et al*., 1972; Kusy *et al*., 1990, 1991; Kusy and Saunders, 1991). Others felt that saliva played an insignificant role (Andreasen and Quevedo, 1970).

Aims

The aims of this study were to investigate the static frictional resistance of three self-ligating brackets Activa®, Mobil-Lock® and SPEED®, and compare them to a conventional stainless steel ligated bracket—Ultratrimm® (Fig. 2). Each of the brackets were examined for three differing archwire sizes (020 inch round, 0·019 × 0·025 inch and 0·021 × 0·025 inch rectangular cross-sectional stainless steel) and at varied bracket to archwire angulations (0, 5 and 10 degrees), in order to simulate the clinical situation by the introduction of binding. The effect of unstimulated saliva at zero angulation was also examined.

Materials and Methods

One-hundred-and-twenty brackets of each type were used, 10 tests were carried out in each sample of bracket/wire

TABLE 1. *Bracket slot lengths*

Bracket Type	Activa®	Mobil-Lock	SPEED®	Ultratrimm®
Width	3.45 mm	4.25 mm	1.53 mm	3.72 mm

combination with a total of 480 tests. The dimensions of the brackets are as shown in Table 1. Each bracket and archwire was degreased with 100 per cent industrial methylated spirits and allowed to air dry for at least 5 min before each test. For the Ultratrimm® brackets, 0·010 inch stainless steel ligatures were tied using a pair of modified ligature locking pliers (Dentaurum – Hawley, Russell and Baker Ltd., Potters Bar, Herts) incorporating a strain gauge so that the ligatures could be placed with a reproducible force level for each test sample. A preliminary calibration study of this technique revealed that this strain was approximately equivalent to a force of 400 g. The locking mechanism of the Mobil-Lock Brackets® was closed to the free sliding position, in a standardized manner, by the use of a pointer attached to the 'Mobil-lock key' (Forestadent®, 5, rue Jacques Peirotes, Strasbourg, France) and a marked piece of card which allowed the key, and hence the locks, to be turned by the same amount for each bracket.

Testing apparatus (Figs 3–6)

Each bracket was secured in a bracket mount by means of an adjustable vice and screw beneath the bracket base. A 0·021 × 0·025-inch wire was placed into the archwire slot and through the turrets of the jig. The bracket holding vice was then adjusted for correct horizontal alignment of the bracket to the wire. The bracket mount was firmly tightened at 0 degrees, or rotated to 5 or 10 degrees as required. If the test was to be carried out in the presence of fresh, non-stimulated, human saliva, then a drop was added at this stage. The testing jig consisted of a 'frictionless piston' to which an axial tensile force could be applied by an Instron Universal Testing Instrument (Model number

FIG. 3 Testing apparatus positioned on Instron.

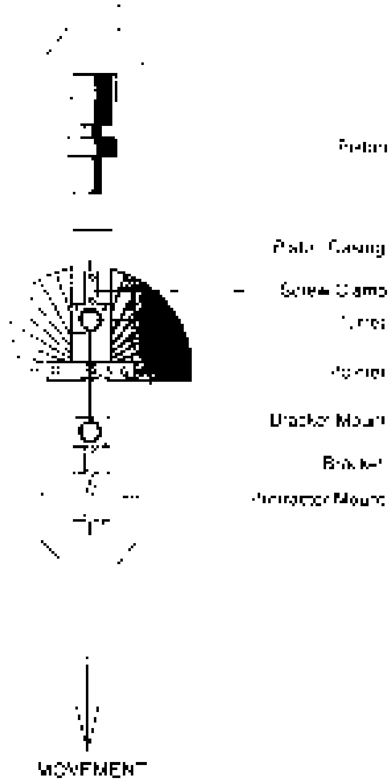

FIG. 4 Superior view of testing apparatus.

