# Frictional Resistance Between Begg and Tip-Edge Brackets and Archwires

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## 1.2 Abbreviations used in the text

**Table 1 Abbreviations used in the text with their meanings**

| Abbreviation | Meaning |
|---|---|
| Alast | Alastik |
| Aux | Auxiliary |
| BP | Brass pin |
| Co-Ax | Co-axial (Co-Ax®) |
| DF | Degree of freedom |
| Deflect | Deflection |
| Elast | Elastomeric |
| Envir | Environment |
| Lig | Ligature/Ligation |
| Mod | Module |
| NiTi | Nickel-titanium |
| N | Newton (unit) |
| SS | Stainless steel |
| S.winder | Side-winder |
| S.E.M. | Scanning Electron Microscope |
| TP | TP Orthodontics |
| Tp | T pin |
| Treat | Treatment |
| URS | Uprighting spring |

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### 1.5 Abstract

The present *in vitro* study aims to measure the frictional resistance between Begg and Tip Edge brackets and some commonly used arch wire combinations. The combinations simulated the various stages in the Begg and Tip Edge technique. A testing apparatus was specially designed to measure the dynamic frictional resistance of both the metal and ceramic Begg and Tip Edge brackets. This apparatus creates second order deflections to be offset from 0.00mm to 0.75mm in increments of 0.25mm. Two pairs of brackets are aligned vertically at the 0.00mm offset initially and the arch wire is connected to the brackets with either lock pins in Begg brackets or steel ligatures and elastomeric modules in Tip Edge brackets. The arch wires included Australian Wilcock stainless steel wires, nickel-titanium wires and TP Co-Ax® braided stainless steel wires. An Instron Universal testing machine is used to slide the wire through the brackets at a rate of 5mm/min for a period of 2 minutes with measurements plotted on a computer. Each combination was tested 3 times. Each set of combinations was first tested in a dry environment and then again tested after lubrication with artificial saliva (wet environment). A total of 50 combinations were tested. The data were analyzed with a repeated measures analysis of variance testing the main effects of 1) arch wire/bracket combinations, 2) environment, 3) deflections and 4) method of ligation. The level of significance was predetermined at $p<0.01$. Begg Stage I with Co-Ax® wire produced the lowest friction while the Australian stainless steel produced the highest frictional resistance with the ribbon arch brackets. A wet environment with artificial saliva significantly increased the frictional resistance with only the metal Begg bracket. Steel ligatures produced a significantly higher frictional resistance than elastomeric modules with the metal Tip Edge bracket. At higher deflections, Stage III with rectangular wire produced higher frictional resistance than with round wires. An increase in deflection increased the frictional resistance in all the brackets tested. It should be recognized that since there are many variables affecting friction in the various bracket and arch wire combinations, it is difficult to design an in vitro study and extrapolate its findings to an in vivo or clinical situation.

### 1.6 Signed Statement

This report contains no material which has been accepted for the award of any other degree or diploma in any university. To the best of my knowledge and belief, it contains no material previously published or written by another person, except where due reference is made in the text.

I hereby give consent to this copy of my thesis, when deposited in the Library, to be made available for photocopy and loan.

C.W. Henry Ho

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# 2. Introduction and Aims

## 2.1 Introduction

A review of the current orthodontic literature has revealed a proliferation of publications evaluating the role of friction in orthodontics. Friction had been mentioned in the orthodontic literature as far back as 1960 when **Stoner, 1960** stated that "recognition must always be given the fact that, because of appliance inefficiency, sometimes applied force is dissipated by friction or improper application and it is difficult both to control and to determine the amount of force that was received by the individual tooth".

According to **Garner et al, 1986,** the earliest recorded experiments on friction were carried out by the versatile genius Leonardo da Vinci approximately 450 years ago but his works were never published because of his methods of writing. Consequently, Coulomb and Morin were credited with the classic works on the laws of friction, reporting that when one body slid or tended to slide over another body, the force that acted to oppose the tendency to move was called 'the force of friction' and this frictional force was always parallel to the surfaces that were in contact. **Buck et al, 1963** reported a study that dealt with canine retraction by activating a coil spring They observed the canine tipped until friction was so great that it stopped movement, and they concluded that tooth movement took place until friction overcame the distal force. Unfortunately, the authors made no attempt to quantify the frictional force.

According to **Morris, 1969**, friction is defined as a force tangential to the common boundary of two bodies in contact that resists the motion or tendency to motion of one relative to the other. It may be described as a force acting parallel to the direction of motion. According to **Tselepis et al, 1994**, friction may exist in 2 forms : (1) Static friction, which is the resistance that prevents actual motion, and (2) Dynamic (kinetic) friction, which exists during motion.

Orthodontists are aware that most fixed appliance techniques involve some degree of sliding between the bracket and arch wire. Whenever sliding occurs, frictional resistance is encountered between arch wires and brackets or tubes, but the magnitude and clinical significance of this frictional resistance still requires more understanding. **Drescher et al,**

**1989,** wrote that "guiding a tooth along an arch wire can be divided into a series of tipping, binding and then uprighting movements which resulted in the tooth 'walking' along the arch wire."

**Liew, 1993**, considered friction to be significant in decreasing the effective orthodontic force available to move teeth, thus reducing the efficiency and rate of tooth movement. An increase in applied force may be required to overcome frictional resistance, and this would cause additional strain on any anchorage. Accordingly, understanding the frictional forces between the brackets and the wires was essential for adequate tooth movement and optimum biologic response.

According to **Tidy, 1989**, one approach to this problem was to adopt "frictionless" mechanics, which avoided tooth movement along the arch wire as far as possible. Another approach was to use sliding mechanics but to design the appliance to reduce friction as in the Begg technique and the Tip Edge technique. Recent researchers have adopted the latter approach and developed various bracket, arch wire materials and ligature designs to reduce the amount of frictional force in the system. **(Rose and Zernik, 1996, Harradine and Birnie, 1996, Keith et al, 1994, Mendes et al, 1996, Riley et al, 1979**, **Vaughan et al, 1995, Shivapuja and Berger, 1994, Ogata et al, 1996)**

## 2.2 Aims of Research

1. To develop a suitable method to measure friction generated under various orthodontic appliance simulations.
2. To compare friction characteristics of variations in

(a) bracket design,

(b) arch wire type, and

(c) Stage I, II and III of the Begg/Tip Edge technique

3. To determine whether wet or dry test conditions might influence friction measurements.

## 2.3 Null Hypothesis

1. Begg brackets do not exhibit any difference in frictional resistance compared with Tip Edge brackets in the various simulated stages of treatment.
2. Effect of a wet environment on both bracket systems is negligible.
3. Effect of ligation on the frictional characteristics with the Tip Edge brackets is negligible.
4. Increase in wire deflection does not increase the frictional resistance.

# 3. Literature Review

A variety of factors have been shown to influence the frictional resistance between brackets and arch wires. A review of the literature is arranged in the following categories:

3.1 Type and design of brackets

3.2 Shape, size and type of arch wires

3.3 Surface roughness

3.4 Lubrication (*i.e.* wet versus dry environment)

3.5 Ligature design

3.6 Angulation of the wires to bracket.

## 3.1 Bracket design

### *3.1.1 Vertical vs. horizontal slot brackets*

**Frank and Nikolai, 1980,** is possibly the only study that has attempted to measure friction in Begg brackets (vertical brackets) and Edgewise brackets (horizontal brackets). They concluded that "friction between the 'pinned in' 0.016" and 0.018" wires and the Begg brackets was negligible .....and in the Begg subsample of the 0.020" wire, full sized in the Begg system, produced larger frictional forces because of the snug fit and immediate binding."

### *3.1.2 Bracket width*

Studies that have examined the influence of the bracket width on friction are inconclusive.

**Andreasen and Quevedo, 1970,** found that a change in the bracket width did not influence the frictional forces.

Most studies found an increase in frictional forces with an increase in bracket width. **(Frank and Nikolai, 1980, Kapila et al, 1990, Yamaguchi et al, 1996)**

These were possibly due to an increase in its binding capacity with the arch wire.

**Tidy, 1989,** however found that friction is inversely proportional to bracket width, *i.e.* narrow bracket had the greatest amount of friction, in his sliding mechanics set-up according to the following formula:

$$P = \frac{2Fh\lambda}{W}$$

where $P$ = frictional resistance and $W$ =bracket width.

**Omana et al, 1992,** in their experiment with both metal and ceramic cuspid brackets produced significantly less friction with wider brackets than narrow incisor versions at lower load levels (determined by the amount of bracket engagement). With increasing load, however, the frictional force of the wider brackets approached that of the narrow brackets. They hypothesized that it could be due to the narrow bracket allowing more tipping of the teeth resulting in a more acute angle of interface between wire and bracket. Increased loads overcome the mechanical advantage of wider brackets (*i.e.* increasing the amount of bracket engagement) and increased the frictional force.

### *3.1.3 Bracket material*

Studies that compared the friction between ceramic and metal brackets generally agreed that ceramic brackets had a higher frictional resistance than metal brackets. (**Tanne et al, 1991, Pratten et al, 1990, Tselepis et al, 1994, Bednar et al, 1991, Ireland et al, 1991, Omana et al, 1992).** It was also agreed that the ceramic brackets had a rougher surface compared with the metal brackets and thus the higher frictional resistance. However, according to **Kusy and Whitney, 1990,** it was not due to the surface roughness but rather to the chemical structure of the ceramic brackets.

Other studies examined the friction between various types of ceramic brackets, *e.g.* monocrystalline (crystal sapphire) vs. polycrystalline alumina brackets (**Saunders and Kusy, 1994**), zirconia vs. polycrystalline brackets (**Keith et al, 1994, Tanne et al, 1994**). Generally, the smoother the surface of the ceramic, the less the friction *i.e.* monocrystalline (smoother) < polycrystalline brackets (**Saunders and Kusy, 1994)** and zirconia < polycrystalline brackets (**Tanne et al, 1994**). However, **Keith et al, 1994,** concluded in their study that the "currently available zirconia brackets offered no significant improvement over alumina brackets with regard to their frictional characteristics". **Vaughan et al, 1995,** compared sintered stainless steel brackets and conventional cast stainless steel brackets and reported approximately 40% to 45% less friction in the sintered brackets. The stainless steel particles were compressed into a contoured, smooth rounded shape thus improving the surface texture, as opposed to casting procedures which left sharp angular brackets that are bulky and rough.

### *3.1.4 Slot size*

The slot size of the bracket was generally agreed to have little effect on the frictional resistance of the system according to **Kusy and Whitney, 1990** and **Tidy, 1989** . These studies actually reported an increase in friction with a snugly fitting wire in a 0.018" slot bracket compared with the same dimension wire in a larger 0.022" slot bracket but the results were not significant.

### *3.1.5 Other bracket designs*

Through the years, clinicians had modified the standard Edgewise bracket to reduce friction within the bracket and also for ease of arch wire insertion and removal.

Studies on the self ligating bracket systems *i.e.* Activa ("A" Company, Johnson and Johnson, San Diego, Calif.), Edgelok (Ormco, Glendora, Calif.) and SPEED (Strite Industries Ltd, Cambridge, Ontario) have found that they displayed a significantly lower level of frictional resistance amidst other advantages. **(Shivapuja and Berger, 1994, Harradine and Birnie, 1996)**

However, **Bednar et al, 1991** found that the self ligating steel bracket (SPEED bracket) in their study did not demonstrate less friction when compared with the alastik or steel ligated stainless steel brackets.

Other bracket designs that aim to reduce friction or allow free sliding mechanics include Tip-Edge brackets (TP Orthodontics, LaPorte, Ind.) and Synergy (RMO, Denver, Colo.).

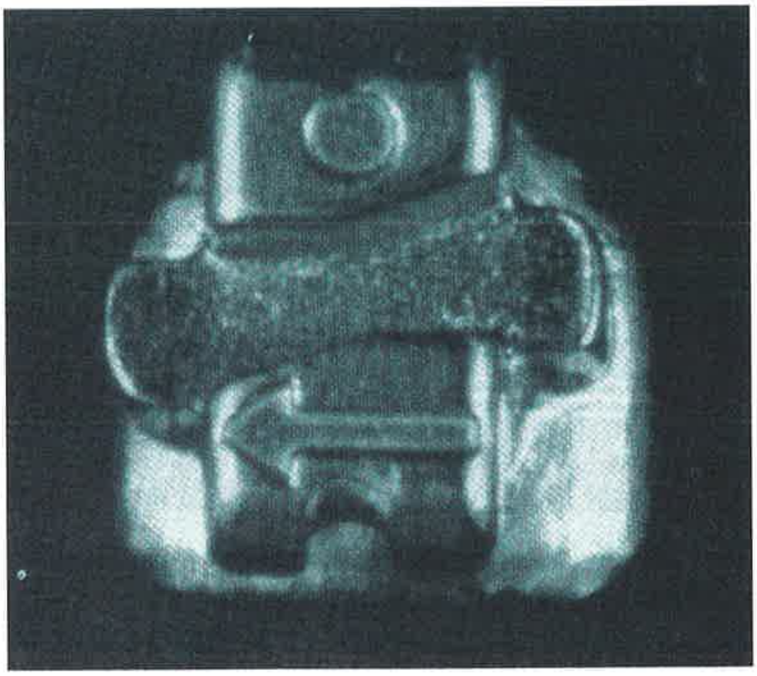


**Figure 1 TP Tip Edge bracket**

(Ogata et al, 1996)

The TP brackets have a design in which 20° wedges are cut out of the bracket slot on diagonally opposite corners. With this design, when the tooth tips on retraction, the binding of the wire at the edges of the bracket is greatly minimised and thus reportedly reduces the frictional resistance of the system.

The Synergy brackets have bumps on the bracket walls and floor which reduce the surface area in contact with the wires and thus help reduce the friction at the bracket/wire interface.

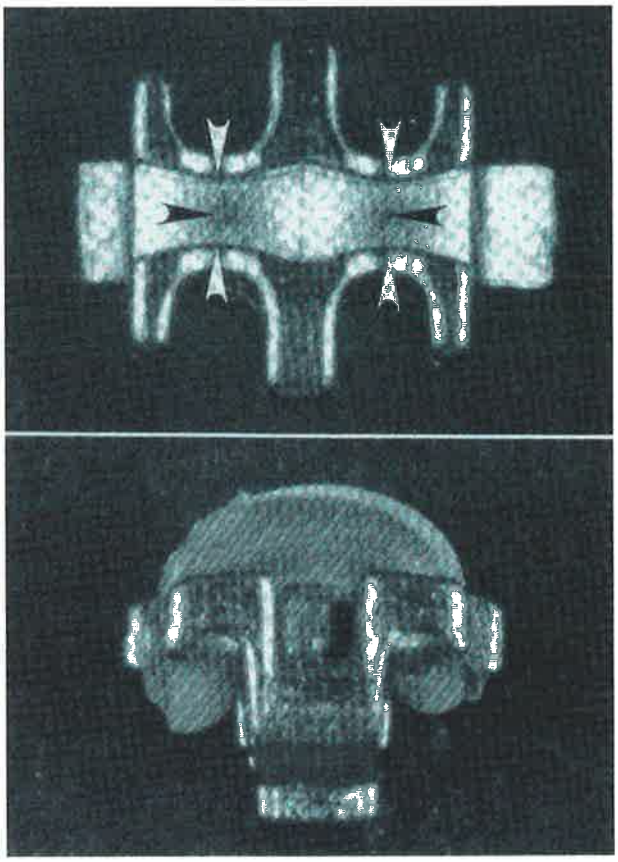


**Figure 2 RMO Synergy bracket**

(Ogata et al, 1996)

**Ogata et al, 1996,** compared the frictional characteristics of newer bracket designs (TP Tip Edge brackets and RMO Synergy brackets and standard Edgewise, Unitek Mini Twin and Ormco Mini Diamond brackets) with a combination of arch wires under the same conditions and concluded that the newly designed brackets (Synergy brackets) revealed lower values of frictional resistance than the standard Edgewise brackets in their study.

## 3.2 Arch wire design

### *3.2.1 Types of wires*

Most studies are in agreement that for most wire sizes, lower frictional forces are generated with the stainless steel (SS) and cobalt-chromium (CoCr) wires than with the beta-titanium (β-Ti) or nickel-titanium (NiTi) wires (**Vaughan et al, 1995, Saunders and Kusy, 1994, Kusy and Whitney, 1990, Kusy et al, 1991, Kapila et al, 1990, Drescher et al, 1989).**

**Tidy, 1989, Garner et al, 1990, Pratten et al, 1990,** reported the same findings without CoCr wires in their study.

**Tidy, 1989,** reported that Nitinol (NiTi) and TMA (titanium molybdenum alloy, β-Ti) arch wires produced frictional resistance two and five times respectively greater than those of stainless steel wires.

**Drescher et al, 1989,** reported that the effective force (of a bracket/arch wire system to overcome its frictional resistance) must increase sixfold for TMA wires compared with just twofold for stainless steel wires under their experimental conditions of testing the frictional characteristics of a single bracket with these wires.

Most studies agreed that this was due to an increase in surface roughness of the titanium wires, especially the titanium-molybdenum alloys compared with the stainless steel wires. **(Garner et al, 1986, Drescher et al, 1989, Vaughan et al 1995, Kapila et al, 1990).**

**Kusy and Whitney, 1990,** suggested that the high coefficients of friction of the β-Ti arch wires against either stainless steel or polycrystalline alumina brackets were due to substantial cold welding or mechanical abrasion occurring in both combinations. **Kapila et al, 1990,** also wrote that, in addition to their relatively high surface roughness, β-Ti wires might form microwelds with stainless steel brackets in dry conditions thereby further increasing the frictional forces. **Pratten et al, 1990,** were of the opinion that the presence of an oxide layer or intrinsic lubrication might influence the friction of these materials (*i.e.* stainless steel and NiTi) more than surface roughness. However, no further studies were conducted to measure friction with wires where the oxide layer has been removed.

**Burstone and Farzin-nia, 1995,** reported a lowering of the coefficient of friction and an increase in the hardness of TMA wires with a process of surface treatment known as 'Ion implantation'. Ion implantation is a process by which various elements or compounds are ionized and then accelerated toward a target - in this case, the orthodontic arch wire. The ions penetrate the surface of the wire on impact, building up a structure that consists of both the original wire and in this material, a layer of tin compounds (SnN and SnO) on the surface and immediate subsurface. This layer is extremely hard and creates considerable compressive forces in the material at the atomic level. The compressive forces and increased surface hardness improve the fatigue resistance and ductility and reduce the coefficient of friction of the wire. Unlike conventional coating processes, ion implantation produces no sharp interface between coating and wire and does not alter the wire dimensions. Two 'state of the art' varieties of TMA, the low-friction and coloured TMA wires were produced by varying the type and size of the ions.

**Dickson et al, 1994,** studied the static planar frictional resistance of five initial alignment wires and reported that Co-Ax® stainless steel demonstrated the lowest frictional resistance compared with Australian stainless steel, Titanol®, epoxy-coated stainless steel and fibre-optic glass wires. Australian stainless steel demonstrated the most variable levels of frictional resistance, *i.e.*, as the angulation of the bracket/wire increased, frictional resistance increased disproportionately to it. Epoxy-coated stainless steel demonstrated significantly higher frictional resistance than all the other wires. No explanation was offered for these observations.

### *3.2.2 Size and shape of the arch wire*

The influence of the size (*i.e.* diameter) and shape (*i.e.* round or rectangular) of the arch wire is examined in this section.

According to **Tidy, 1989,** friction generated by sliding a bracket along an arch wire with the centre of resistance at a distance from the arch wire could be predicted to a first approximation, if one assumed that the classical laws of friction were valid, by the equation:

$$P = \frac{2Fh\lambda}{W}$$

where:

$P$ = frictional resistance

$F$ = force

$h$ = distance of the load from the arch wire

$W$ = bracket width

$\lambda$ = coefficient of friction (between bracket and arch wire) ; a constant for any given pair of materials.

The author showed that friction should therefore be independent of arch wire stiffness, arch wire dimension, or shape of arch wire cross section. However the author also added that to reduce friction clinically, practitioners preferred the use of round wires as they eliminated friction caused by active torque and they generally produced less friction than rectangular wire when engaged in brackets out of alignment because of their greater flexibility and possibly less surface area engagement in the bracket.

**Riley et al, 1979,** reported that rectangular wires generated higher frictional forces compared with round wires and increasing the rectangular wire size also increased the force.

According to **Drescher et al, 1989,** when selecting the proper arch wire size for a mesiodistal tooth movement, the clinician should bear in mind that friction depended primarily on the *vertical* dimension of the wire and this finding was substantiated by the physical definition of friction:

$$F = \mu N$$

where:

$F$ = friction

$\mu$ = coefficient of friction

$N$ = vertical force (not a horizontally applied force)

With the above equation, a 0.016 inch round wire and a 0.016x0.022 inch rectangular wire showed virtually the same amount of friction.

In general, (**Vaughan et al, 1995; Tanne et al, 1994; Frank and Nikolai; 1980 Andreasen and Quevedo, 1970; Riley et al, 1979**) an increase in wire size, relative to bracket slot dimension, generally resulted in increased bracket-wire friction.

According to **Andreasen and Quevedo, 1970,** frictional forces are less with a smaller diameter wire because there is more freedom of movement between the wire and bracket slot and less surface area contact.

**Kapila et al, 1990,** studied the effect of wire size and bracket-wire friction on various types (narrow single, medium twin, wide twin) of both 0.018 inch and 0.022 inch brackets and also concluded that an increase in wire size is associated with increased bracket-wire friction, although small increases in size might not significantly affect friction. It was also stated that with the larger 0.019" by 0.025" wires, there is little difference between steel and Nitinol wires. **Garner et al, 1986**, showed an increase in friction occurred with an increase in wire size and changing from steel to Nitinol wires.

### 3.3 Surface Roughness

Both the surface roughness of the bracket and the arch wire contribute to the frictional resistance of the bracket/arch wire system and ceramic brackets generally have a rougher surface than metal brackets.

**Tanne et al, 1991,** reported S.E.M.. examinations that revealed wire surfaces were slightly damaged when metal brackets were used and scratches were present on the wire surfaces when ceramic brackets were used. They also reported that the slot surfaces and edges of the ceramic brackets were more porous and rougher than those of the metal brackets. **Tanne et al, 1994,** showed that refinements to the slot surfaces of the ceramic brackets might be effective in reducing friction. **Rose and Zernik, 1996,** both tumbled and manually rounded the slot corners of ceramic brackets and found that it significantly reduced (32% to 38%) the resistance of the brackets to arch wire sliding. **Vaughan et al, 1995,** reported an overall reduction of approximately 40% to 45% in friction of sintered stainless steel compared with the conventional cast stainless steel brackets. **Mendes et al, 1996,** studied the effect of ion implantation on arch wire and/or bracket surface and suggested that ion implantation of

NiTi and β-Ti wires was effective in reducing their friction. Ion implantation of the bracket surfaces also reduced the friction with untreated wires. Ion implantation of the wire surface appeared to be more effective than treatment of the bracket surface. There was no additional reduction in friction by implanting both wire and bracket surface.

**Drescher et al, 1989,** examined the surface texture characteristics of some wire materials and found that stainless steel and CoCr wires demonstrated a smooth surface texture whereas the NiTi alloy, especially the titanium-molybdenum alloy (TMA) showed an extensive surface roughness. It was apparent that surface texture was a substantial factor in dictating friction magnitude. According to **Vaughan et al, 1995,** laser spectroscopic studies showed that stainless steel wires have the smoothest surface followed by CoCr, β-Ti and NiTi wires in order of increasing surface roughness. However, surface roughness was not always related to frictional forces, especially for β-Ti wires. Although NiTi is rougher, the β-Ti wires had a greater mean frictional force. **Ireland et al, 1991** and **Kusy et al, 1988** (using laser spectroscopy), also concluded that the degree of surface roughness does not correspond directly with measured friction. In the study by **Ireland et al, 1991,** the single ceramic brackets were shown to have less friction than the smoother steel brackets. **Kusy and Whitney, 1990,** also showed that a clear relationship did not always exist between surface roughness and friction, when adhesive or abrasive mechanisms were present. The occurrence of adhesive wear in the form of cold welding was not uncommon in titanium alloys since they could be quite reactive, with metal-metal bonds being formed, broken, and reformed as the surface topography underwent modification. The authors then concluded that although the surface roughness of stainless steel, cobalt-chromium and nickel-titanium arch wires generally showed a slight positive correlation with frictional coefficients, the β-Ti arch wires were anomalous. With chemical adhesion (metal-metal bonds) or mechanical abrasion, the frictional coefficient of β-Ti increased, independent of the initially measured arch wire roughness.

### 3.4 Lubrication

Several studies have looked at the effect of saliva or lubrication on friction in an orthodontic system but their findings were not conclusive. Some studies reported a decrease in friction when tested with saliva (**Saunders and Kusy, 1994, Ireland et al, 1991, Tselepis et al, 1994, Baker et al, 1987**), some reported an increase (**Riley et al 1979, Pratten et al, 1990, Shivapuja and Berger, 1994, Stannard et al, 1986)** while yet others reported insignificant and inconclusive results. (**Andreasen and Quevedo, 1970, Kusy et al, 1991, Keith et al, 1994)**

Some studies used human saliva from healthy individuals while others used artificial saliva for their experiment. Again, some studies had their experimental environment maintained at approximate body temperature saliva bath while others had not. According to **Tselepis et al, 1994,** the different findings may be related to the formulations of different artificial saliva solutions as well as the technique of applying the saliva to the bracket/arch wire assembly.

According to **Kusy et al, 1991,** when saliva is present, frictional forces might increase, decrease or remain unchanged depending on the arch wire alloy. The authors also reported that the composition of the saliva appeared to be significant with ceramic brackets as friction increased with artificial saliva whereas in human saliva it decreased. **Andreasen and Quevedo, 1970,** found in their study that saliva played an insignificant role in lubricating the surfaces of the wire and bracket slot. The authors offered two explanations First, perhaps saliva was not a good lubricant between the arch wire and bracket slot under orthodontic conditions. Secondly, because the arch wire touched the bracket at only 2 points, where the pressure was relatively great, the lubricant could be expelled from the areas of contact allowing no lubrication between the arch wire and bracket to exist. **Keith et al, 1994,** concluded from their studies on zirconia brackets that the presence of human saliva produced only slight changes in the frictional behaviour of the zirconia brackets.

**Saunders and Kusy, 1994,** found that when saliva obtained from a healthy human subject was introduced into their experimental system, the friction reduced in both the titanium alloys (*i.e.* NiTi and β-Ti) but appeared to rise for stainless steel and CoCr alloys. However, the magnitude of change was not significant. Again, their results also showed that friction was reduced in the presence of saliva for both the smooth monocrystalline and rough polycrystalline brackets against titanium alloys but not against the stainless steel and Co Cr arch wires. Because sapphire was much harder and stiffer than the titanium alloy, the ceramic peeled material from the metal as the arch wire entered the bracket slot. Fortunately, the lubricating effect of saliva provided a 'boundary layer' that reduced the interaction of titanium arch wire with the crystalline alumina bracket slot.

**Ireland et al, 1991,** reported a significant reduction of frictional values with smaller wires and a minimal change with larger dimension wires in the wet environment.

According to **Tselepis et al, 1994,** the function of a lubricant is to reduce the strength and number of bridges formed between the asperities of a sliding surface and it is generally perceived that saliva acts as a lubricant. Both **Tselepis et al, 1994** and **Baker et al, 1987,** found that frictional resistance decreases under wet conditions with artificial saliva. **Tselepis et al, 1994,** concluded that lubrication significantly reduces the frictional resistance up to 60.5 % and **Baker et al, 1987,** concluded a significant reduction of 15% to 19%.

**Riley et al, 1979,** reported an increase in friction with distilled water as lubricant because of corrosion. **Shivapuja and Berger, 1994,** reported a higher frictional resistance with artificial saliva because of the rapid rate of desiccation of the cellulose constituent adhering to the arch wire.

According to **Pratten et al, 1990,** at low loads saliva acts as a lubricant whereas at high loads saliva might increase friction if it is forced out from the contacts between the brackets and the arch wire. In the latter situation, saliva might produce shear resistance to sliding forces thus increasing the friction.

**Downing et al, 1995,** proposed the adhesion theory of friction originated by Rabinowicz in 1965, where he described that the adhesion of asperities of like surfaces took place more readily in the presence of saliva and the subsequent force necessary for their rupture was higher. The presence of a polar liquid, such as water improved the adhesion properties of the surface asperities and thus increased the frictional force. The coefficients of friction of saliva and water are similar and indicates that saliva would seem to be a poor lubricant.

The authors concluded that artificial saliva did not appear to act as a lubricant.

### 3.5 Ligature design

**Ireland et al, 1991,** reported that ligation led to significantly higher frictional values. Studies have been done with alastik modules and steel ligatures on steel and ceramic brackets (**Riley et al, 1979, Frank and Nikolai, 1980, Andreasen and Quevedo, 1970**). Other studies have compared self ligating bracket systems with conventional ligating systems (**Shivapuja and Berger, 1994, Bednar et al, 1991, Taylor et al, 1996**).

**Riley et al, 1979,** reported that steel ligatures generated higher frictional forces compared with alastik modules, especially when plastic brackets are used. **Omana et al, 1992,** when comparing steel ligatures and elastomeric modules on both stainless steel and NiTi wires and on metal and ceramic brackets found that steel ligatures produced lower friction on average, but the variation was considerable and they attributed it to be possibly due to the inability to standardize the tightness of the ligature tie.

**Andreasen and Quevedo, 1970,** concluded that friction increased as wire ligatures are tightened. In their study, metal Edgewise brackets were used and a coil spring was used to keep the ligature tight and to deliver an approximately constant force between the arch wire and the bracket. **Echols, 1975,** showed that elastomeric ligatures contribute to effective frictional forces and **Taylor and Ison, 1996,** reported that permanent deformation of the elastomerics and hydrolysis in the oral environment could alter the degree of frictional resistance.

**Ogata et al, 1996,** and **Suyama et al, 1995** concluded that those bracket designs which restricted the ligation force (American Friction Free, GAC Shoulder and Mini-Taurus Synergy brackets) generated lower kinetic frictional force when compared with bracket designs that did not.

**Politt, 1996,** developed a technique called "twisted ligation" and claimed to accomplish the same objective without the need for specially designed brackets simply by twisting the ligatures clockwise or in a gingival-to-occlusal direction, away from the arch wire.

**Bednar et al, 1991,** compared elastomeric, steel and self ligating systems and concluded that self ligating steel brackets (Orec SPEED) do not demonstrate less friction than the alastik or steel ligated stainless steel brackets and that steel ligated steel brackets demonstrate less friction than the elastomeric ligated ceramic or steel brackets used in their study. Elastomeric ligated ceramic brackets demonstrate the greatest friction when compared with other bracket/ligation combinations. The authors also highlighted that clinicians commonly use elastomeric power chains to translate teeth and these chains are attached to the bracket tie wings which in effect results in high friction elastomeric-type ties. One way to minimize friction with a twin bracket would be to lightly steel tie the wire to the bracket and attach any elastomeric chains to a power arm or hook on the bracket rather than the tie wings.

However, **Shivapuja and Berger, 1994,** reported a significantly lower level of frictional resistance with the self ligating bracket systems (Strite Industries SPEED, "A" Company ACTIVA and Ormco EDGELOK) compared with elastomeric and steel ligation for ceramic and metal twin brackets. The authors also reported that elastomeric ties are associated with higher frictional resistance when compared with other modes of ligation and in particular with self ligation and that 'this, combined with the rapid rate of decay for these elastomeric ties and their predilection for harbouring large quantities of plaque suggested that there was little merit in their use, especially in translatory movement and sliding mechanics.'

**Taylor and Ison, 1996,** also reported that ligation with loosely placed ligatures or stretched modules reduced frictional forces in the standard straight wire brackets, the reduction being greatest for round wires. In addition, frictional forces recorded from arch wires secured with elastomeric modules showed a steady reduction over a 3 week period, depending on how long the module had been in position on the bracket.

**Edwards et al, 1994,** compared 4 methods of ligation and found that the first method with a elastomeric module in a figure 8 pattern tie produced the highest amount of friction. The other 2 methods using elastomeric modules and steel ligatures in the conventional tie did not produce any significant differences. The last method with the use of Teflon-coated steel ligatures however produced the lowest frictional forces. They explained that the Teflon may have acted as a solid lubricant to reduce friction.

### 3.6 Angulation of wire to bracket

The effect of having an angulation of the wire to the bracket generally produced a higher value for friction (**Tselepis et al, 1994, Ho and West, 1991, Dickson et al, 1994, Tidy, 1989, Frank and Nikolai, 1980, Andreasen and Quevedo, 1970, Suyama et al, 1995, Ogata et al, 1996**). According to **Dickson et al, 1994,** this was more correctly attributed to binding due to contact force rather than true friction.

These studies generally had a single bracket placed at an angulation to the arch wire ranging from zero degrees to 3, 5, 6 and 10 degrees, or had several brackets placed vertically offset.

According to **Frank and Nikolai, 1980,** frictional resistance was found to be non-linearly dependent upon the bracket and arch wire angulation. With small and non-binding angulations, the other factors (e.g. bracket width and ligature force) were the dominant influences on the level of friction. As the angulations increased it produced binding forces between the bracket and wire and this variable was now the controlling parameter. All other variables apparently exerted substantial influence only at relatively high angulations. The stiffness of the wire in bending (dependent upon the wire cross-sectional size and shape, wire material and interbracket distances) is apparently quite influential in determining the frictional resistance as is the contact area between the wire and bracket slot as they affected the binding of the wire within the bracket.

With regard to the wire material, according to **Dickson, 1994,** the Australian stainless steel had a low frictional resistance at zero degrees angulation but with increasing angulation (from zero degrees to ten degrees), the frictional resistance of the stainless steel rises sharply compared with other materials. For the nickel-titanium wires, their frictional resistance dropped below that of the stainless steel as the angulation increased. The authors did not offer any explanation for this observation.

**Garner et al, 1986,** compared nitinol and stainless steel arch wires and reported a lower friction for the nitinol only when the bracket/wire angulation is more than 5°.

### 3.7 Summary

In summary, frictional resistance appears to be influenced by :

a) bracket type (ceramic *versus* metal) and design (slots and bumps incorporated in the design, ribbon arch versus edgewise brackets).

b) type of wires (stainless steel, Co Cr, NiTi, TMA, Ion implanted)

c) lubrication

d) surface roughness (of the brackets and wires)

e) ligature design

f) size and shape of arch wires

g) angulation of wire to bracket.

It can be seen that there are many potential influences and they may be confusing especially when the methods of measuring friction also vary with the individual investigators and study designs.

# 4. Materials and Methods

## 4.1 Materials

### *4.1.1 Brackets*

*Begg*

36 TP 256-500 metal brackets (flat base)

36 Mxi Ceramic brackets (flat base)

(TP Orthodontics, LaPorte, Indiana)

*Tip-Edge*

60 Tip Edge metal brackets (central incisor, 0.022" slot with deep groove)

60 Mxi Ceramic Tip Edge brackets (central incisor, 0.022")

(TP Orthodontics, LaPorte, Indiana)

### *4.1.2 Wires*

*Australian Wilcock stainless steel wires*

12 pieces of 0.016" (*Premium Plus*)

6 pieces of 0.020" (*Special Plus*)

6 pieces of 0.022" (*Special Plus*)

12 pieces of 0.012" (*Premium Plus*)

*3M wires*

6 pieces of 0.021" x 0.025" stainless steel wires

*Dentaurum wires*

6 pieces of 0.016" Nickel-titanium wires (Rematitan® "Lite")

*TP wires*

6 pieces of 0.016" Co-Ax® braided wires

### *4.1.3 TP springs*

A box of Begg uprighting springs 0.014" (clockwise)

A box of side-winder uprighting springs (clockwise)

### *4.1.4 TP pins*

A box of brass lock pins (Stage III brass pins)

A box of T pins (stainless steel)

### *4.1.5 Other materials*

Artificial saliva (lubricant) *Oralube- Orion Laboratory.*

| | | |
|---|---|---|
| *Composition* : | Potassium Chloride B.P. | 0.063% w/v |
| | Sodium Chloride B.P. | 0.086% w/v |
| | Magnesium Chloride B.P. | 0.013% w/v |
| | Calcium Chloride B.P. | 0.022% w/v |
| | Flavoured sugar free base | |
| | Preservative methyl hydroxybenzoate B.P. | 0.2% w/v |

Bottle of ethanol and packets of swabs

Cutters (ligature and wire cutters)

Mathieu forceps

Elastomeric modules

Steel ligatures 0.010”

Scanning Electron Microscope (S.E.M.) allows the study of surface roughness of brackets and arch wires.

> *Philips* XL30 Field Emission Gun Scanning Electron Microscope (F.E.G.S.E.M.) at either 10.0 or 20.0 kV.

### *4.1.6 Testing equipment*

Specially designed testing apparatus (see Figure 3) to allow a maximum of six brackets to be bonded and deflected in the second order at 0.25mm increments. Brackets were all bonded, so that the arch wire may be vertically placed, by a single operator. The positions were measured and marked clearly prior to each bonding.

Loading cell (200 N) connected to the Instron testing machine.

An IBM computer is connected to the Instron testing machine to enable the graphic recording of each measurement and thus calculate the average frictional force value for each measurement (see Figure 4).

Figure 3 shows the specially designed apparatus for the testing of frictional resistance used in this investigation. Frictional resistance was measured using the Instron Universal Testing machine (Instron Corporation, Canton, Mass.) and plotted on the computer, which is shown in Figure 4.

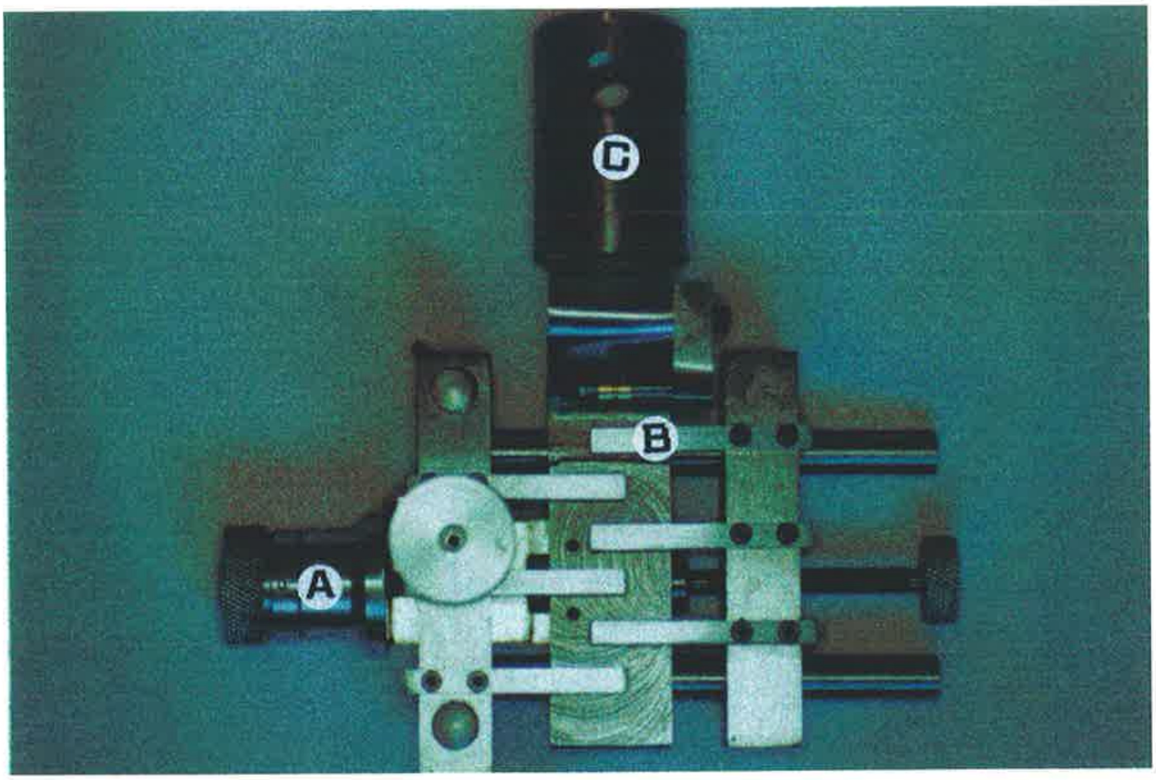



**Figure 3 Specially designed testing apparatus**

| | |
|---|---|
| **A** | Knob to precisely adjust the amount of required deflection. |
| **B** | Where brackets are attached. |
| **C** | Connection to the Instron testing machine. |

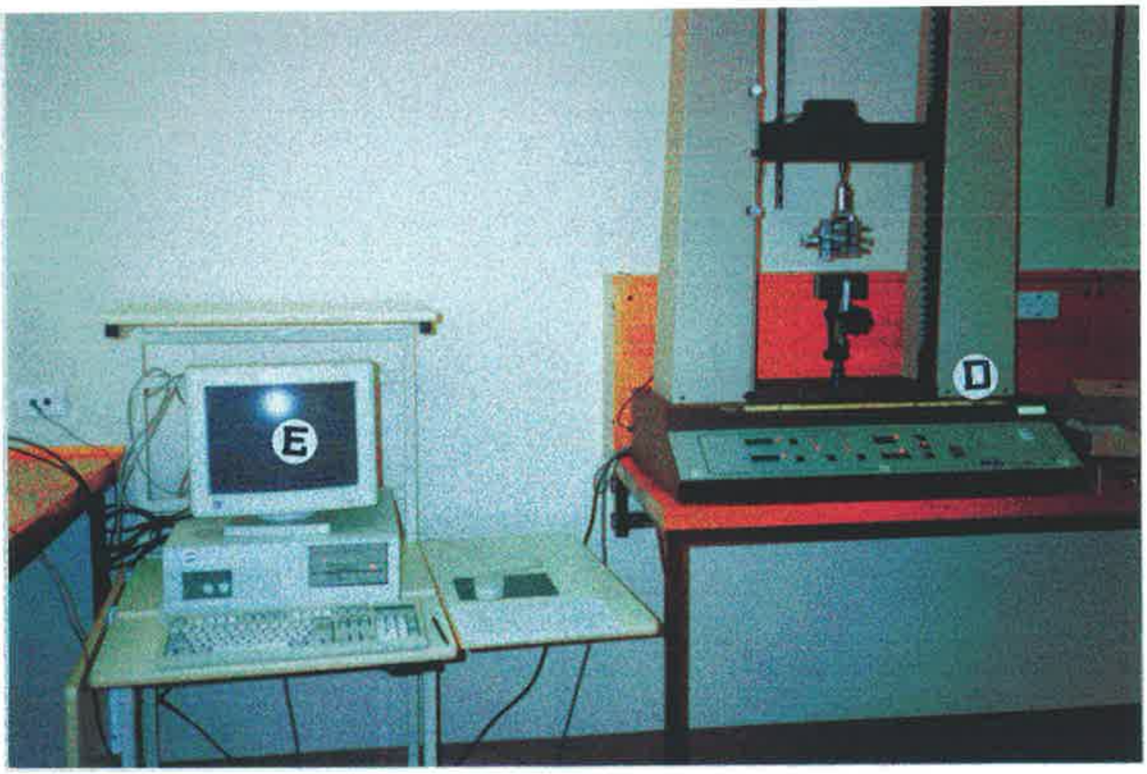



**Figure 4 Instron Universal Testing machine with the X-Y recorder**

**D** Instron testing machine

**E** Computer connected to the Instron.

## 4.2 Methods

The study measured the kinetic frictional forces developed between the various brackets (Begg and Tip Edge, metal and ceramic) and arch wire combinations simulating the various stages (I, II, III) in the Begg/Tip Edge appliance technique. All tests were conducted on the testing apparatus connected to the Instron Universal testing machine with the data being plotted on an IBM computer. Second order deflections were created by a specially designed testing apparatus that allowed four brackets, vertically placed, to be offset from 0.00mm to a maximum of 0.75mm in increments of 0.25mm (measured from the middle of each bracket). Bracket movement was implemented by the Instron at a rate of 5mm/minute for a total period of 2 minutes. The design of this study was similar to **Ogata et al, 1997**.