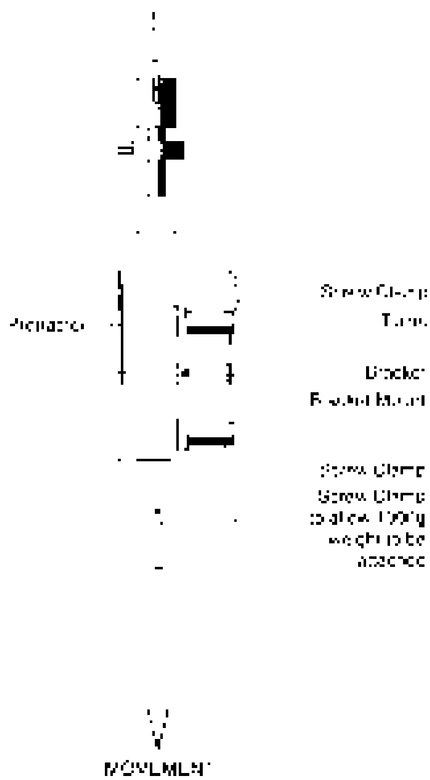

FIG. 5 Lateral view of testing apparatus.

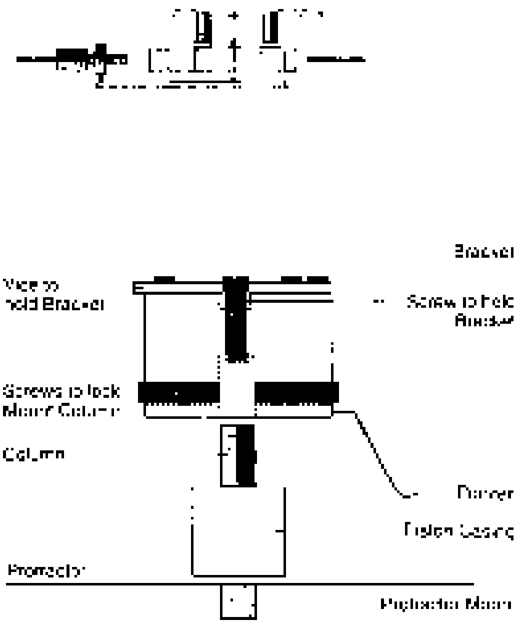

FIG. 6 Exploded lateral cross-section through bracket mount.

4505. Instron Ltd., High Wycombe, Buckinghamshire, U.K.) with a cross-head velocity of 0·5 mm min^{-1}. The force levels were processed by computer and displayed as a force displacement graph. The curve produced, took the form of an initial peak followed by a plateau region, the former corresponding to the force required to commence movement of the bracket relative to the archwire and was taken as the value for the static frictional resistance.

Results

The results were entered onto the NANOSTAT (Alphabridge Ltd, 26 Downing Court, Grenville Street, London) statistical computer programme. Initial examination of the data to determine the mean, standard deviation and 95 per cent confidence intervals and as shown in the graphs of the untransformed data (Figs 7 and 8), this revealed that the data was not normally distributed and logarithmic transformation was performed in order to carry out parametric statistical analysis. One-way analysis of the data (ANOVA) was used to identify any significant differences between groups. The Neuman–Keuls test was then used to locate where the differences arose (Armitage and Berry, 1987). The effect of saliva was analysed using Student's two-sample *t* tests (Bulman and Osborn, 1989).

Comparison of the brackets were made with three different wire sizes (0·020, 0·019 × 0·025 and 0·021 × 0·025-inch) at 0, 5 and 10 degrees angulation under dry conditions (Fig. 7). The significant results were as follows.

At 0 degree angulation with 0·020-inch wires, Mobil-Lock® had the least frictional resistance, being significantly less than SPEED® ($P \leq 0{\cdot}01$) and Ultratrimm® ($P \leq 0{\cdot}01$). Activa® also had significantly less friction than Ultratrimm® ($P \leq 0{\cdot}05$). With 0·021 × 0·025-inch wires, SPEED® brackets caused significantly greater friction than Activa® brackets ($P \leq 0{\cdot}05$) and very significantly greater than Mobil-Lock® brackets ($P \leq 0{\cdot}01$). At 5 degrees angulation with 0·020-inch wires, Activa® brackets had the greatest friction being significantly greater than Mobil-Lock®, SPEED® ($P \leq 0{\cdot}01$) and Ultratrimm® brackets ($P \leq 0{\cdot}05$).