The brackets and wires were degreased and cleaned of surface impurities with 95% ethanol prior to testing. The various combinations are listed in the tables on the following pages.

**Table 2 List of reference codes with corresponding arch wire and bracket combinations**

| Brackets | Wires | Treatment |
|---|---|---|
| Begg | 0.016" SS | T1 |
| | 0.016" SS+Tp | T2 |
| | 0.016" Co-Ax | T3 |
| | 0.016" NiTi | T4 |
| | 0.020" SS | T5 |
| | 0.020" SS+Tp | T6 |
| | 0.020"+0.012" SS | T7 |
| | 0.020" SS+ URS | T8 |
| Tip Edge | 0.016" SS | T9 |
| | 0.016" SS+S.winder | T10 |
| | 0.016" Co-Ax | T11 |
| | 0.016" NiTi | T12 |
| | 0.020" SS+S.winder | T13 |
| | 0.022" +0.012" SS | T14 |
| | 0.022" SS+S.winder | T15 |
| | 0.021"x0.025" SS | T16 |
| | 0.021"x0.025" SS+S.winder | T17 |

**Table 3 Combinations of bracket, wire and fixation simulating Stage I Begg treatment**

| Bracket | Material | Wire | Fixation | Treatment |
|---|---|---|---|---|
| Begg | metal | 0.016îSS | lock pin | T1 |
| | | 0.016î Co-Ax | lock pin | T3 |
| | | 0.016î NiTi | lock pin | T4 |
| | ceramic | 0.016îSS | lock pin | T1 |
| | | 0.016î Co-Ax | lock pin | T3 |
| | | 0.016î NiTi | lock pin | T4 |
| Tip Edge | metal | 0.016î SS | SS ligature | T9 |
| | | 0.016î Co-Ax | SS ligature | T11 |
| | | 0.016î NiTi | SS ligature | T12 |
| | | 0.016î SS | module | T9 |
| | | 0.016î Co-Ax | module | T11 |
| | | 0.016î NiTi | module | T12 |
| | ceramic | 0.016î SS | SS ligature | T9 |
| | | 0.016î Co-Ax | SS ligature | T11 |
| | | 0.016î NiTi | SS ligature | T12 |
| | | 0.016î SS | module | T9 |
| | | 0.016î Co-Ax | module | T11 |
| | | 0.016î NiTi | module | T12 |

**Table 4 Combinations of bracket, wire and fixation simulating Stage II Begg treatment with and without braking mechanics**

| Bracket | Material | Wire | Springs | Fixation | Treatment |
|---|---|---|---|---|---|
| Begg | metal | 0.016î | | T pins | T2 |
| | | 0.020î | | lock pin | T5 |
| | | 0.020î | | T pins | T6 |
| | ceramic | 0.020î | | lock pin | T5 |
| Tip Edge | metal | 0.016î | sidewinders | SS ligature | T10 |
| | | 0.020î | sidewinders | SS ligature | T13 |
| | | 0.016î | sidewinders | module | T10 |
| | | 0.020î | sidewinders | module | T13 |
| | ceramic | 0.016î | sidewinders | SS ligature | T10 |
| | | 0.020î | sidewinders | SS ligature | T13 |
| | | 0.016î | sidewinders | module | T10 |
| | | 0.020î | sidewinders | module | T13 |

Note : Stage II combinations using uprighting springs as brakes are found in Table 4 as they are similar to Stage III uprighting combinations.

**Table 5 Combinations of bracket, wire and fixation simulating Stage III Begg treatment including torque and uprighting**

| Bracket | Material | Wire | Auxiliary | Springs | Fixation | Treatment |
|---|---|---|---|---|---|---|
| Begg | metal | 0.020î | 012î | | lock pin | T7 |
| | | 0.020î | | URS | lock pin | T8 |
| | ceramic | 0.020î | 012î | | lock pin | T7 |
| | | 0.020î | | URS | lock pin | T8 |
| Tip Edge | metal | 0.022î | 012î | | SS ligature | T14 |
| | | 0.022î | | sidewinders | SS ligature | T15 |
| | | 0.021x0.025îSS | | | SS ligature | T16 |
| | | 0.021x0.025îSS | | sidewinders | SS ligature | T17 |
| | | 0.022î | 012î | | module | T14 |
| | | 0.022î | | sidewinders | module | T15 |
| | | 0.021x0.025îSS | | | module | T16 |
| | | 0.021x0.025îSS | | sidewinders | module | T17 |
| | ceramic | 0.022î | 012î | | SS ligature | T14 |
| | | 0.022î | | sidewinders | SS ligature | T15 |
| | | 0.021x0.025îSS | | | SS ligature | T16 |
| | | 0.021x0.025îSS | | sidewinders | SS ligature | T17 |
| | | 0.022î | 012î | | module | T14 |
| | | 0.022î | | sidewinders | module | T15 |
| | | 0.021x0.025îSS | | | module | T16 |
| | | 0.021x0.025îSS | | sidewinders | module | T17 |

There are a total of 50 combinations. The Tip Edge bracket combinations were tested both with steel ligatures and elastomeric modules whereas the Begg brackets were only tested with lock pins. The first set was tested with a dry environment and then a second set in a wet environment with artificial saliva. Each combination was tested 3 times.

### 4.3 Statistical analysis

A predicted mean value and standard error of the mean of the frictional forces were calculated for each specific bracket-wire-deflection combination. The data were analysed with repeated measures analysis of variance for the main effects of 1) arch wire/bracket combinations, 2) environment, 3) deflections and 4) method of fixation. A compound symmetric error structure was used to describe the relationship between the 3 mean values. Wald Tests (**Rao, 1973**), which were tests for the significance of treatment differences, were used to test the significance of the various effects and their interactions.

For each type of bracket, a table of predicted mean values of the frictional force and their standard error of mean was calculated. The standard error of mean reflects the accuracy of a statistical estimate. A small standard error of mean would reflect a precise estimate of the data whereas a large standard error of mean would reflect an imprecise estimate. A pairwise comparison value was also calculated for each bracket type. Pairwise comparison was used for comparing pairs of means. If the difference between the pair of means exceeds the critical value of the pairwise comparison, the pair is statistically significant.

Programme No. 5 V from the BMDP statistical software package (Release 7, 1993) was used. The level of statistical significance was predetermined at $p < 0.01$. This level was determined to minimise the possibility of a significant finding due to chance as there were a large number of readings obtained.

### 4.4 Limitations of this experimental design

It is difficult to simulate clinical conditions in laboratory studies. However, most studies on friction in orthodontics have been in vitro studies. Our study was unable to simulate the clinical situation of a rounded archform and malocclusion. The brackets were adhered to the testing apparatus which did not allow any tipping as in a clinical situation. Furthermore, the system is rigid unlike teeth with periodontal ligament. The bracket positions were measured and marked prior to bonding. The brackets were aligned and bonded vertically by a single operator as accurately as possible with the guide of the markings. Artificial saliva was used as a form of lubrication and may not be the true representation of the oral environment. It was also difficult to standardize the tightness of fixation, whether with lock pins, steel ligatures or alastik modules. Use of Stage III lock pins in a Stage I set-up may not be appropriate. Occasional bracket breakages posed some inconveniences. These were mainly from adhesive failure and whenever this happened, the test was repeated. Because of the low fracture resistance of the ceramic brackets, no measurements were obtained at high deflection of 0.75mm.

# 5. Results

The raw experimental data from the tests are presented in full in Volume II of this thesis. Here the analysis of those results for statistical significance is presented.

## 5.1 Begg metal brackets

The Wald tests of significance for the Begg metal bracket and the various main effects and their interactions are shown in Table 6.

The mean predicted values of the frictional forces for the various arch wire/bracket combinations are shown in Table 7.

For the Begg metal brackets, it was shown that all 3 main effects were statistically significant in relation to frictional forces.

**Table 6 Wald Tests of significance of fixed effects and covariates for metal Begg brackets**

| Test | DF | Chi-Square | *p* |
|---|---|---|---|
| Treatment (T1-T8) | 7 | 46.7193 | **0.0001** |
| Environment | 1 | 12.2119 | **0.0005** |
| Deflection | 3 | 35.8282 | **0.0001** |
| Treat / Envir | 7 | 16.8528 | 0.0184 |
| Treat / Deflect | 21 | 13.9630 | 0.8712 |
| Envir / Deflect | 3 | 11.0543 | 0.0114 |

Values that are statistically significant are highlighted.

### *5.1.1 Effect of arch wire/bracket combinations*

Comparing the various stage I (alignment) wires with the Begg metal brackets, T1 (SS wires) produced higher frictional forces when compared with T3 (Co-Ax wires). Comparing T1 with T4 (NiTi wires), there were no statistically significant differences between the 2 materials. When comparing T3 with T4, the Co-Ax wires again showed a lower frictional force than NiTi wires. Therefore, stage I treatment with stainless steel and NiTi wires produced higher frictional resistance than stage I treatment with Co-Ax® wires of the same dimensions. Comparing the various stages of treatment (Stage I, II and III), Stage I (with stainless steel and NiTi wires) resulted in higher frictional resistance than in Stage II and III set-ups (T2,5-8).

### *5.1.2 Effect of environment*

A wet environment with artificial saliva as lubricant significantly increased the frictional resistance of this bracket system for all readings (p = 0.0005).

### *5.1.3 Effect of deflections*

Frictional resistance was seen to increase with increased deflection for all readings ($p <$ 0.0001).

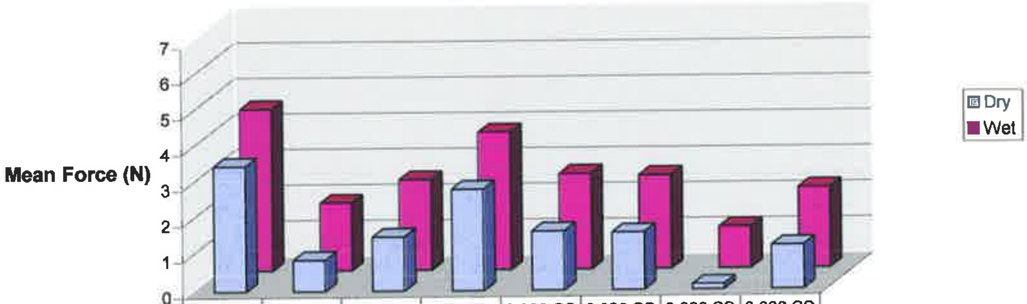
**Table 7 Frictional forces in Newton ( N ) for arch wires with metal Begg brackets with lock pins and auxiliaries at various deflections in wet and dry environments**

| | | Deflections (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.00 | | 0.25 | | 0.50 | | 0.75 | |
| Wire | Pin/aux | dry | wet | dry | wet | dry | wet | dry | wet |
| 0.016” SS (T1) | BP | 3.51 | 4.53 | 3.54 | 4.56 | 4.52 | 5.54 | 5.64 | 6.67 |
| 0.016” SS (T2) | Tp | 0.87 | 1.89 | 0.91 | 1.92 | 1.88 | 2.90 | 3.01 | 4.03 |
| 0.016” Co-Ax (T3) | BP | 1.51 | 2.53 | 1.54 | 2.56 | 2.52 | 3.54 | 3.64 | 4.67 |
| 0.016” NiTi (T4) | BP | 2.83 | 3.85 | 2.87 | 3.89 | 3.84 | 4.86 | 4.97 | 5.99 |
| 0.020” SS (T5) | BP | 1.65 | 2.67 | 1.69 | 2.71 | 2.63 | 3.68 | 3.79 | 4.80 |
| 0.020” SS (T6) | Tp | 1.60 | 2.61 | 1.63 | 2.65 | 2.61 | 3.62 | 3.73 | 4.75 |
| 0.020” SS (T7) | 0.012 SS | 0.14 | 1.16 | 0.17 | 1.19 | 1.15 | 2.17 | 2.27 | 3.29 |
| 0.020” SS (T8) | URS | 1.23 | 2.24 | 1.26 | 2.28 | 2.23 | 3.25 | 3.36 | 4.38 |

Tp T pin
BP Brass lock pin
URS Uprighting spring
SS Stainless steel

Standard error of mean = 0.56
Pairwise comparison = 0.79

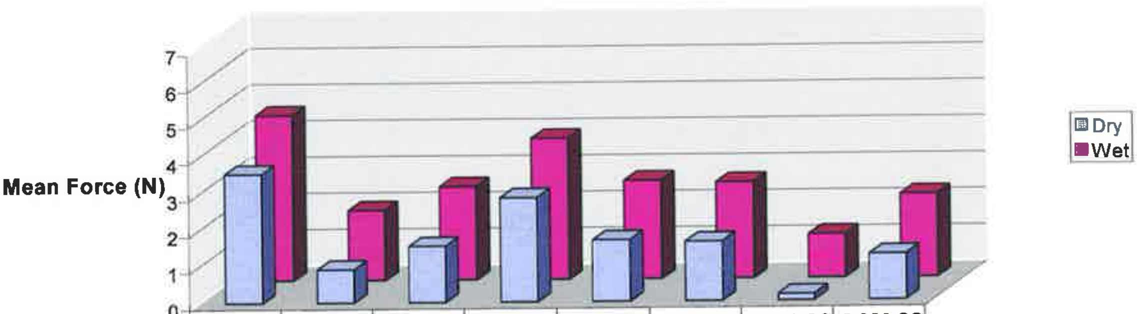
Figures 5-8 represent the various combinations (T1-8) under both the dry and wet conditions and their respective mean frictional force in Newton at the various deflections.




| | 0.016 SS + BP (T1) | 0.016 SS + Tp (T2) | 0.016 CoAx (T3) | 0.016 NiTi (T4) | 0.020 SS + BP (T5) | 0.020 SS + Tp (T6) | 0.020 SS + .012 SS | 0.020 SS + URS (T8) |
|---|---|---|---|---|---|---|---|---|
| Dry | 3.509 | 0.874 | 1.51 | 2.835 | 1.654 | 1.598 | 0.141 | 1.226 |
| Wet | 4.528 | 1.894 | 2.529 | 3.854 | 2.673 | 2.617 | 1.16 | 2.244 |

Type of archwire/bracket combination

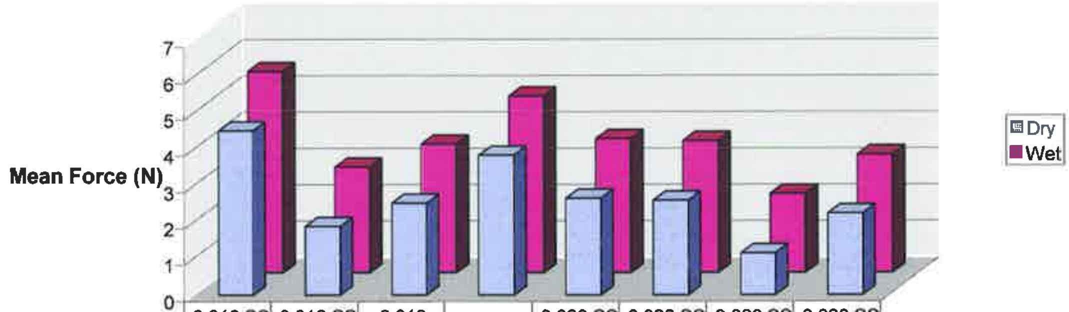
**Figure 5 Metal Begg bracket at 0.00mm deflection**




| | 0.016 SS + BP (T1) | 0.016 SS + Tp (T2) | 0.016 CoAx (T3) | 0.016 NiTi (T4) | 0.020 SS + BP (T5) | 0.020 SS + Tp (T6) | 0.020 SS + .012 SS (T7) | 0.020 SS + URS (T8) |
|---|---|---|---|---|---|---|---|---|
| Dry | 3.544 | 0.909 | 1.543 | 2.869 | 1.688 | 1.632 | 0.175 | 1.259 |
| Wet | 4.563 | 1.927 | 2.563 | 3.888 | 2.707 | 2.651 | 1.194 | 2.279 |

Type of archwire/bracket combination

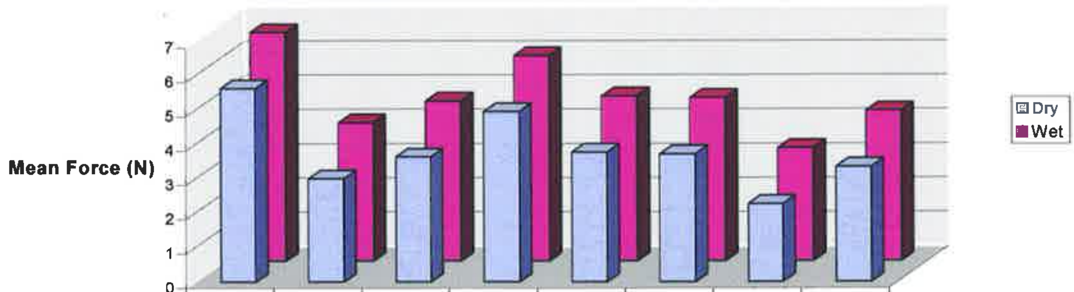
**Figure 6 Metal Begg bracket at 0.25mm deflection**




| | 0.016 SS + BP (T1) | 0.016 SS + Tp (T2) | 0.016 CoAx (T3) | 0.016 NiTi (T4) | 0.020 SS + BP (T5) | 0.020 SS + Tp (T6) | 0.020 SS + .012 SS (T7) | 0.020 SS + URS (T8) |
|---|---|---|---|---|---|---|---|---|
| Dry | 4.519 | 1.884 | 2.519 | 3.844 | 2.663 | 2.607 | 1.149 | 2.235 |
| Wet | 5.537 | 2.903 | 3.538 | 4.863 | 3.682 | 3.626 | 2.169 | 3.253 |

Type of archwire/bracket combination

**Figure 7 Metal Begg bracket at 0.50mm deflection**




| | 0.016 SS + BP (T1) | 0.016 SS + Tp (T2) | 0.016 CoAx (T3) | 0.016 NiTi (T4) | 0.020 SS + BP (T5) | 0.020 SS + Tp (T6) | 0.020 SS + .012 SS (T7) | 0.020 SS + URS (T8) |
|---|---|---|---|---|---|---|---|---|
| Dry | 5.642 | 3.007 | 3.642 | 4.968 | 3.786 | 3.73 | 2.273 | 3.358 |
| Wet | 6.661 | 4.026 | 4.661 | 5.987 | 4.805 | 4.75 | 3.292 | 4.379 |

Type of archwire/bracket combination

**Figure 8 Metal Begg bracket at 0.75mm deflection**

## 5.2 Begg ceramic brackets

With the Begg ceramic bracket, T pins were not used as they were not able to fit the slot of the bracket. As such, T2 and T6 were not performed.

For the Begg ceramic bracket, only the main effects of treatment (T1,3,4,5,7,8) and deflection were statistically significant. The interactive effects were also not significant.

Refer to Table 8.

**Table 8 Wald Tests of significance of fixed effects and covariates for ceramic Begg brackets**

| Test | DF | Chi-Square | *P* |
|---|---|---|---|
| Treatment (T1,3,4,5,7,8) | 5 | 40.44 | **0.0001** |
| Environment | 1 | 0.25 | 0.6177 |
| Deflection | 3 | 22.99 | **0.0001** |
| Treat / Envir | 5 | 26.53 | 0.0201 |
| Treat / Deflect | 15 | 29.67 | 0.0132 |
| Envir / Deflect | 3 | 4.26 | 0.2351 |

### *5.2.1 Effect of arch wire/bracket combinations*

Table 9 shows values for the frictional forces obtained from the various arch wire combinations with ceramic Begg brackets. It can be seen that Stage I with Australian Wilcock stainless steel 0.016” (T1) wire produced more friction than the other 2 types with similar dimension arch wires *i.e.* Co-Ax (T3) and NiTi (T4). This difference was statistically significant ($p < 0.0001$).

**Table 9 Frictional forces in Newton ( N ) for arch wires with ceramic Begg brackets at various deflections with pins or auxiliaries**

| | | Deflections (mm) | | | |
|---|---|---|---|---|---|
| Wire | Spring/aux | 0.00 | 0.25 | 0.50 | 0.75 |
| 0.016" SS (T1) | BP | 4.65 | 3.89 | 4.82 | 6.56 |
| 0.016" Co-Ax (T3) | BP | 1.32 | 0.56 | 1.49 | 3.23 |
| 0.016" NiTi (T4) | BP | 1.80 | 1.04 | 1.97 | 3.71 |
| 0.020" SS (T5) | BP | 2.07 | 1.32 | 2.25 | 3.98 |
| 0.020" SS (T7) | 0.012 SS | 3.09 | 2.33 | 3.26 | 5.00 |
| 0.020" SS (T8) | URS | 4.50 | 3.74 | 4.68 | 6.41 |

BP Brass lock pin
URS Uprighting spring
SS Stainless steel

Standard error of mean = 0.61
Pairwise comparison = 1.73

The frictional force for the Stage I with 0.016" SS (T1) combination was 4.65N. This was significantly greater than both the value of 1.32N for the Stage I with 0.016" Co-Ax combination (T3), and the value of 1.80N for the NiTi combination (T4). There was however no statistical significance between values for Co-Ax (T3) and NiTi (T4) arch wires.