Comparison of the brackets at 0° angulation under wet conditions (Fig. 8) revealed that for 0·020-inch wires, there were highly significant differences ($P \leq 0{\cdot}01$) between all the brackets apart from Activa® and SPEED®, where this was at the $P \leq 0{\cdot}05$ level. The ranking was unchanged from that under dry conditions. For 0·019 × 0·025-inch wires, Mobil-Lock® brackets had very significantly less friction than all the other brackets ($P \leq 0{\cdot}01$). There was also a very significant difference between SPEED® and Activa® brackets ($P \leq 0{\cdot}01$). For 0·021 × 0·025-inch wires Activa® brackets had the least friction being significantly less than Ultratrimm® ($P \leq 0{\cdot}01$) and Mobil-Lock® ($P \leq 0{\cdot}05$) brackets.

Discussion

The various 'mechanisms' of self-ligation may have a great effect on the development of friction and thus upon sliding mechanics. This study aimed to compare the different brackets under a set of specific variables (bracket, increasing wire size, angulation of bracket to wire and saliva) maintaining all other factors constant.

In general

1. The effect of increasing wire size resulted in increased friction, which was in agreement with the results of other previous studies (Andreasen and Quevedo, 1970; Riley *et al*., 1979; Peterson *et al*., 1982; Garner *et al*., 1986; Drescher *et al*., 1989, 1990; Kapila *et al*., 1990; Tanne *et al*., 1991).
2. The effect of increasing angulation resulted in increased friction, which also agreed with previous work (Andreasen and Quevedo, 1970; Frank and Nikolai, 1980; Peterson *et al*., 1982; Spiller *et al*., 1990; Dickson *et al*., 1994; Sims *et al*., 1994).
3. The presence of saliva had an inconsistent effect on the static frictional resistance, in some cases with saliva functioning as a lubricant and at other times acting to increase friction. This variation in the effect of saliva confirms the unpredictability obtained in previous investigations, for example in the work by Stannard *et al*. (1986) or the work by Baker *et al*. (1987) using different artificial salivas, where saliva was found either to increase or decrease friction respectively, thus reiterating the multifactorial nature of friction within a system, where saliva is only one of the factors.