Examination of the values for the various stages (I, II and III) of treatment shows that Stage I with SS (T1) produced comparable frictional values with Stage III with SS and uprighting springs (T8).

The frictional force found for Stage I with Co-Ax and NiTi wires (T3 and T4) were 1.32N and 1.80N respectively. These values were not statistically significant from the force of 2.07N found for the Stage II (T5) combination.

Stage I with SS (T1) produced higher friction than in the stage II (T5) or stage III (T7) with auxiliary but was comparable with stage III with uprighting springs.

Stage II (T5) produced less frictional resistance than stage III with uprighting springs.

### 5.2.2 *Effect of environment*

There was no statistical significance between lubricating with artificial saliva and ceramic Begg brackets ($p = 0.6177$). Therefore only the dry values are presented.

### 5.2.3 *Effect of deflections*

With increased deflection, there was an increase in frictional resistance. However, it was seen that at 0.25mm deflection, there was an initial decrease in frictional value with all the various arch wire/bracket combinations and a subsequent increase with further increase in deflections (see Table 8).

Figures 9-12 represent the various combinations (T1,3,4,5,7,8) and their respective mean frictional force in Newton at the various deflections.

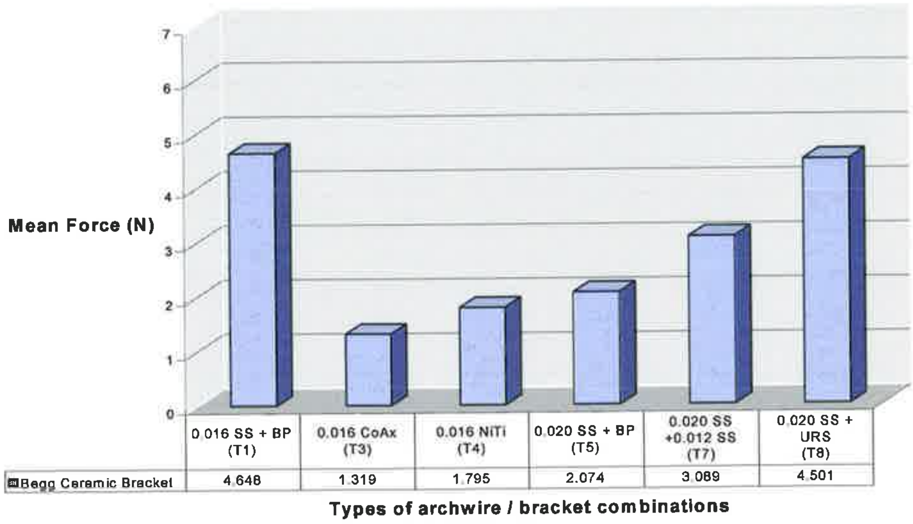



**Figure 9 Ceramic Begg bracket at 0.00mm deflection**

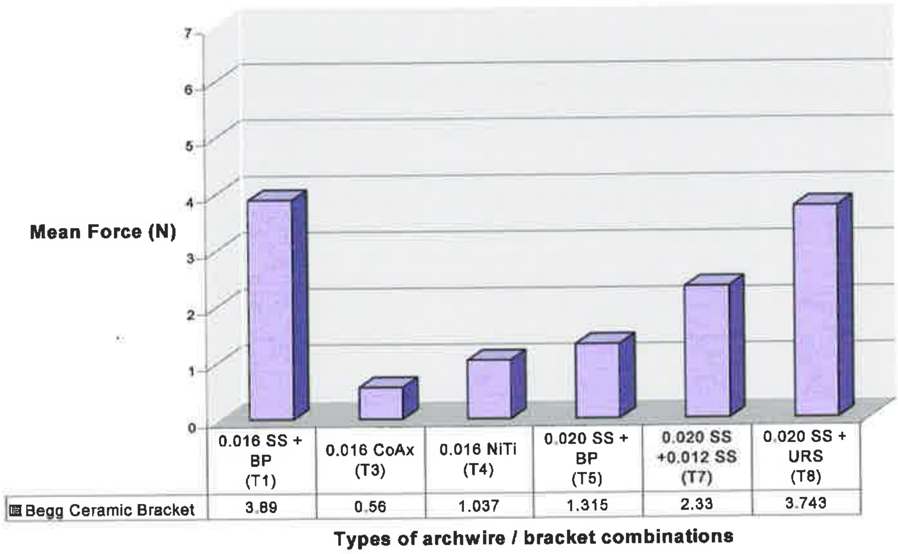



**Figure 10 Ceramic Begg bracket at 0.25mm deflection**

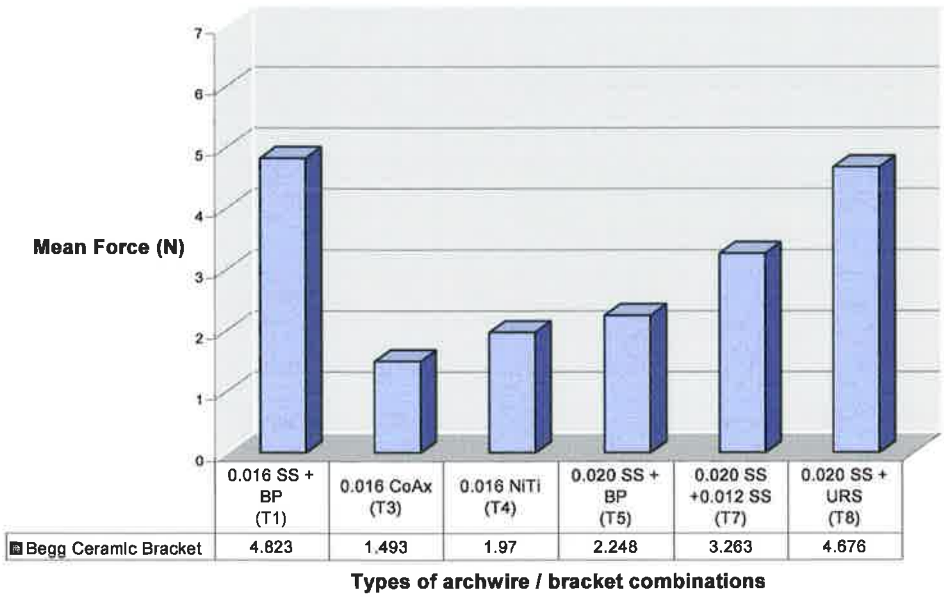



**Figure 11 Ceramic Begg bracket at 0.50mm deflection**

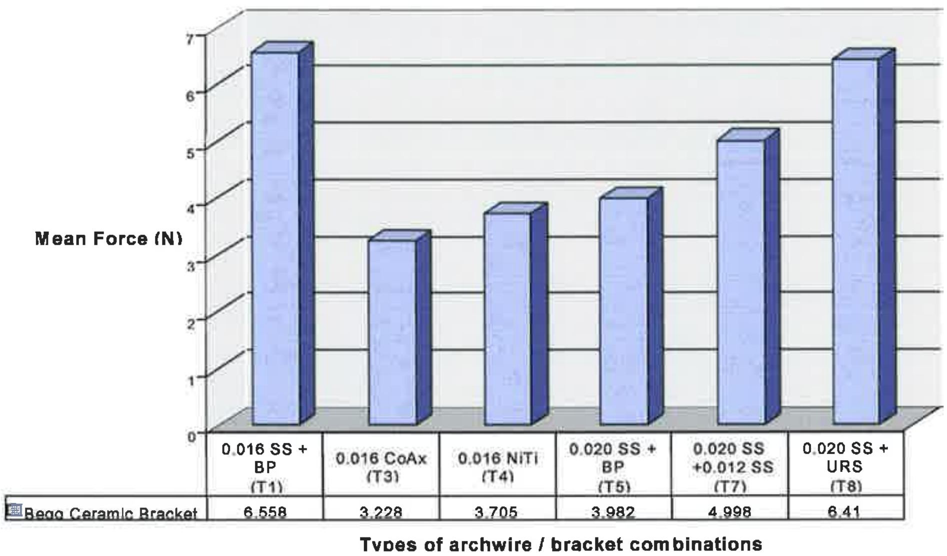



**Figure 12 Ceramic Begg bracket at 0.75mm deflection**

## 5.3 Metal Tip Edge brackets

The Wald Tests of significance for the main effects and their interactions for the Tip Edge metal bracket are shown in Table 10.

The mean predicted values for this bracket with the various arch wire / bracket combinations are shown in Table 11.

For the Tip Edge metal bracket, only the effect of a wet environment did not play a significant role in the frictional characteristic. The interactive effect between treatment and deflection was shown to be significant.

**Table 10 Wald Tests of significance of fixed effects and covariates for metal Tip Edge brackets**

| Test | DF | Chi-Square | *p* |
|---|---|---|---|
| Treatment (T9-T17) | 8 | 138.41 | **0.0001** |
| Environment | 1 | 3.36 | 0.0667 |
| Deflection | 3 | 109.33 | **0.0001** |
| Ligation | 1 | 13.18 | **0.0003** |
| Treat / Envir | 8 | 12.42 | 0.1335 |
| Treat / Deflect | 24 | 123.50 | **0.0001** |
| Envir / Deflect | 3 | 0.07 | 0.9950 |
| Treat / Lig | 8 | 19.57 | 0.0121 |
| Envir / Lig | 1 | 0.55 | 0.4578 |
| Deflect / Lig | 3 | 5.97 | 0.1131 |

**Table 11 Frictional forces in Newton ( N ) for arch wires with metal Tip Edge brackets with and without sidewinders at various deflections with modules and ligatures**

| | | Deflection (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.00 | | 0.25 | | 0.50 | | 0.75 | |
| Wire | Spring/aux | Lig | Mod | Lig | Mod | Lig | Mod | Lig | Mod |
| 0.016" SS (T9) | | 3.45 | 1.73 | 3.94 | 2.21 | 4.65 | 2.92 | 5.15 | 3.43 |
| 0.016" SS (T10) | sidewinder | 7.31 | 5.59 | 4.04 | 2.31 | 6.55 | 4.82 | 8.53 | 6.81 |
| 0.016" Co-Ax (T11) | | 4.01 | 2.37 | 4.00 | 2.27 | 4.17 | 2.46 | 4.80 | 6.81 |
| 0.016" NiTi (T12) | | 3.58 | 1.86 | 3.66 | 1.94 | 4.20 | 2.48 | 4.72 | 2.99 |
| 0.020" SS (T13) | sidewinder | 3.63 | 1.91 | 2.75 | 1.03 | 3.42 | 1.69 | 7.02 | 5.30 |
| 0.022" SS (T14) | 0.012" SS | 2.91 | 1.19 | 4.07 | 2.35 | 5.63 | 3.91 | 10.13 | 8.41 |
| 0.022" SS (T15) | sidewinder | 3.44 | 1.72 | 4.67 | 2.95 | 7.45 | 5.72 | 9.92 | 8.12 |
| 0.021x0.025" SS (T16) | | 3.39 | 1.66 | 4.69 | 2.97 | 17.50 | 15.77 | 17.31 | 15.59 |
| 0.021x0.025" SS (T17) | sidewinder | 4.38 | 2.65 | 7.37 | 5.64 | 12.85 | 11.13 | 23.51 | 21.78 |

Standard error of mean = 1.56
Pairwise comparison = 4.4

### *5.3.1 Effect of arch wire/bracket combinations*

Differences between the frictional force values found for the metal Tip Edge bracket system with aligning Stage I SS wires (T9), with Co-Ax wires (T11), and with NiTi wires(T12) failed to reach statistical significance.

No statistically significant difference could be detected between the various stages of treatment with the metal Tip Edge bracket at deflections of 0.00mm and 0.25mm. However, at deflections of 0.50mm and 0.75mm, mean frictional values for Stage III (T14 - T17) were significantly higher ($p < 0.0001$).

### *5.3.2 Effect of environment*

A wet environment lubricated with artificial saliva did not produce a statistically significant difference in the frictional characteristics of the metal Tip Edge bracket system. ($p$ = 0.0667). Therefore only dry values are presented.

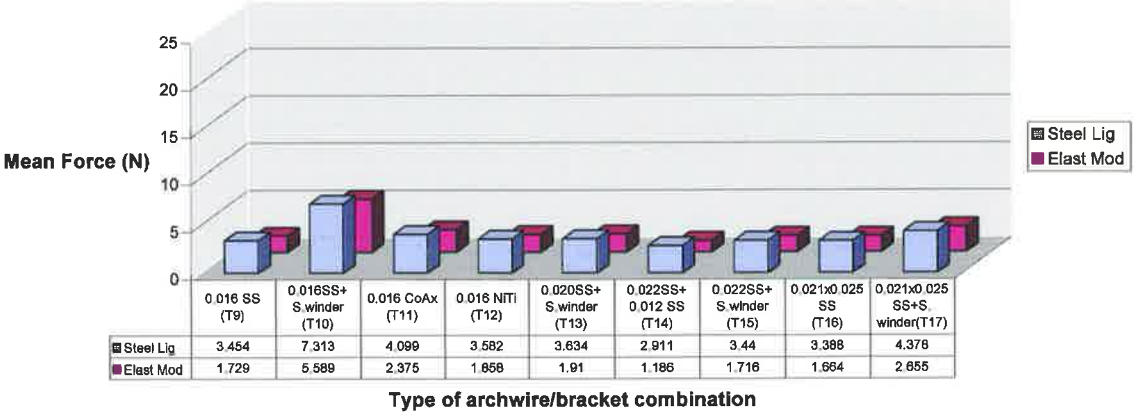
### *5.3.3 Effect of deflections*

Generally, an increase in deflection increased the frictional resistance ($p < 0.0001$). However, Stage I with Co-Ax (T11) and Stage II with 0.016" and 0.020" with sidewinder springs produced a slight initial decrease with increased deflection. These values did not reach statistical significance.

### *5.3.4 Effect of ligation*

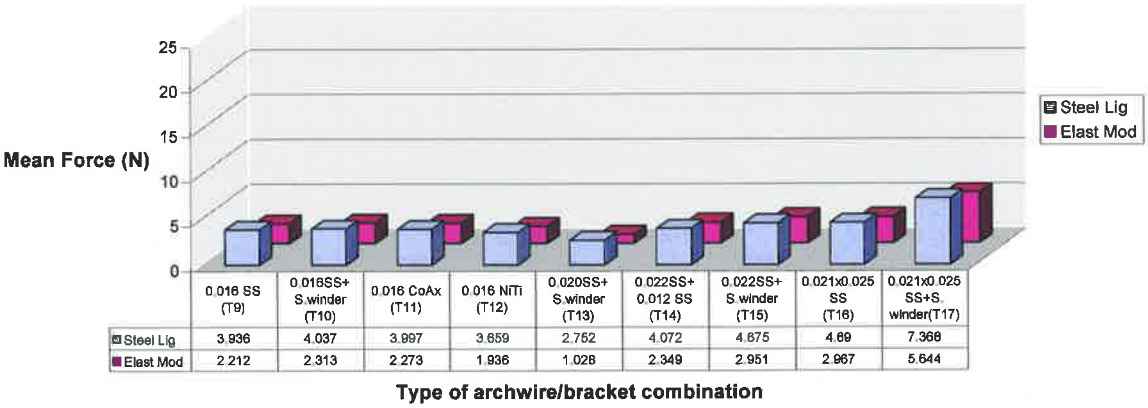
Results showed that steel ligatures produced a significantly higher frictional resistance than alastik modules for most treatments and deflections ($p < 0.0001$) except for T11 at 0.75mm deflection.

Figures 13-16 represent the various combinations (T9-17) with the different method of fixation and their respective mean frictional force in Newton at the various deflections.




| | 0.016 SS (T9) | 0.016SS+ S.winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020SS+ S.winder (T13) | 0.022SS+ 0.012 SS (T14) | 0.022SS+ S.winder (T15) | 0.021x0.025 SS (T16) | 0.021x0.025 SS+S. winder(T17) |
|---|---|---|---|---|---|---|---|---|---|
| Steel Lig | 3.454 | 7.313 | 4.099 | 3.582 | 3.634 | 2.911 | 3.44 | 3.388 | 4.378 |
| Elast Mod | 1.729 | 5.589 | 2.375 | 1.658 | 1.91 | 1.186 | 1.716 | 1.664 | 2.655 |

**Figure 13 Metal Tip Edge bracket at 0.00mm deflection**




| | 0.016 SS (T9) | 0.016SS+ S.winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020SS+ S.winder (T13) | 0.022SS+ 0.012 SS (T14) | 0.022SS+ S.winder (T15) | 0.021x0.025 SS (T16) | 0.021x0.025 SS+S. winder(T17) |
|---|---|---|---|---|---|---|---|---|---|
| Steel Lig | 3.936 | 4.037 | 3.997 | 3.659 | 2.752 | 4.072 | 4.675 | 4.69 | 7.368 |
| Elast Mod | 2.212 | 2.313 | 2.273 | 1.936 | 1.028 | 2.349 | 2.951 | 2.967 | 5.644 |

**Figure 14 Metal Tip Edge bracket at 0.25mm deflection**

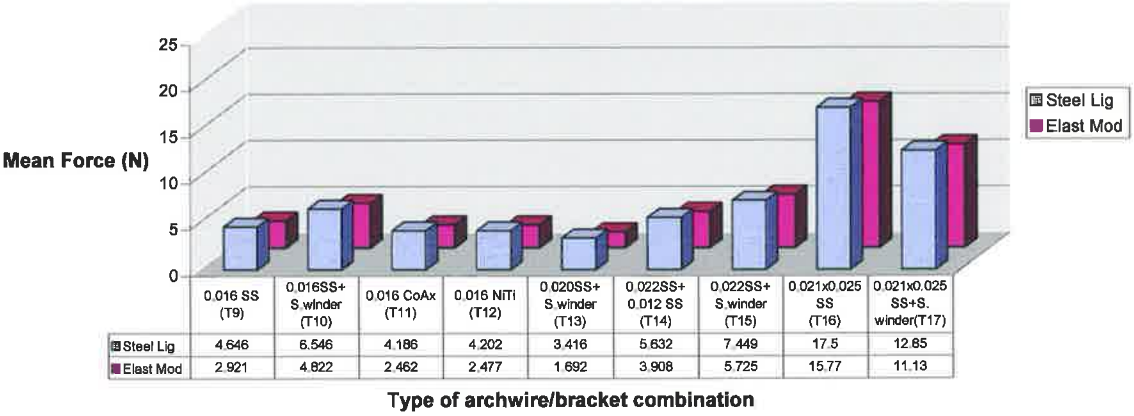



**Figure 15 Metal Tip Edge bracket at 0.50mm deflection**

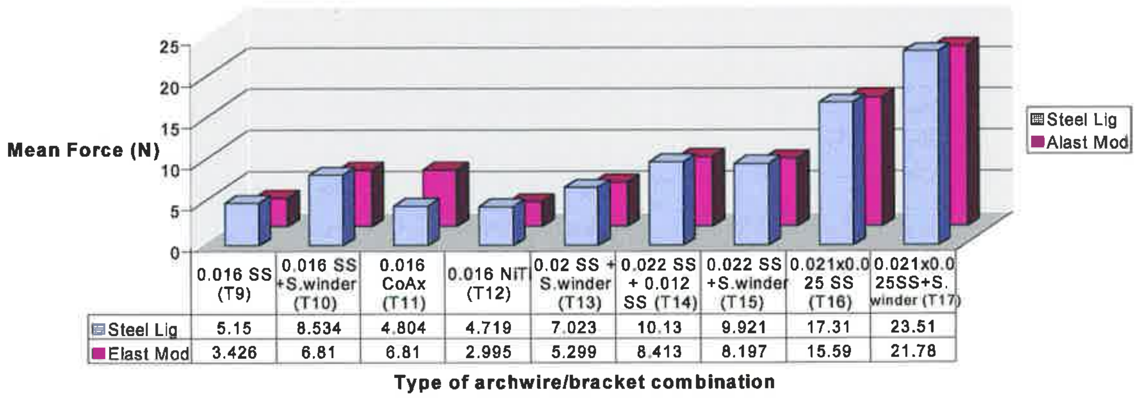



**Figure 16 Metal Tip Edge bracket at 0.75mm deflection**

## 5.4 Ceramic Tip Edge brackets

The ceramic Tip Edge brackets fractured at 0.75mm deflection with the stiffer stage III wires due to the inherent weakness of the ceramic brackets with low fracture resistance (**Karamouzos et al, 1997**). No readings were therefore obtained at 0.75mm deflection for the stage III combinations (T14 - 17).

Therefore 2 sets of results were obtained. Table 12 shows values for stage I and II (T9 - 13) and values for stage III (T14 - 17) are shown in Table 13.

**Table 12 Wald Tests of significance of fixed effects and covariates for ceramic Tip Edge brackets (T9 - T13)**

| Test | DF | Chi-Square | *p* |
|---|---|---|---|
| Treatment (T9-13) | 4 | 71.41 | **0.0001** |
| Deflection | 3 | 74.03 | **0.0001** |
| Ligation | 1 | 0.26 | 0.6100 |
| Environment | 1 | 6.14 | 0.0230 |
| Treat / Deflect | 12 | 107.16 | **0.0001** |
| Treat / Ligate | 4 | 40.41 | **0.0001** |
| Deflect / Ligate | 3 | 0.25 | 0.9690 |
| Treat / Envir | 4 | 11.21 | 0.0240 |
| Deflect / Envir | 3 | 0.48 | 0.9240 |
| Ligate / Envir | 1 | 1.04 | 0.3090 |

**Table 13 Wald Tests of significance of fixed effects and covariates for ceramic Tip Edge brackets (T14 - T17)**

| Test | DF | Chi-Square | *p* |
|---|---|---|---|
| Treatment (T14-17) | 3 | 18.82 | **0.0001** |
| Deflection | 2 | 34.61 | **0.0001** |
| Ligation | 1 | 4.72 | 0.0300 |
| Environment | 1 | 0.46 | 0.4960 |
| Treat / Deflect | 6 | 36.81 | **0.0001** |
| Treat / Ligate | 3 | 4.85 | 0.1830 |
| Deflect / Ligate | 2 | 1.41 | 0.4930 |
| Treat / Envir | 3 | 8.10 | 0.0440 |
| Deflect / Envir | 2 | 0.99 | 0.6100 |
| Ligate / Envir | 1 | 0.70 | 0.4030 |

For the combinations of T9 - 13, only the effects of various arch wire/bracket combinations and deflection were statistically significant. Interactive effects between treatment and deflection, and treatment and ligation reached statistical significance with the ceramic Tip Edge bracket system.

For the T14 - T17 combinations, the statistically significant effects were similar whereas the interactive effects that were significant were only between treatment and deflection.

### *5.4.1 Effect of arch wire/bracket combinations*

Table 14 shows values for frictional force obtained for Stage I and II combinations (T9 - T13) with ceramic Tip Edge brackets.

Differences between frictional forces for the 3 different aligning wires in Stage I (T9, T11 and T12) failed to reach statistical significance.

The addition of the sidewinder to the SS wire increased the frictional value slightly, but again the difference did not reach significance.

Between treatment and deflection as an interactive effect, Stage II (T13) with alastik modules produced higher frictional value than the various Stage I combinations (T9-12).

Again, between treatment and ligation as an interactive effect, steel ligatures produced higher frictional values than alastik modules in all Stage I (T9-12) but alastik modules produced higher frictional values than steel ligatures in Stage II (T13) for all deflections.

Table 15 shows values for frictional force obtained for Stage III combinations (T14 - T17) with ceramic Tip Edge brackets. Method of fixation was not statistically significant, therefore only values for steel ligation are presented.

As can be seen from the table, the value of 10.55N for round 0.022" stainless steel wire with sidewinder (T15) was higher than the other Stage III combinations (T14, T16 and T17) at 0.00mm deflection (5.76N, 4.79N and 3.98N respectively). However, these differences failed to reach statistical significance. At the higher deflection of 0.50mm, the higher values were found for the rectangular wires (T16 and T17) than for the round wires (T14 and 15). These differences reached statistical significance ($p < 0.001$).

**Table 14 Frictional forces in Newton ( N ) for arch wires with ceramic Tip Edge brackets in Stage I and II with and without sidewinders at various deflections with modules and ligatures (T9 - T13)**

| | | Deflection (mm) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.00 | | 0.25 | | 0.50 | | 0.75 | |
| Wire | Spring/aux | Lig | Mod | Lig | Mod | Lig | Mod | Lig | Mod |
| 0.016 SS (T9) | | 3.36 | 1.24 | 3.79 | 1.67 | 4.28 | 2.16 | 7.68 | 5.56 |
| 0.016 SS(T10) | sidewinder | 4.31 | 1.63 | 4.01 | 1.32 | 5.25 | 2.56 | 8.07 | 5.38 |
| 0.016 Co-Ax (T11) | | 3.31 | 2.78 | 3.68 | 3.15 | 4.12 | 3.59 | 3.52 | 2.99 |
| 0.016 NiTi (T12) | | 3.17 | 1.92 | 3.34 | 2.09 | 4.13 | 2.88 | 4.86 | 3.62 |
| 0.020 SS (T13) | sidewinder | 1.51 | 8.09 | 0.95 | 7.53 | 2.02 | 8.60 | 19.02 | 25.60 |

Standard error of mean = 1.37
Pairwise comparison = 3.9

**Table 15 Frictional forces in Newton ( N ) for arch wires with ceramic Tip Edge brackets in Stage III at various deflections (T14 - T17)**

| Wire | Spring/aux | Deflection (mm) | | |
|---|---|---|---|---|
| | | 0.00 | 0.25 | 0.50 |
| 0.022" SS (T14) | 0.012" SS | 5.76 | 2.63 | 7.76 |
| 0.022" SS (T15) | sidewinder | 10.55 | 7.19 | 6.54 |
| 0.021x0.025" SS (T16) | | 4.79 | 8.47 | 32.73 |
| 0.021x0.025" SS (T17) | sidewinder | 3.99 | 10.84 | 27.21 |

Standard error of mean = 3.64
Pairwise comparison = 10.30

### *5.4.2 Effect of environment*

Differences in frictional force values due to the effect of a wet environment failed to reach statistical significance with this bracket system either for Stage I and II ($p = 0.023$) or for Stage III ($p = 0.496$). Therefore, only dry values are presented.

### *5.4.3 Effect of deflections*

For all treatment combinations (T9 - 17), an increase in deflection increased the frictional resistance. This is especially seen in rectangular wires (T16 and T17).

In the Stage III combinations, an initial increase in deflection with round wires (T14 and T15) produced a slight decrease in friction but with the rectangular wires (T16 and T17), it produced a corresponding increase in friction with increase in deflection.

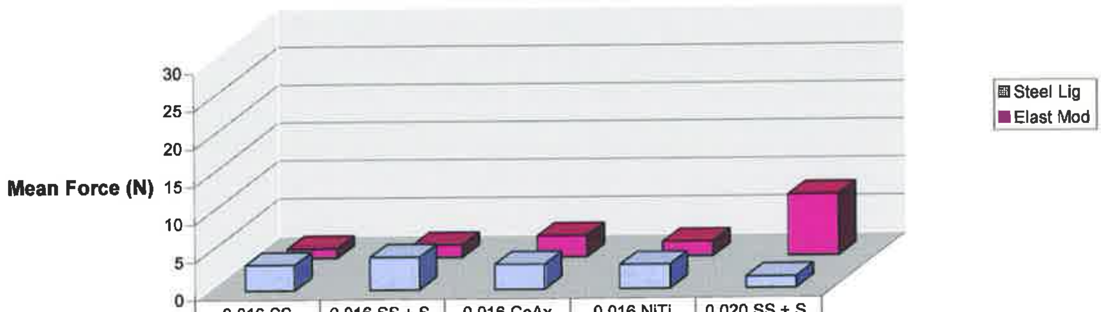
### *5.4.4 Effect of ligation*

Method of ligation did not play a significant role in the frictional characteristics of this bracket system either in Stage I and II ($p = 0.610$), or in Stage III ($p = 0.030$).

However, comparing the frictional force values for T13 (0.020" SS with sidewinder spring), ligating with alastik modules produced higher frictional mean values although the values did not reach significance.

Figures 17-20 represent the various combinations (T9-13) with the different method of fixation and their respective mean frictional force in Newton at the various deflections.

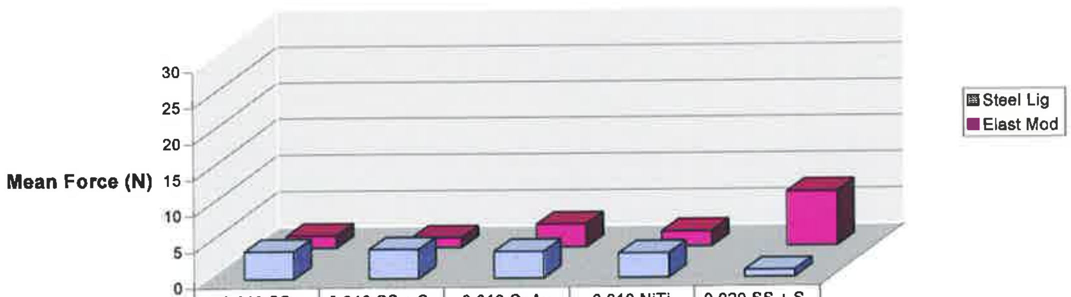
Figures 21-23 represent the various combinations (T14-17) and their respective mean frictional force in Newton at the various deflections.




| | 0.016 SS (T9) | 0.016 SS + S. winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020 SS + S. winder (T13) |
|---|---|---|---|---|---|
| Steel Lig | 3.358 | 4.314 | 3.312 | 3.165 | 1.51 |
| Elast Mod | 1.242 | 1.627 | 2.781 | 1.917 | 8.092 |

Type of archwire/bracket combination

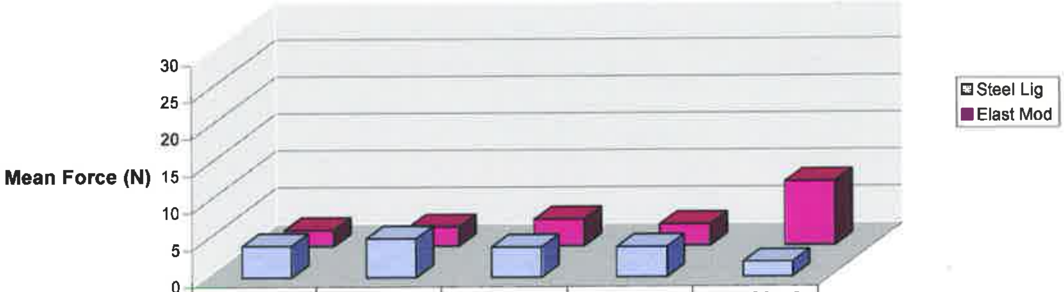
**Figure 17 Ceramic Tip Edge bracket at 0.00mm deflection (T9 - T13)**




| | 0.016 SS (T9) | 0.016 SS + S. winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020 SS + S. winder (T13) |
|---|---|---|---|---|---|
| Steel Lig | 3.79 | 4.009 | 3.681 | 3.338 | 0.948 |
| Elast Mod | 1.674 | 1.321 | 3.151 | 2.089 | 7.531 |

Type of archwire/bracket combination

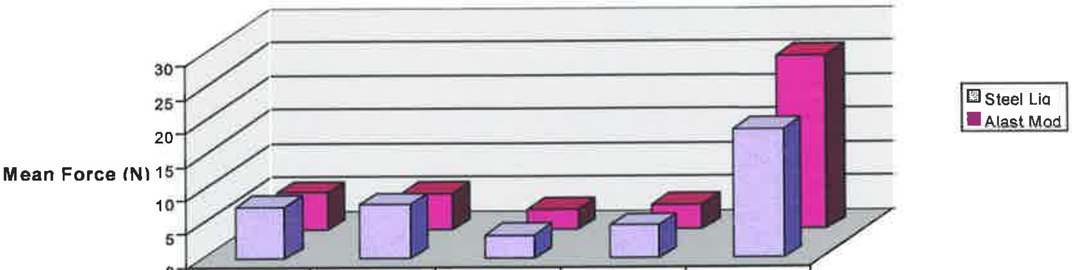
**Figure 18 Ceramic Tip Edge bracket at 0.25mm deflection (T9 - T13)**




| | 0.016 SS (T9) | 0.016 SS + S. winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020 SS + S. winder (T13) |
|---|---|---|---|---|---|
| Steel Lig | 4.279 | 5.252 | 4.116 | 4.125 | 2.021 |
| Elast Mod | 2.163 | 2.564 | 3.586 | 2.877 | 8.603 |

Type of archwire/bracket combination

**Figure 19 Ceramic Tip Edge bracket at 0.50mm deflection (T9 - T13)**




| | 0.016 SS (T9) | 0.016 SS + S. winder (T10) | 0.016 CoAx (T11) | 0.016 NiTi (T12) | 0.020 SS + S. winder (T13) |
|---|---|---|---|---|---|
| Steel Lig | 7.678 | 8.065 | 3.519 | 4.863 | 19.016 |
| Elast Mod | 5.562 | 5.377 | 2.989 | 3.615 | 25.598 |

Type of archwire/bracket combination

**Figure 20 Ceramic Tip Edge bracket at 0.75mm deflection (T9 - T13)**

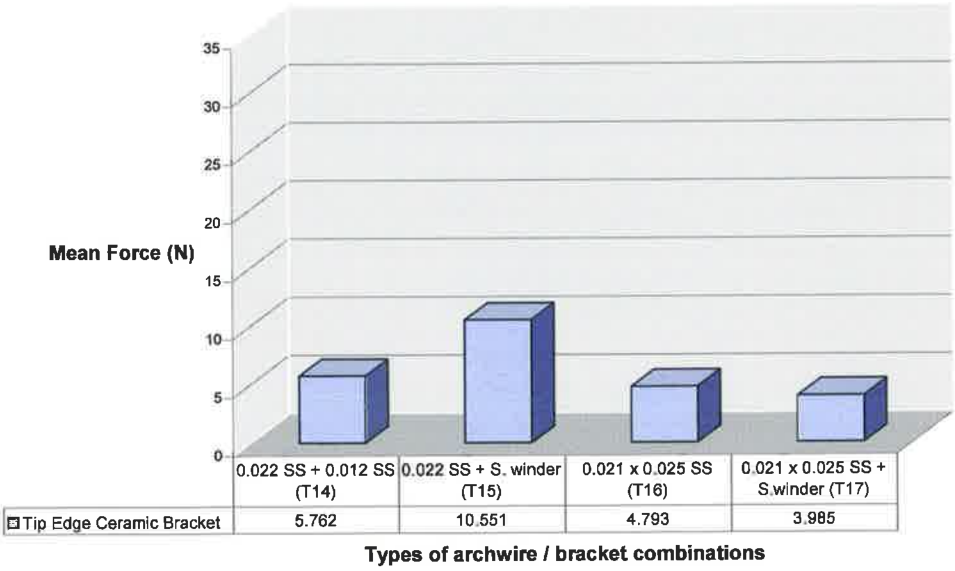



**Figure 21 Ceramic Tip Edge bracket at 0.00mm deflection (T14 - T17)**

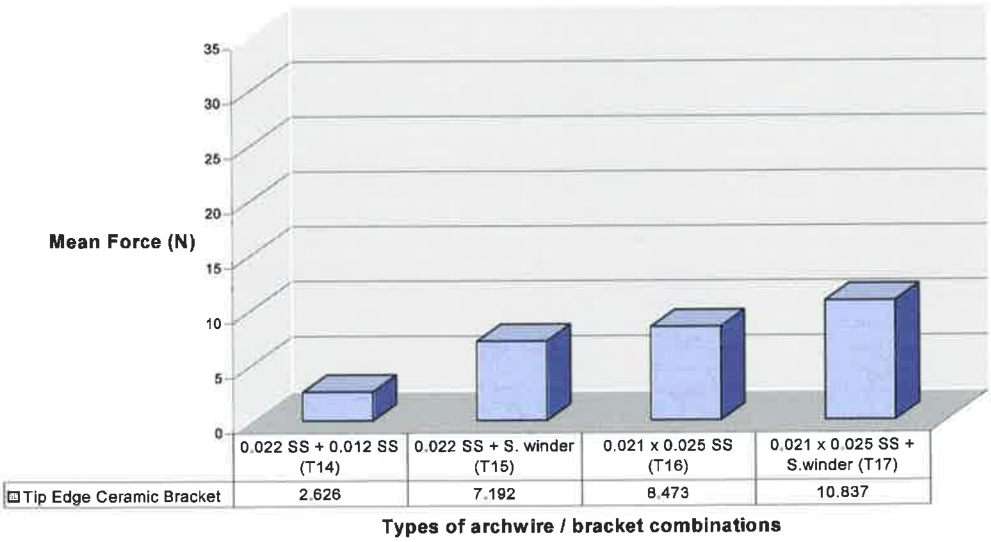



**Figure 22 Ceramic Tip Edge bracket at 0.25mm deflection (T14 - T17)**

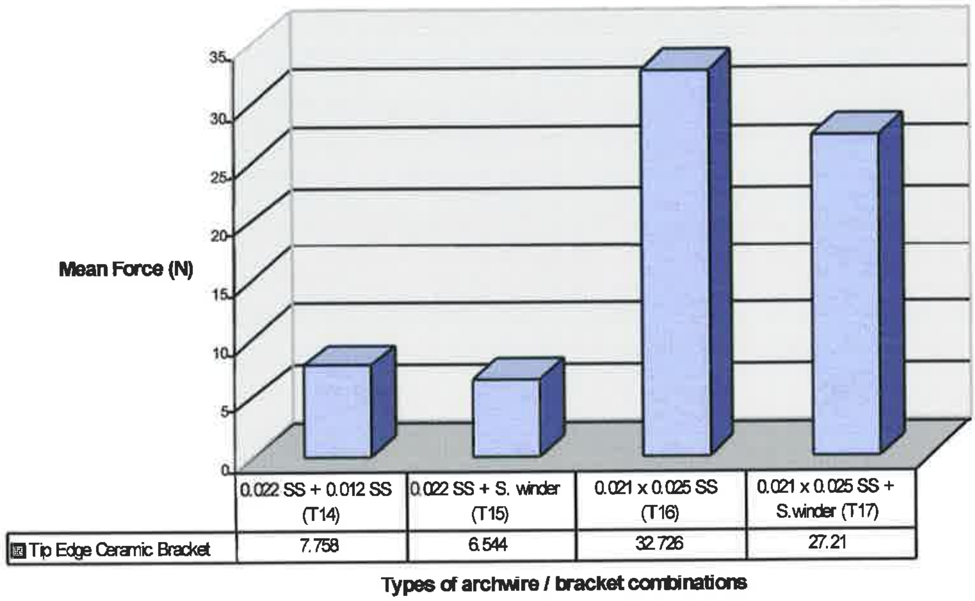



**Figure 23 Ceramic Tip Edge bracket at 0.50mm deflection (T14 - T17)**

## 5.5 Scanning Electron Microscopy (S.E.M.)

The following are prints from specimens obtained before and after selected tests with the intention to reveal surface damage undetected by the naked eye.

A bracket was randomly selected from each of the various combinations to be examined in the S.E.M. Also a 10mm section obtained approximately from the middle of the section of the arch wire under test was randomly selected to be examined in the S.E.M. Only brackets and arch wires that demonstrated surface damage are included in this section.