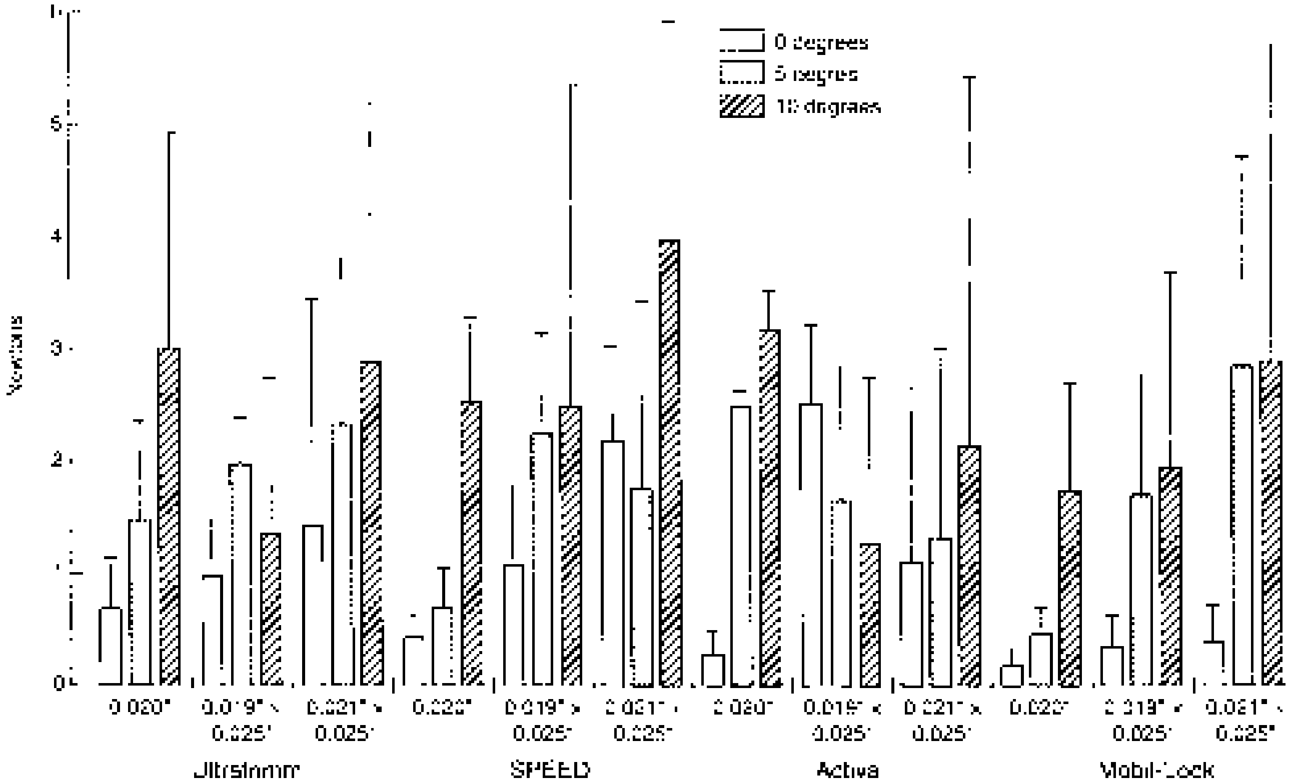

FIG. 7 Bar chart of the untransformed data and standard deviations, illustrating the effect of increasing angulation and wire size, under dry conditions.

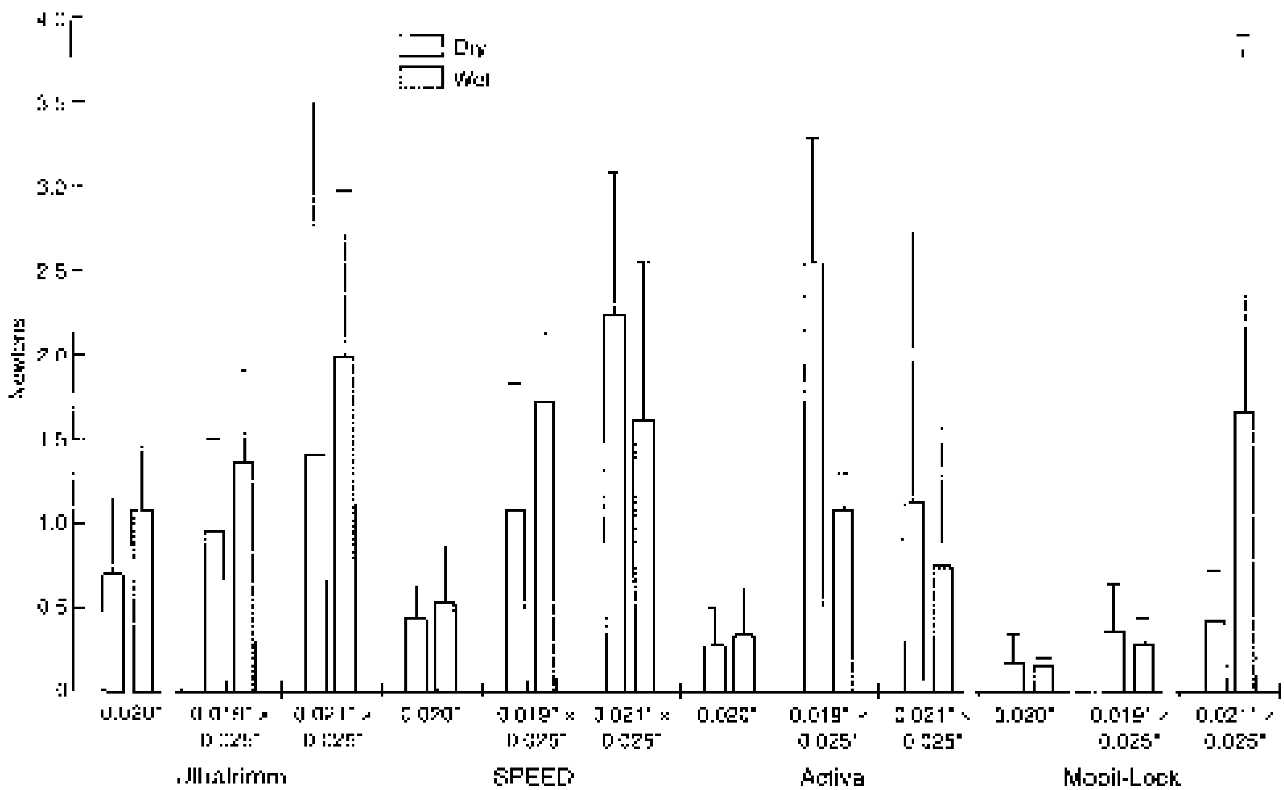

FIG. 8 Bar chart of the untransformed data and standard deviations, illustrating the effect of saliva with increasing wire size, at 0 degrees angulation.

Comparison of the various bracket types

Mobil-Lock® brackets consistently demonstrated the least friction of all the brackets under conditions of increasing wire size. However, when bracket to archwire angulation was introduced, the friction with the rectangular archwires was greatly increased, such that the frictional resistance was comparable to the other brackets. Thus, in a well aligned arch, the cam locking system effectively converts the bracket into a tube with four rigid walls, allowing the wire to pass through the bracket without any direct forces being applied to it. However, under the influence of angulation, the comparatively greater increase in friction may be associated with the larger width of the bracket (4·25 mm), resulting in a larger normal force.

Activa® brackets produced the second lowest frictional resistance for the 0·020-inch wire at 0 degree angulation. In the presence of angulation, for both 0·021 × 0·025-inch and more so for the 0·020-inch wires there was a comparatively large increase such that they caused the greatest friction of all the bracket types, this being consistent with those results of Sims *et al.* (1994), who found, with rectangular wires, an almost proportionate increase for all brackets, but a more profound effect per degree increase for Activa® brackets. They stated that it was the excessive slot length of the Activa® brackets (3·45 mm) which resulted in decreased interbracket span, consequently increasing binding when tip was introduced. The comparatively larger friction resistance associated with the 0·019 × 0·025-inch wires, under both dry conditions and in the presence of saliva, was contrary to the previous findings of Griffies *et al.* (1993), Sims *et al.* (1993) and N. G. Taylor (personal communication). In the presence of angulation, friction was greatly increased by the labial deflection of the spring clip against the spring clip retainer slot, described by Berger (1992) 'as a twisted and rigid metal wall', again resulting in an increased normal force. Thus, with rectangular wires at varying angulations, some of the largest frictional forces were recorded, which is in agreement with the results of Bednar *et al.* (1991), where SPEED® brackets demonstrated no less friction than the other types of brackets tested. However, it is important to mention that 'SPEED® archwires' (Strite Industries Ltd., Cambridge, Ontario, Canada; OREC Corporation, San Clemente, California, U.S.A.) which have one of the corners of the rectangular wire bevelled, may well have altered frictional forces, but as yet have not been investigated.

Ultratrimm® brackets produced the largest frictional values for 0·020-inch archwires and followed the expected patterns for increasing archwire size and angulation except for the values at 10 degrees angulation. However, there were very few significant differences obtained due to the large individual variability in the friction associated with the use of stainless steel ligation, which has been reported previously (Nicholls, 1968; Tidy, 1989; Bednar *et al.*, 1991).

Conclusions

1. For zero angulation, self-ligating brackets systems demonstrated significantly lower static frictional resistance in comparison to a conventional steel ligated brackets, for the 0·020-inch wires under both wet and dry conditions, but for the 0·021 × 0·025-inch wires, and the wires used most commonly in sliding mechanics (0·019 × 0·025-inch), the differences between the brackets were less statistically significant.
2. Increasing angulation resulted in trends of increased frictional resistance with the Activa® brackets having statistically, the greatest friction with the 0·020-inch wires at 5 degrees angulation.
3. The presence of saliva had an inconsistent effect, but the same ranking and statistically significant differences were produced by the various brackets with 0·020-inch wires.

These conclusions would suggest that other advantages of self-ligating brackets, as well as those of potentially reduced friction, should be borne in mind when considering their use.

Acknowledgements

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