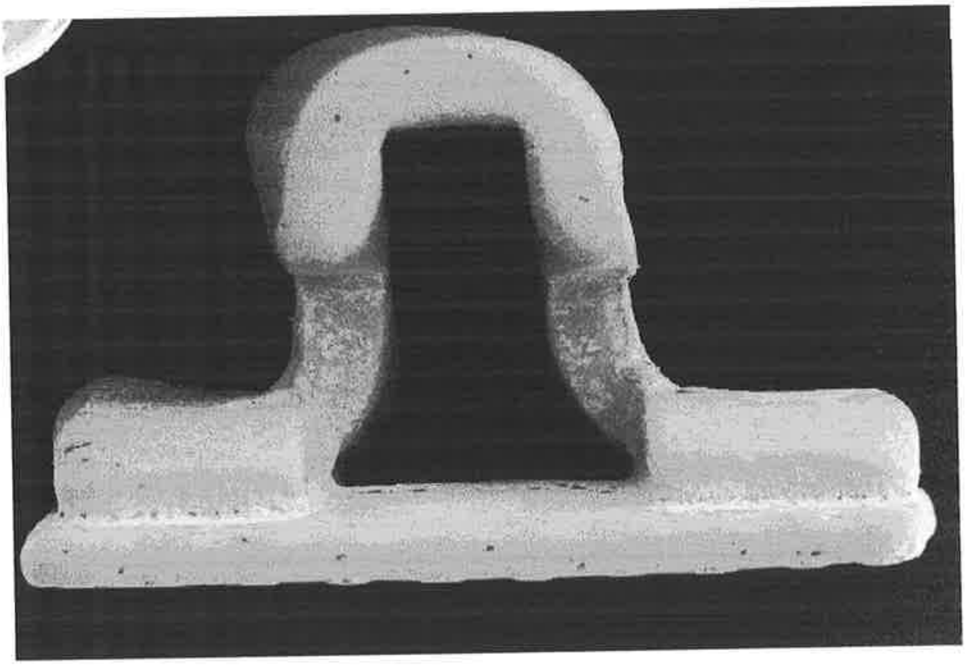


**Figure 24 Begg metal bracket (new)**

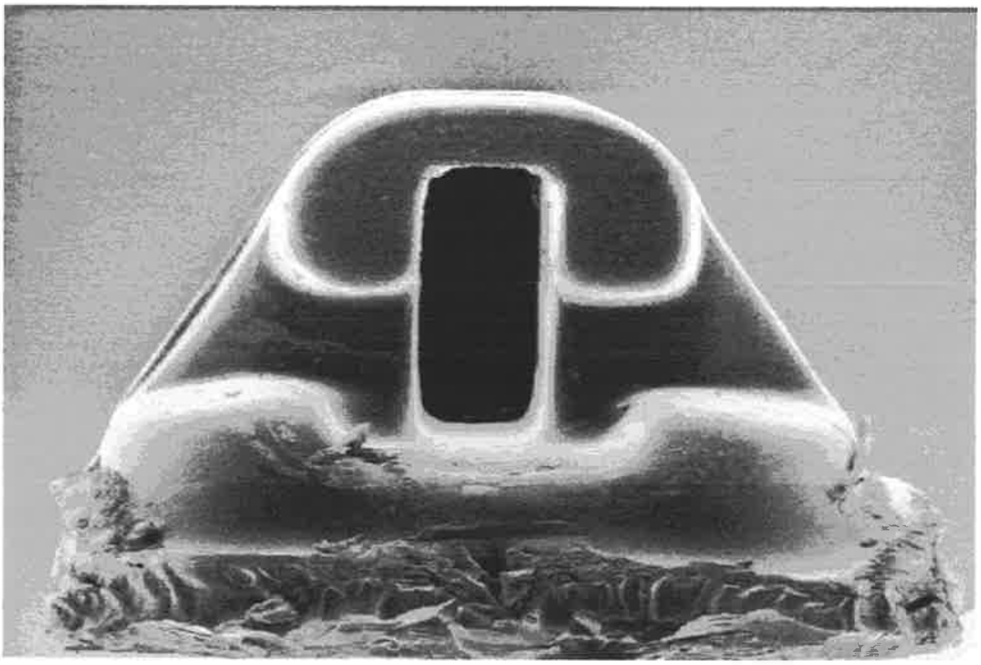


**Figure 25 Begg ceramic bracket (new)**

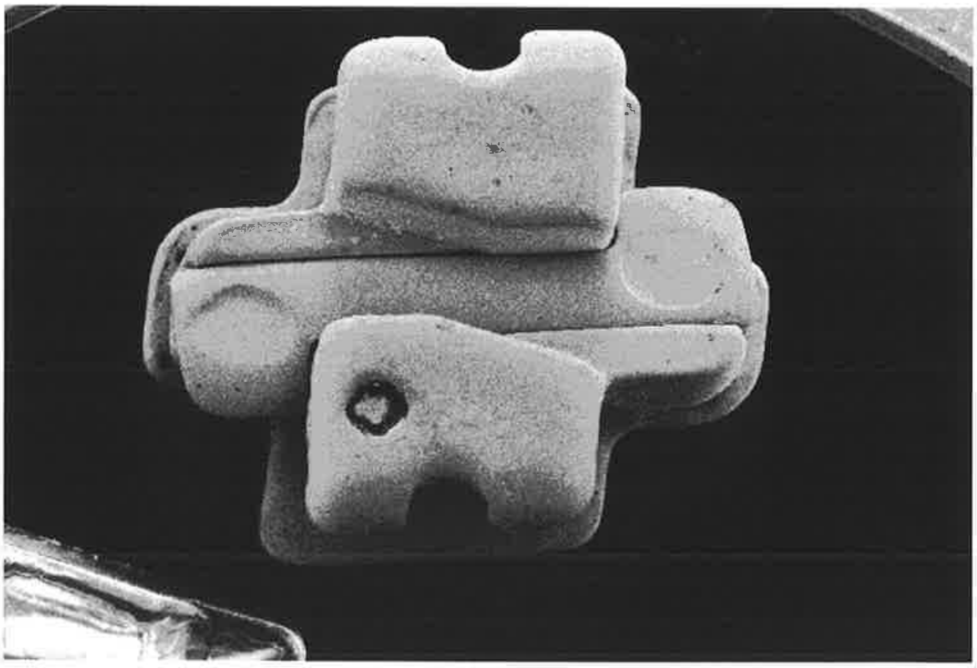


**Figure 26 Tip Edge metal bracket (new)**

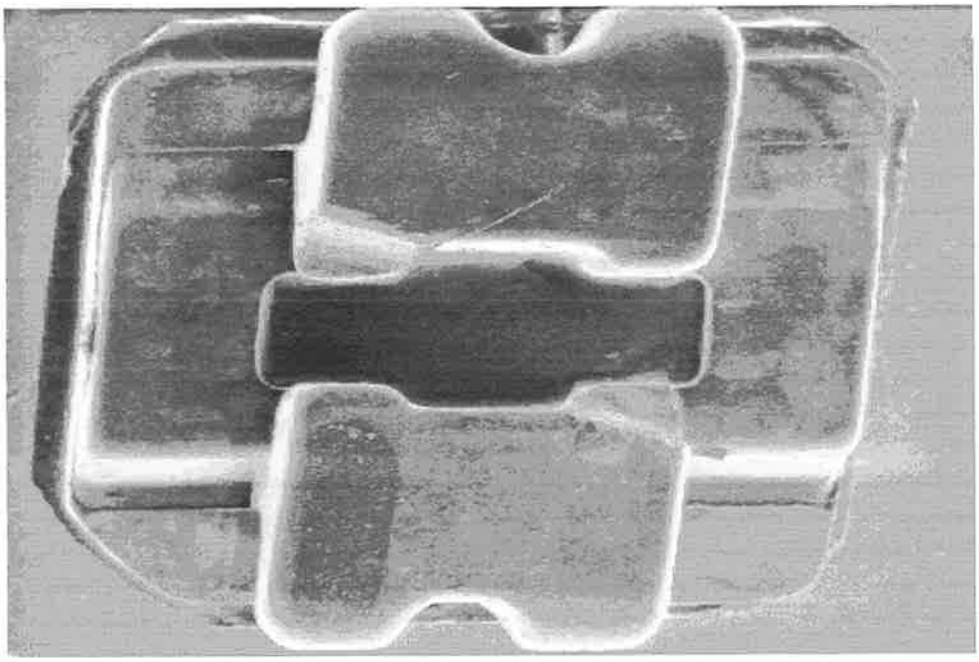


**Figure 27 Tip Edge ceramic bracket (new)**

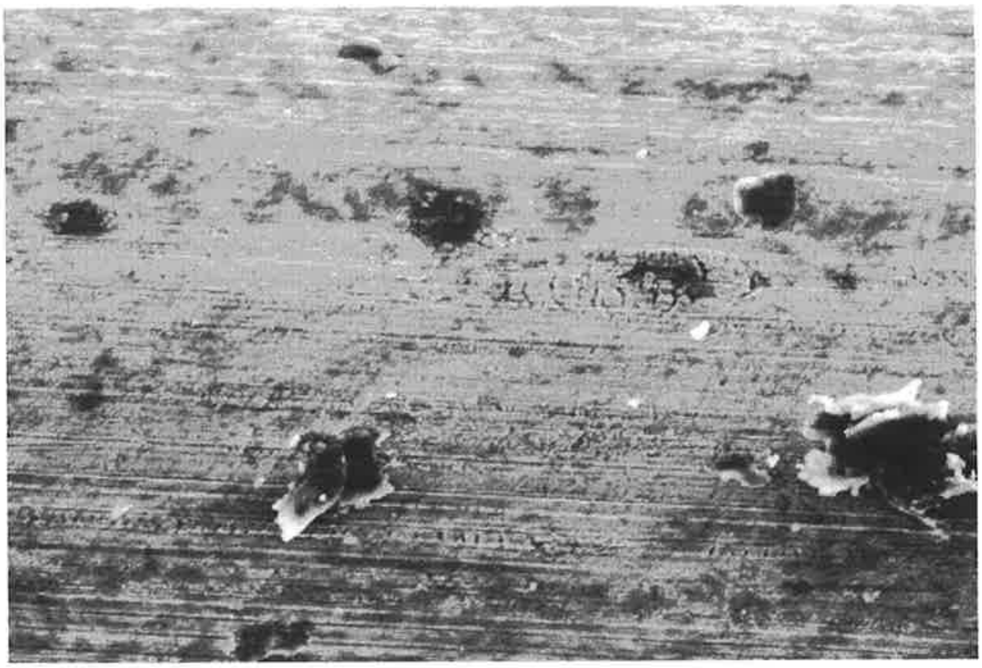


**Figure 28 Australian Wilcock SS wire 0.016" (new)**

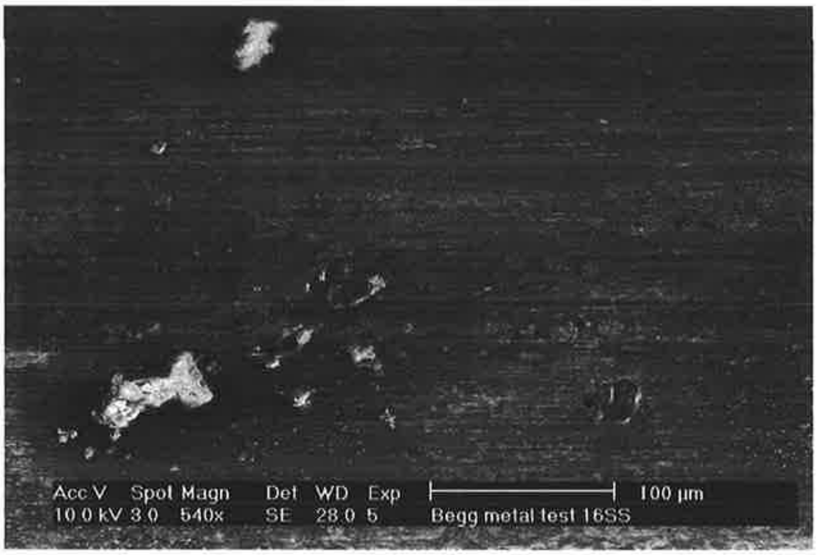



**Figure 29 Australian Wilcock SS wire 0.016" (after test with Begg metal bracket)**

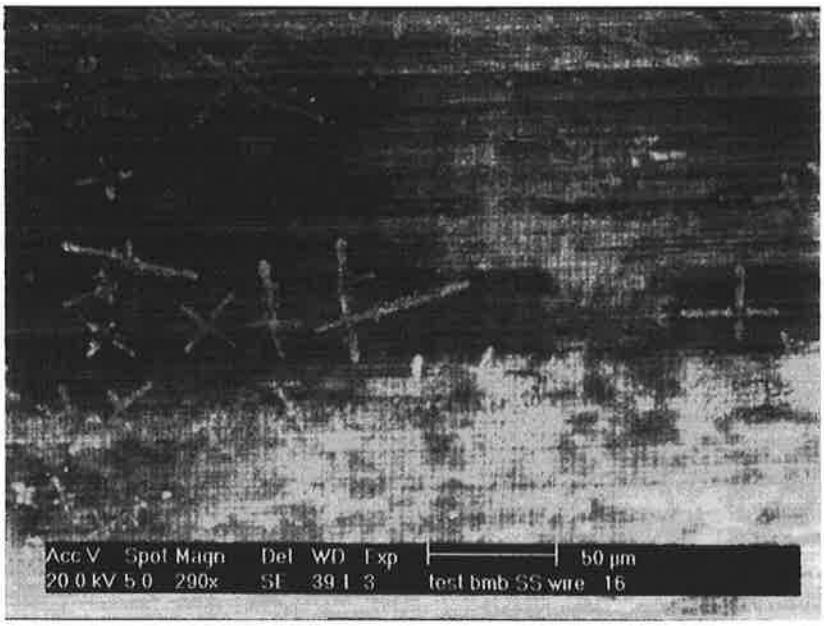



**Figure 30 Australian Wilcock SS wire 0.016" (after test with Begg metal bracket)**

Note: characteristic 'criss-cross' patterns found on a portion of the wire surface but was not found consistently throughout the specimen.

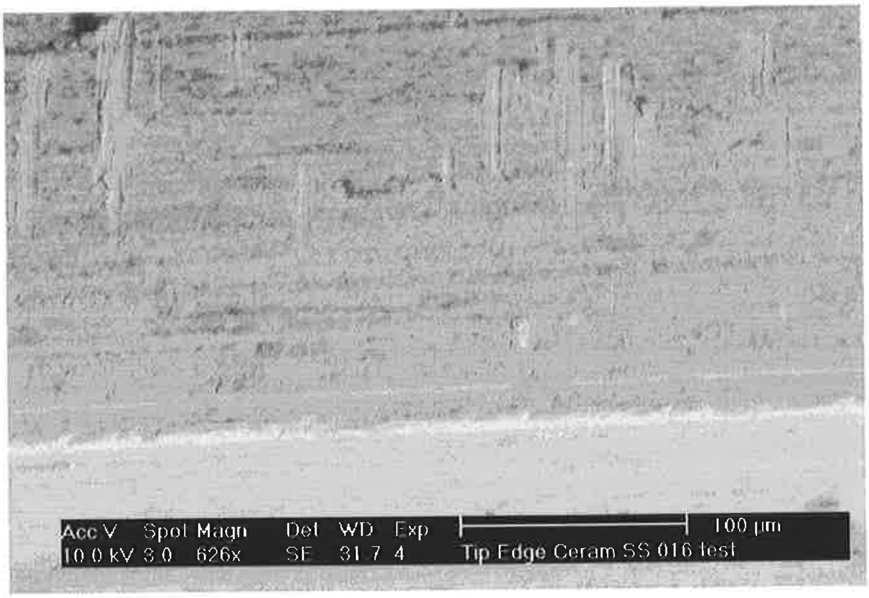



**Figure 31 Australian Wilcock SS wire 0.016" (after test with Tip Edge ceramic bracket)**

Note: scratches seen on the surface of the wire

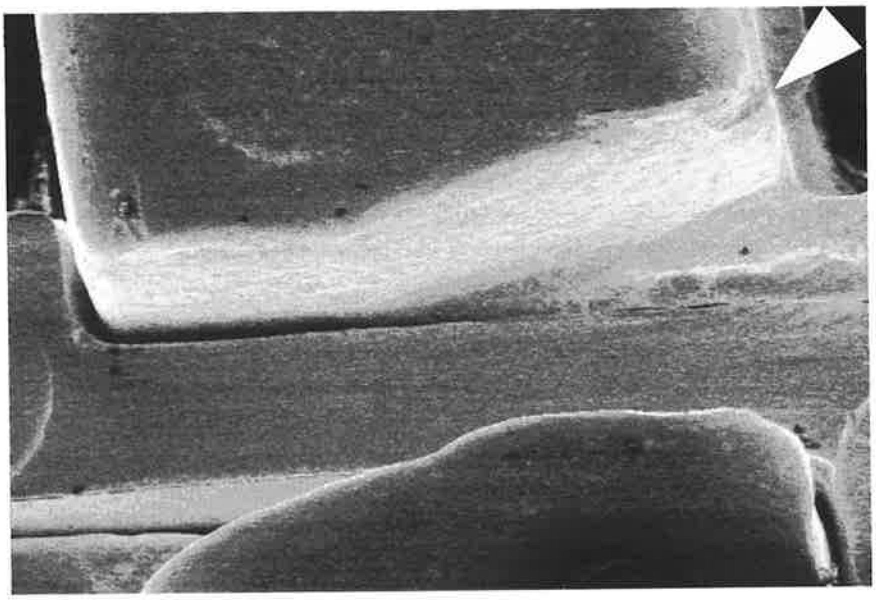


**Figure 32 Tip Edge metal bracket after test with 0.016" SS wire**

Note: microfractures along the corner of the slope of the slot

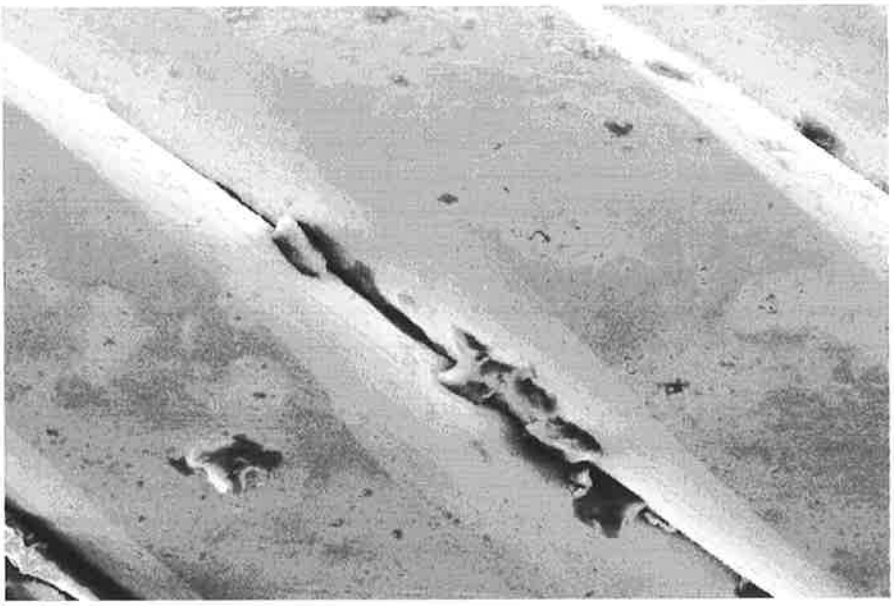


**Figure 33 Co-Ax multistrand SS wire 0.016" (new)**

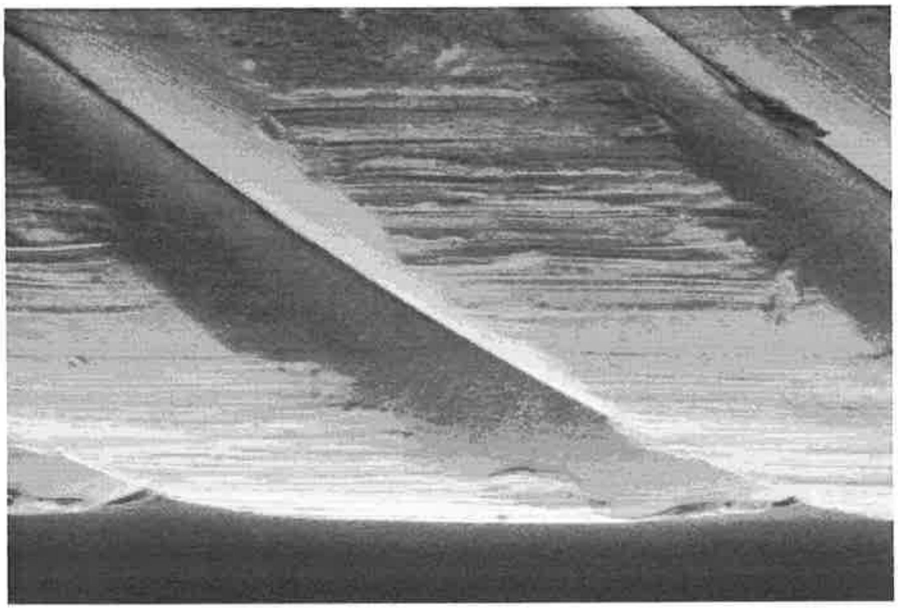


**Figure 34 Co-Ax multistrand SS wire 0.016" (after test with Tip Edge ceramic bracket)**

Note: very scratched surface of the wire

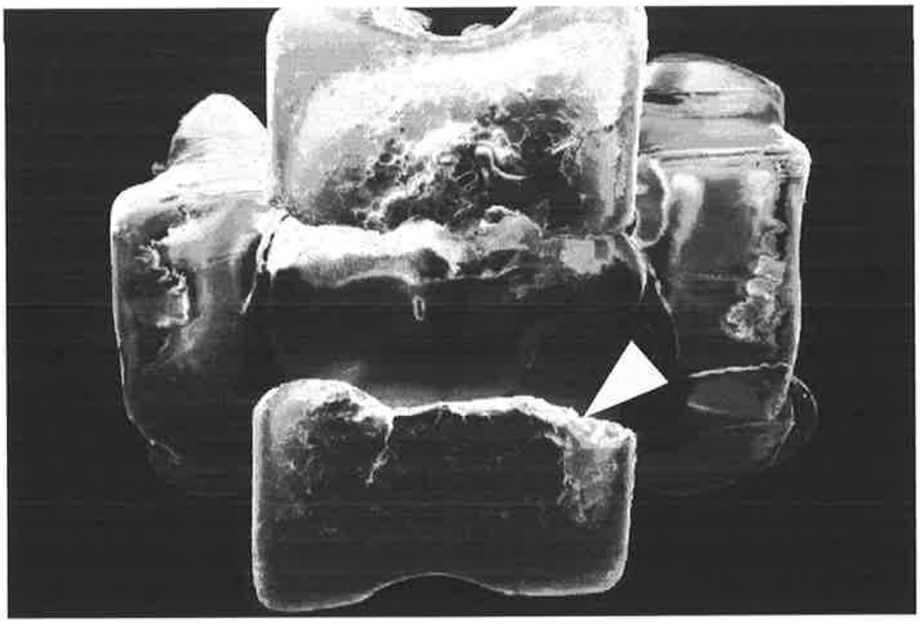


**Figure 35 Tip Edge ceramic bracket after test with Co-Ax 0.016" wire**

Note: some microfractures along the slope surfaces of the slot were evident

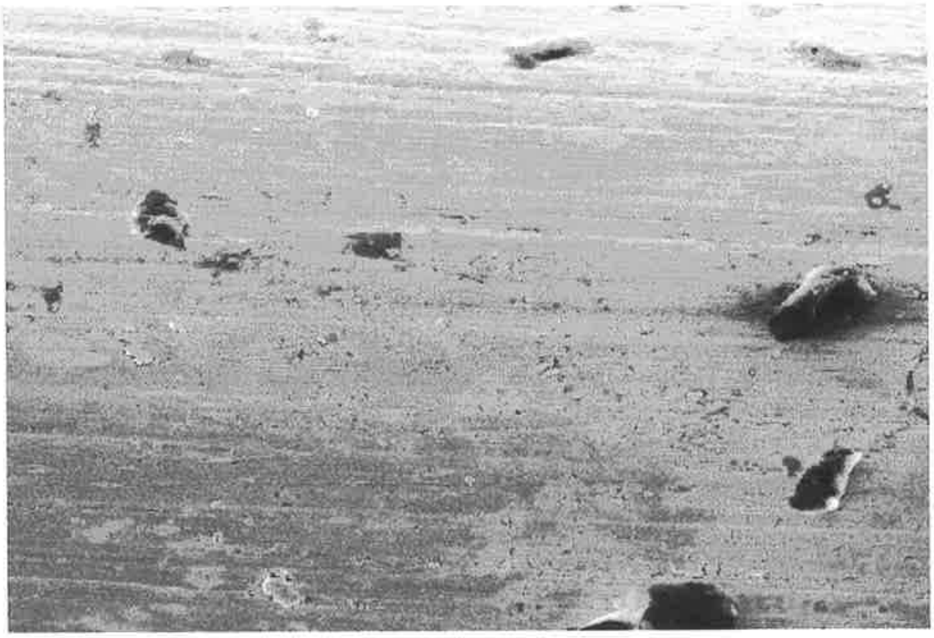


**Figure 36 NiTi wire 0.016" (new)**

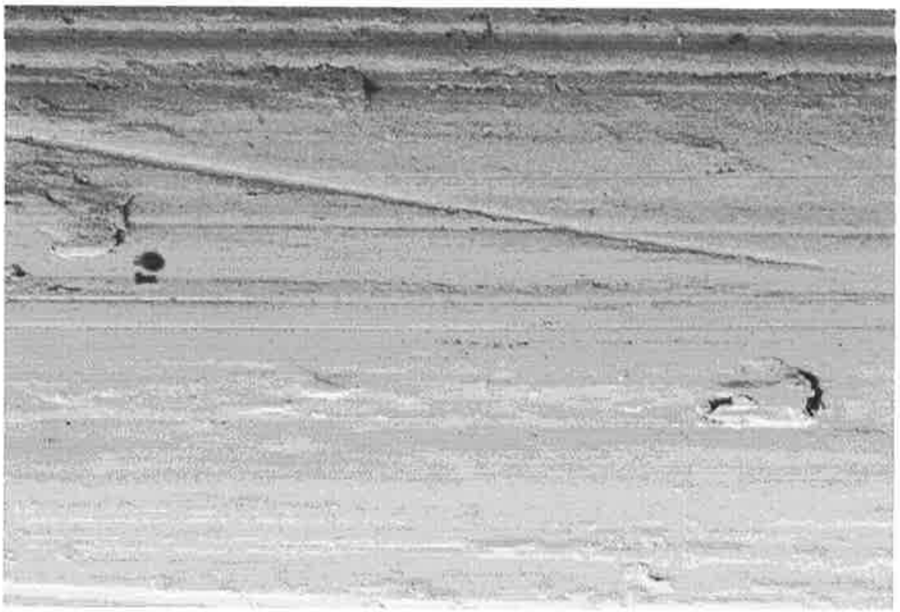


**Figure 37 NiTi wire 0.016" (after test with Begg metal bracket)**

Note: surface scratch lines

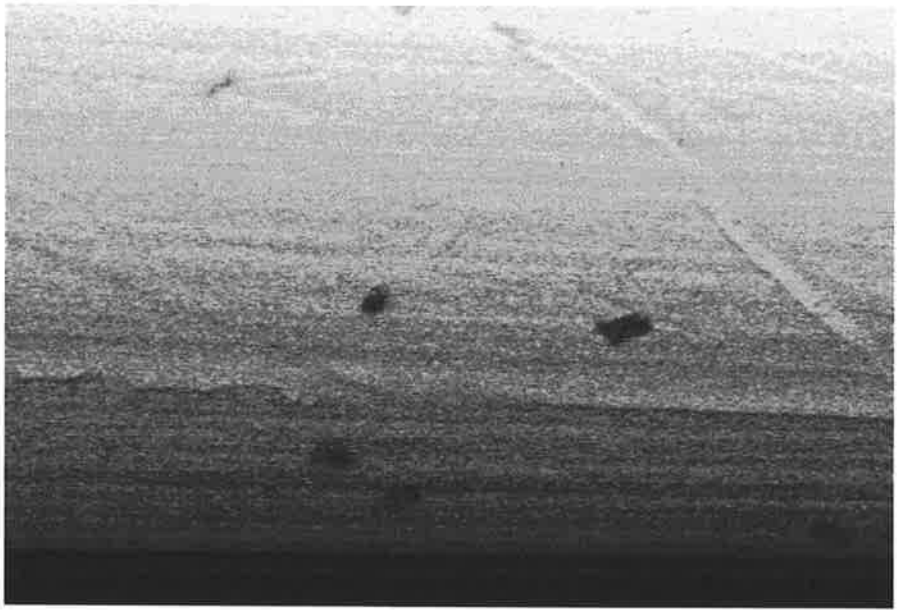


**Figure 38 NiTi wire 0.016" (after test with Tip Edge ceramic bracket)**

Note: gouges along the surface of the NiTi wire

**Figure 39 Stainless steel wire 0.021" x 0.025" (after test with Tip Edge ceramic bracket)**

Note : very scratched and gouged surface

## 5.6 Recordings of graphs.

The following are representation of the graphic recordings from the test series. See Volume II for all the individual recordings. The x axis represents a given time factor whereas the y axis represents the frictional force value in Newton. The pattern of the graph, i.e. whether the line was smooth, represented the amount of binding within the bracket and arch wire interface.

A graph was obtained for each reading, i.e. 3 graphs for each treatment combination.

A frictional force value and its standard deviation was obtained for each graph / treatment combination from averaging all the y values over a given time.

Predicted mean values and the standard error of the mean of the frictional forces were calculated for each specific bracket / arch wire combination and are shown in Tables 6,8,10,13 and 14.

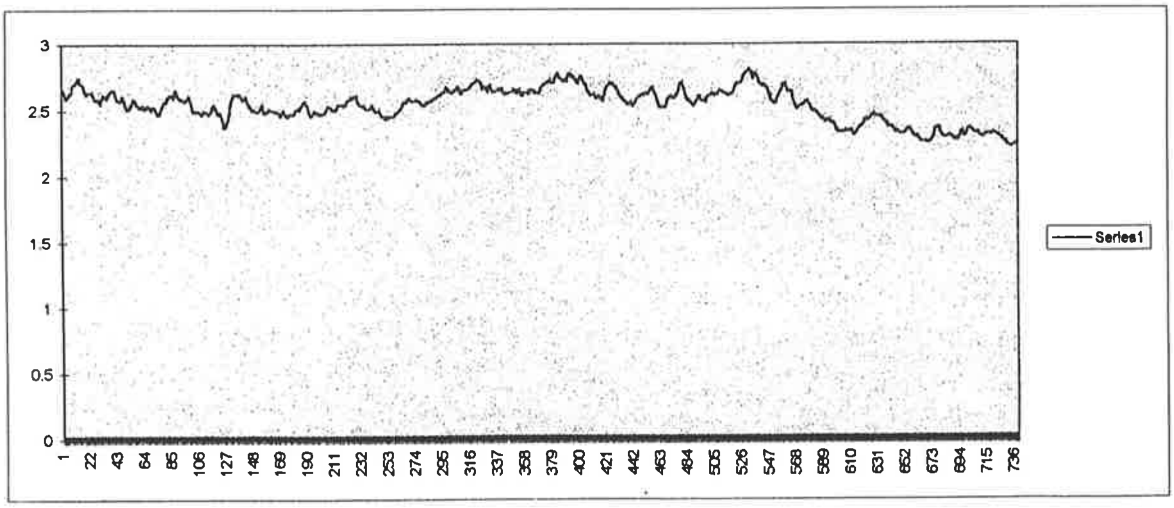



**Figure 40 Representation of the combination of Begg bracket and SS arch wire**

(Begg metal bracket with 0.016"SS and lock pins in a wet environment, T1)

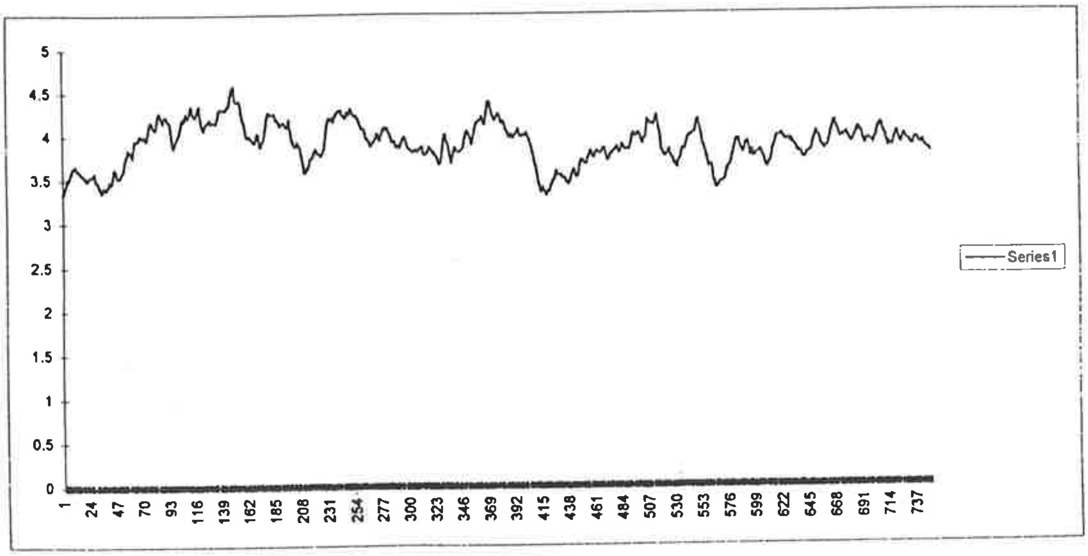



**Figure 41 Representation of the combination of Begg bracket and NiTi arch wire**

(Begg metal bracket with 0.016" NiTi and lock pins, T4)

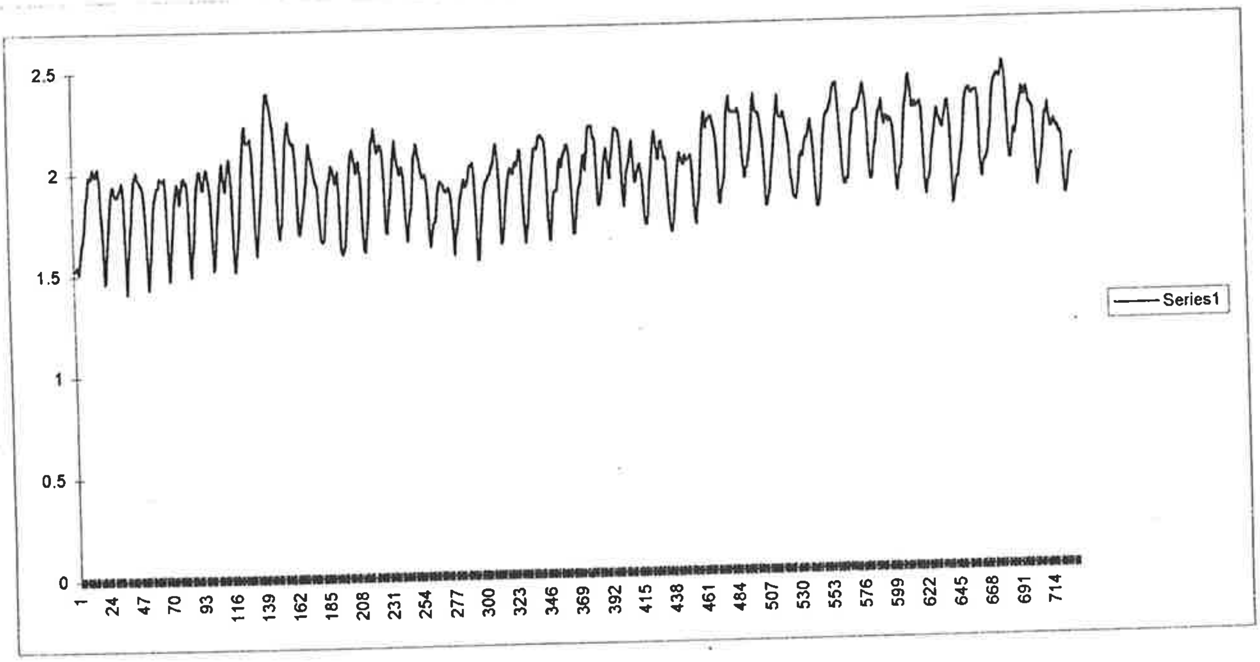



**Figure 42 Representation of the combination of Begg bracket and Co-Ax arch wire**

(Begg metal bracket with 0.016" Co-Ax and lock pins in a wet environment, T3)

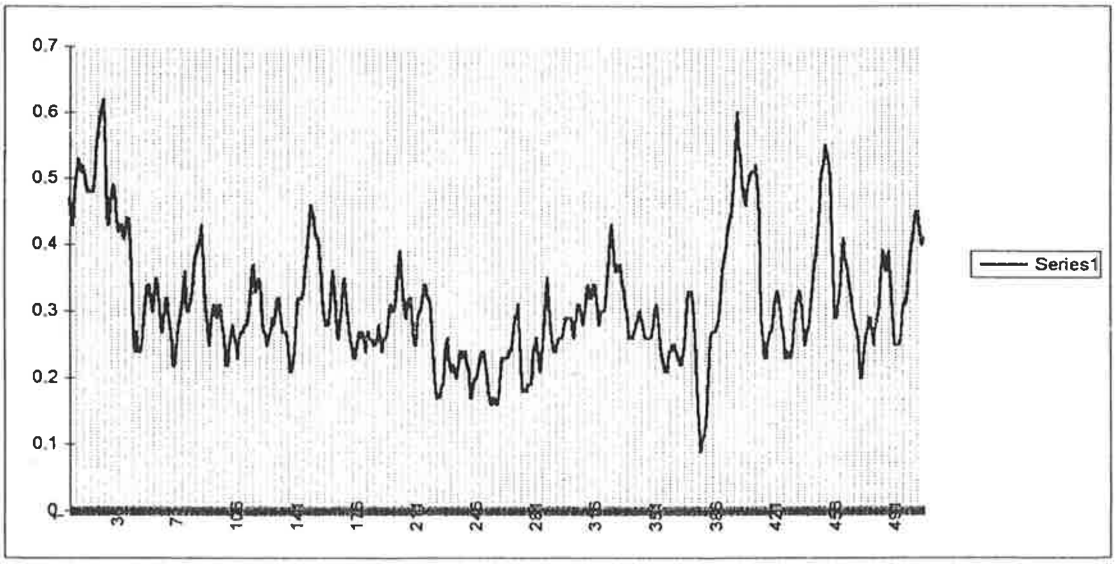



**Figure 43 Representation of the combination of Begg bracket and SS arch wire with uprighting springs.**

(Begg metal bracket with 0.020" SS and uprighting springs, T8)

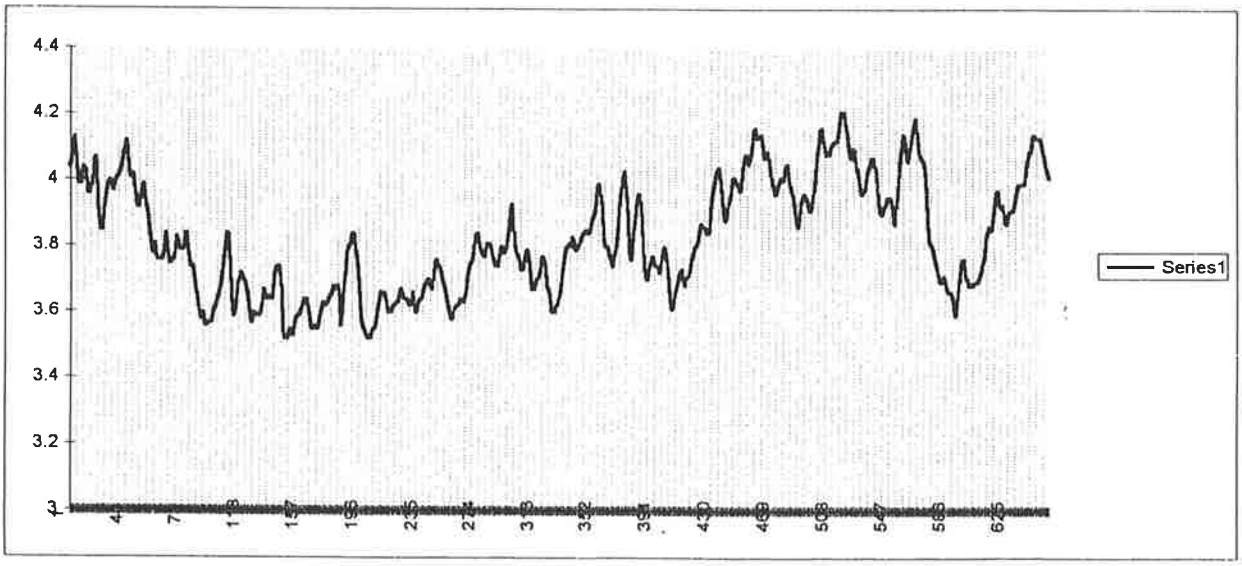



**Figure 44 Representation of the combination of Tip Edge bracket with steel ligatures and SS arch wire**

(Tip Edge metal bracket with 0.016" SS and steel ligature, T9)

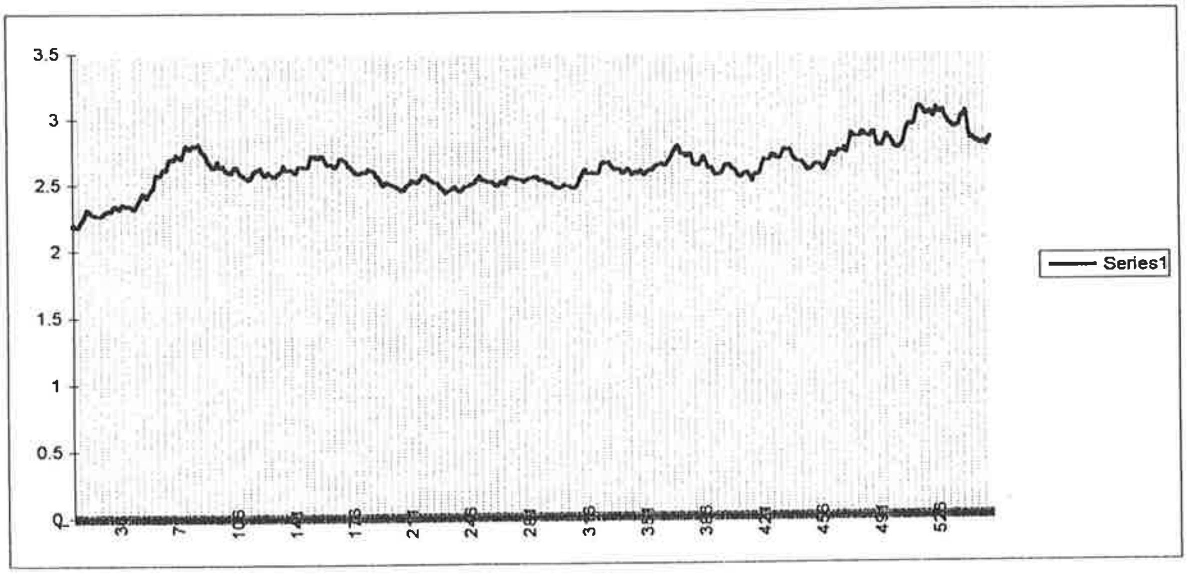



**Figure 45 Representation of the combination of Tip Edge bracket with alastik modules and SS arch wire**

(Tip Edge metal bracket with 0.016" SS and alastik modules, T9)

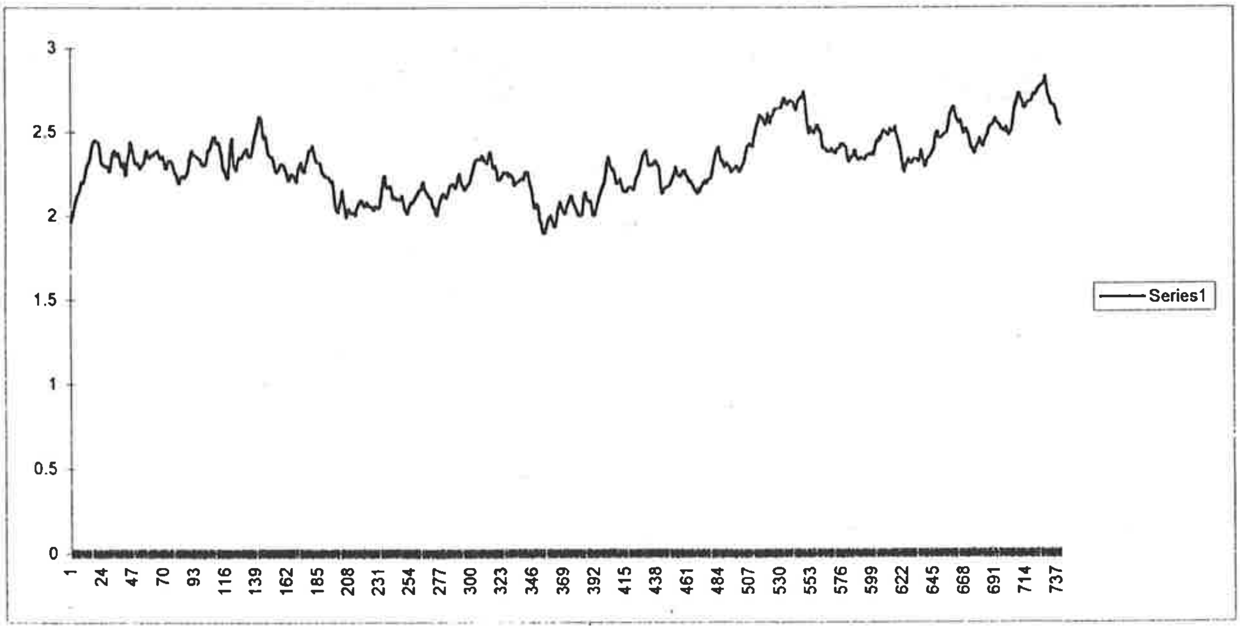



**Figure 46 Representation of the combination of Tip Edge bracket with steel ligatures and NiTi arch wire.**

(Tip Edge metal bracket with 0.016"NiTi and steel ligature, T12)

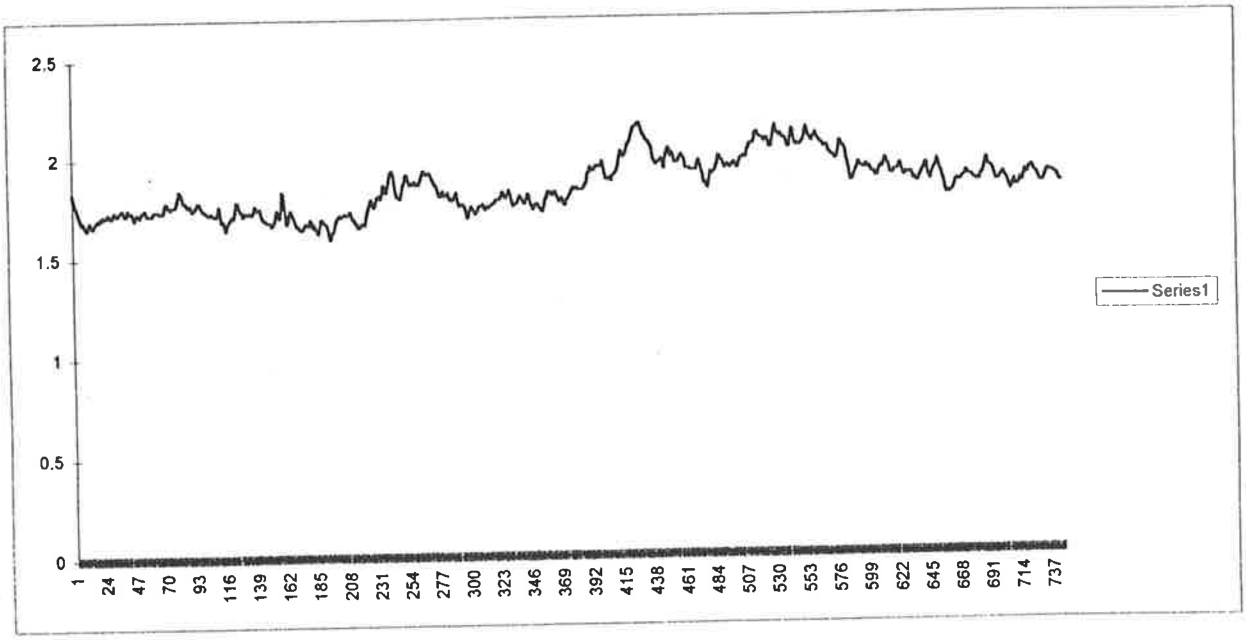



**Figure 47 Representation of the combination of Tip Edge bracket with alastik modules and NiTi arch wire**

(Tip Edge metal bracket with 0.016" NiTi and alastik module, T12)

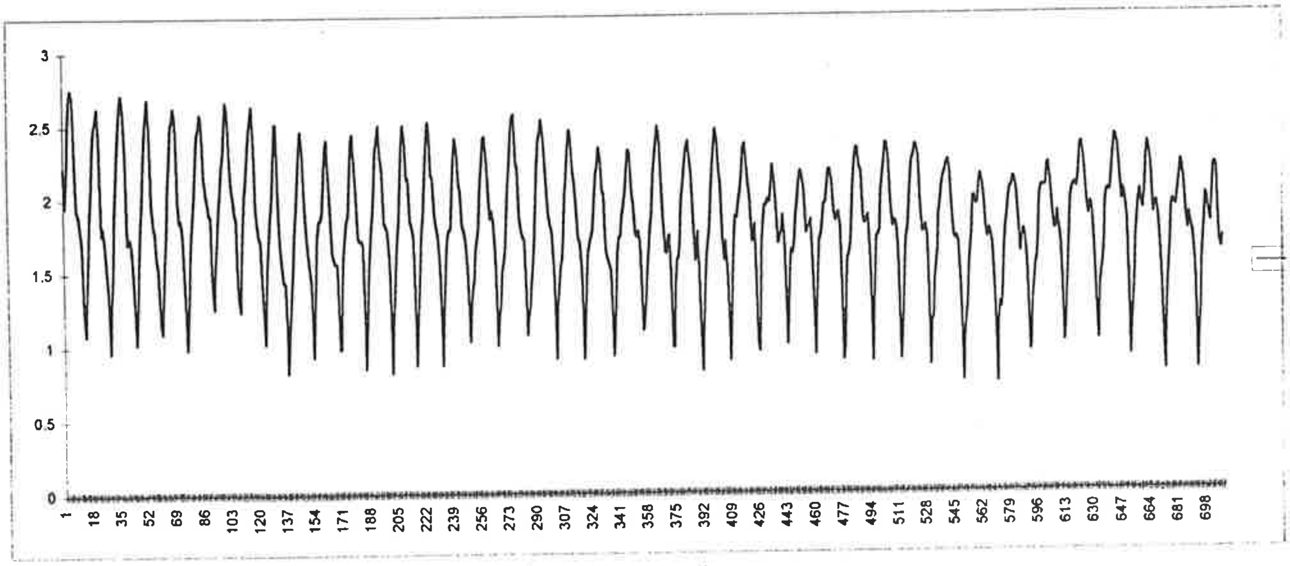



**Figure 48 Representation of the combination of Tip Edge bracket with steel ligatures and Co-Ax arch wire.**

(Tip Edge bracket with 0.016" Co-Ax and steel ligatures, T11)

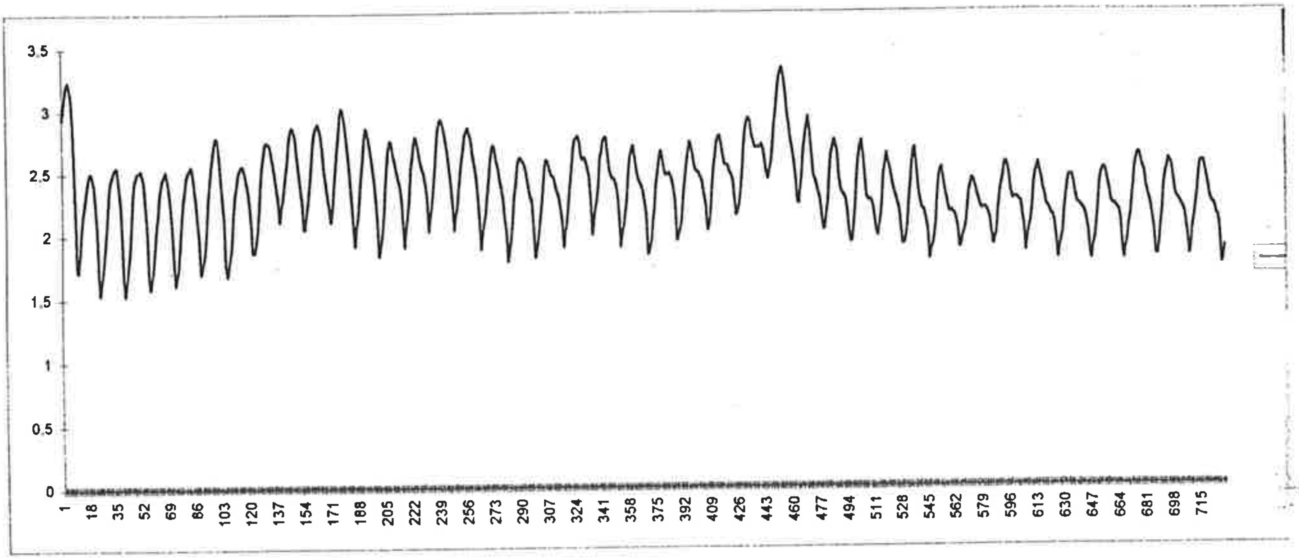



**Figure 49 Representation of the combination of Tip Edge bracket with alastik modules and Co-Ax arch wire**

(Tip Edge metal bracket with 0.016" Co-Ax and alastik module, T11)

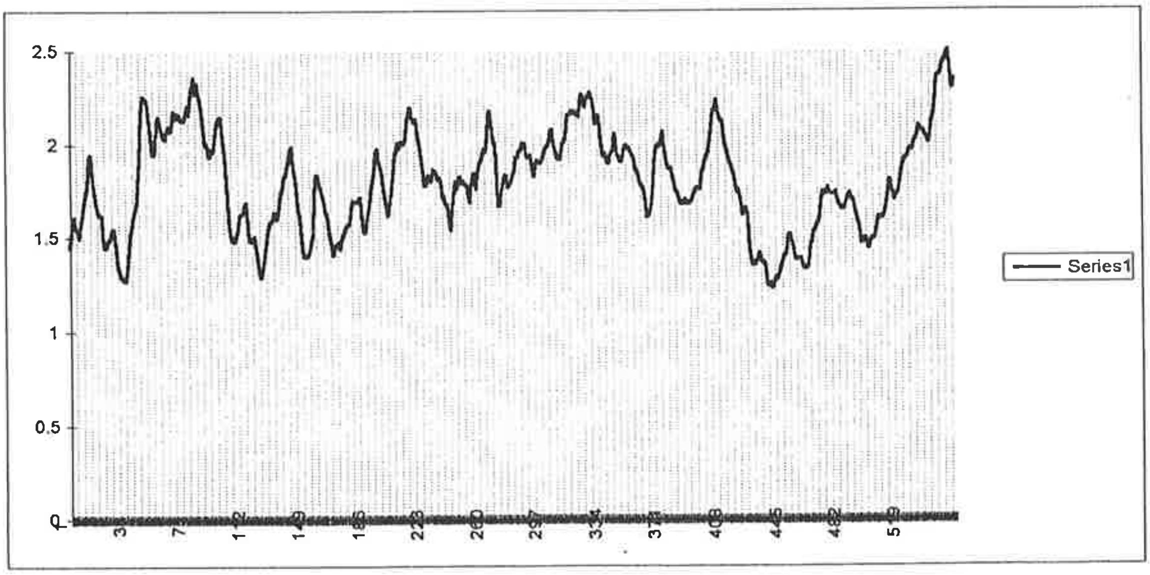



**Figure 50 Representation of the combination of Tip Edge bracket with steel ligatures and rectangular stainless steel arch wire**

(Tip Edge metal bracket with 0.021"x0.025" SS and steel ligature, T16)

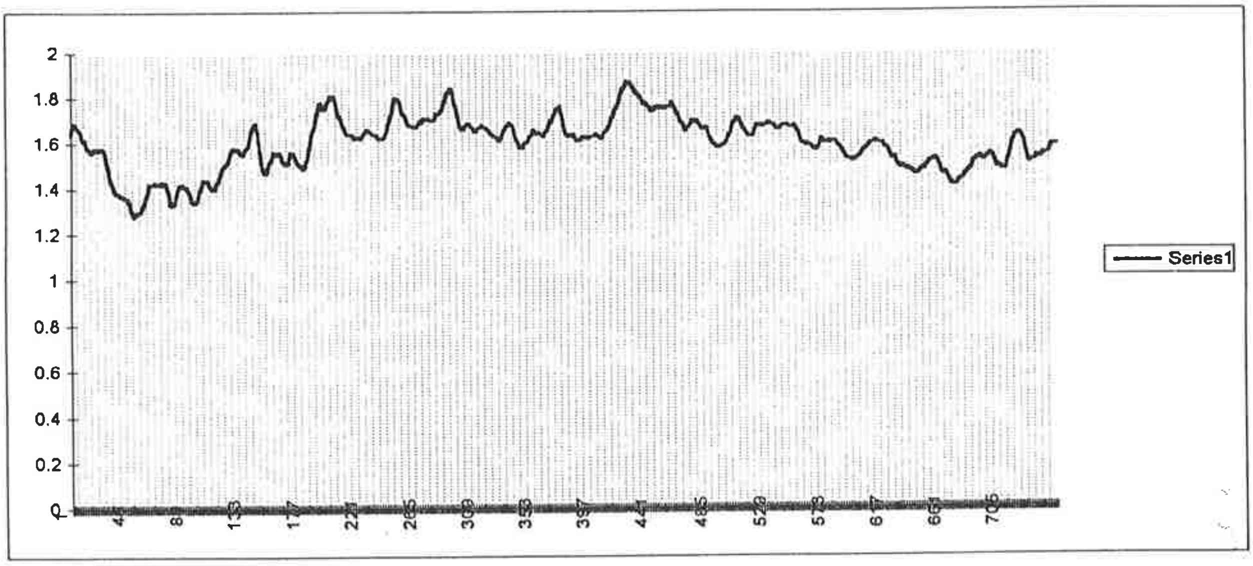



**Figure 51 Representation of the combination of Tip Edge bracket with alastik modules and rectangular stainless steel arch wire**

(Tip Edge metal bracket with 0.021"x0.025" SS and alastik module, T16)

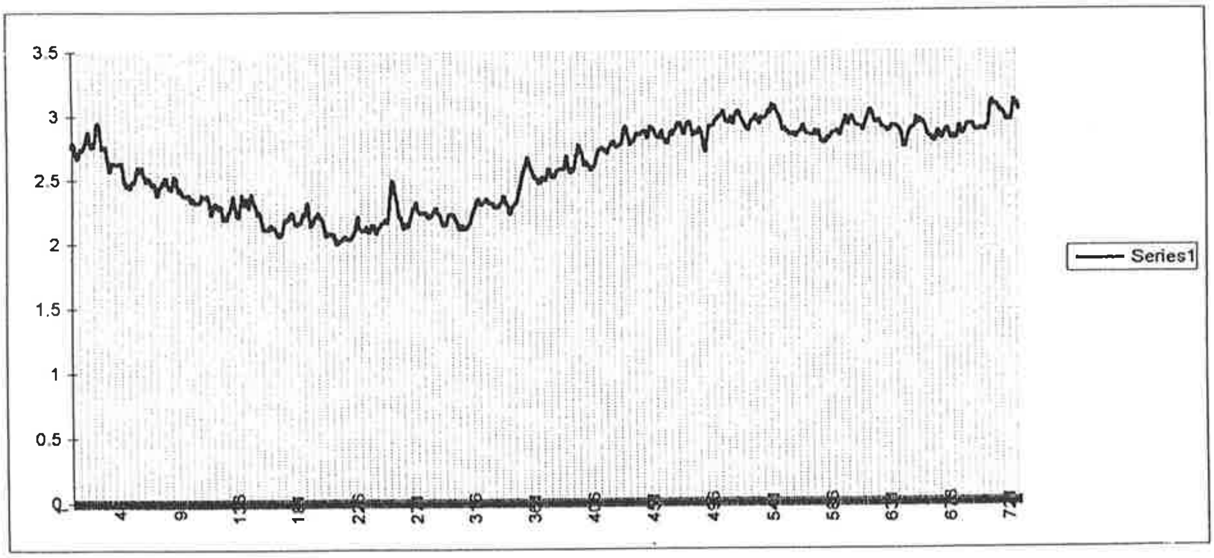



**Figure 52 Representation of the combination of Tip Edge bracket with steel ligatures and round wire with sidewinder spring**

(Tip Edge metal bracket with 0.022" SS, steel ligatures and uprighting spring, T15)

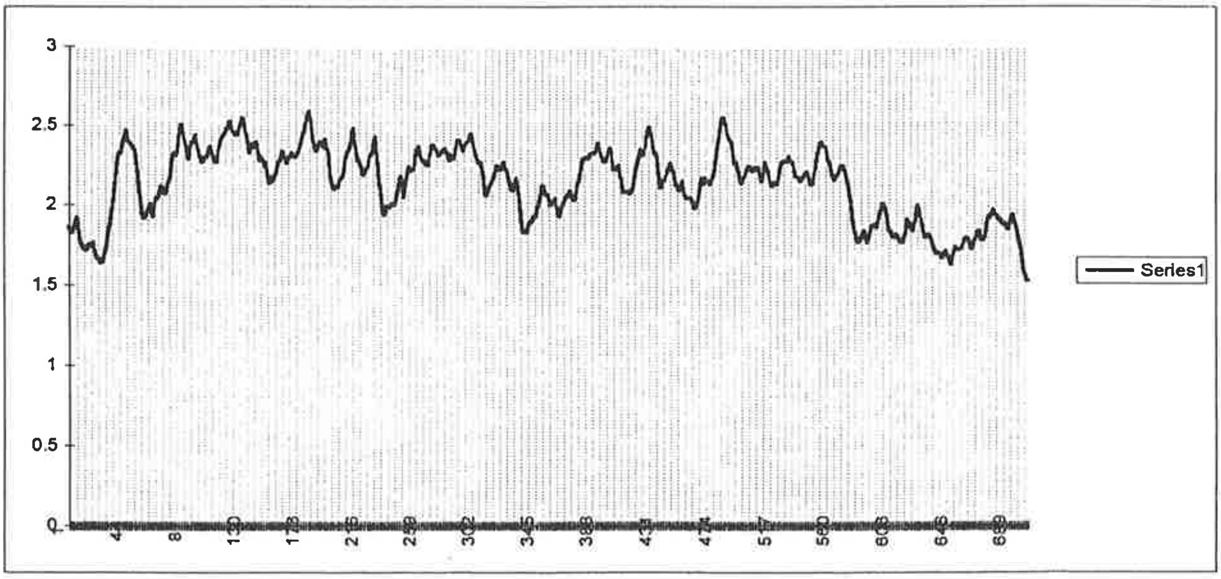



**Figure 53 Representation of the combination of Tip Edge bracket with alastik modules and round wire with sidewinder spring**

(Tip Edge metal bracket with 0.022" SS, alastik module and S.winder in a wet environment, T15)

# 6. Discussion

## 6.1 Effect of arch wire/bracket combination

With the metal Begg brackets, the Co-Ax wire produced lower frictional forces than the NiTi and SS, but for the Begg ceramic brackets, frictional forces for the NiTi and Co-Ax wires were similar, and both were less than the forces found for the SS wire.

**Dickson et al, 1994,** studied 5 initial alignment wires, 3 of which were similar to the wires used in the present study *i.e.* Australian SS, Co-Ax, and NiTi. They found that the Co-Ax wire demonstrated the lowest frictional resistance in all tests. This is supported by results from the present study with the metal Begg bracket. They also found the NiTi wire to produce higher frictional resistance compared with Australian or Co-Ax steel. This, however, was not seen in the present study, in which the NiTi wires were similar to the Australian SS wires with the metal Begg brackets, and similar to the Co-Ax wire with the ceramic Begg brackets. For the ceramic Begg bracket, however, frictional forces for NiTi wires were less than the Australian SS wires.

Previous studies(**Tidy, 1989, Vaughan et al, 1995, Saunders and Kusy, 1994, Kusy and Whitney, 1990, Kusy et al, 1991, Kapila et al, 1990, Drescher et al, 1989, Garner et al, 1990, Pratten et al, 1990**) were in agreement that the NiTi wires produced higher frictional resistance than stainless steel wires. However, most of these studies used rectangular stainless steel wires or round stainless steel from another manufacturer, and few actually used Australian Wilcock stainless steel wires. The results from these previous studies are therefore not directly comparable to the present study. The only rectangular SS wire used in the present study were used in Stage III with the Tip Edge brackets, and were thus not comparable to the Stage I alignment wires.

Findings from the present study showed that the Australian SS wire produced a higher frictional resistance compared with the Co-Ax wires for both the metal and ceramic Begg brackets, and similar resistance to the NiTi wires in the metal Begg brackets.

Unaided visual examination of new NiTi and Australian SS wires indicated that the NiTi wire appeared shinier and smoother than new Australian SS wires. This may be due to the presence of surface oxide layer on the Australian SS wires. However, examination in the

S.E.M. showed that the surface roughness of the two materials was similar. (see Figure 28 and 36) The finding that the frictional forces for SS wires were higher than for NiTi wires may then be due to the a surface oxide layer.

Examination of the Australian Wilcock stainless steel 0.016" wire after testing with the Begg metal bracket revealed a characteristic criss-cross pattern from a portion of the wire. (See Figure 29 and 30). However, this was not found consistently throughout the specimen. This may be a manufacturing artefact of the wire or scratch marks from the bracket and arch wire. Further research is needed to investigate the origin of these patterns.

The new Co-Ax multistrand stainless steel wire appeared shiny and smooth both to the naked eye, and when viewed in the S.E.M.. (see Figure 33). Despite being multistranded, it produced low frictional forces. After a test with the ceramic Begg brackets, the surface appeared rough and scored. This may explain the slightly increased frictional forces found with the ceramic Begg brackets. The scratched surface was more likely to be caused by a rougher ceramic bracket compared to a smoother metal bracket. **(Pratten et al, 1990, Bednar et al, 1991, Omana et al, 1992, Tselepis et al, 1994)** (see Figure 34 and Figure 35).The graphic representation of the Co-Ax wire had a characteristic pattern with regular spikes. (see Figure 42 and Figure 48 and Figure 49) The peak of each spike corresponds to the friction encountered upon binding of the wire and bracket, and the dip corresponds to the bracket not contacting any wire because of the braided nature of the wire. The averaged frictional value obtained may not be the true value of the frictional force within the system as one would expect the peaks of the graph to represent where friction is encountered between the bracket and the arch wire upon contact. This may be a shortcoming of this measurement.

However, for both the metal and ceramic Tip Edge brackets, differences in frictional resistance between the 3 alignment wires did not reach statistical significance.

Considering the various stages of the Begg and Tip Edge technique, a higher frictional resistance might be expected in Stage II (with brakes) and Stage III (with uprighting springs and torquing auxiliaries). However, this was not evident from the results of the present study.

With the Begg brackets, depending on the material and wire used for Stage I, different results were found. Stage I with NiTi and SS wires in the metal Begg bracket produced higher frictional resistance than Stage II (simulated mainly with T pins) and Stage III. For the ceramic Begg bracket and Stage I with SS wires, frictional values were higher than Stage II and Stage III with an auxiliary wire. However, Stage I with SS was comparable to Stage III with uprighting springs (which may also simulate Stage II with brakes). It was then evident that Stage I with SS and Stage III with uprighting springs (or as Stage II with brakes) produced the highest frictional resistance.

Despite the free tipping mechanics of both the bracket systems tested in this study, friction in Stage I is clinically undesirable. A low friction set-up allows efficient alignment of teeth.

In the Stage II set-up with T pins acting as brakes, the effectiveness of the T pins depends on the tightness of the pin placement. However, this varies (as with the use of steel ligature ties in Tip Edge brackets) and thus its effectiveness as a brake changes accordingly. The same may be said for any stage in the Begg bracket set-up whenever lock pins or T pins are used, as frictional forces are dependent on the tightness of pin placement. In order to standardize fixation better, only Stage III lock pins were used. However, in retrospect, this may not be appropriate as Stage III lock pins when tightly placed, binds the arch wire to the bracket slot, unlike the Stage I lock pins. This may explain the increase in frictional forces for some Stage I values. Another explanation could be the binding between the bracket and arch wire. Damage to the bracket or the arch wire will result in surface roughness and subsequent increase in friction.

The use of springs as either brakes or uprighting in Stage II and Stage III was not expressed in our experimental set-up. Clinically, its desirable to increase friction in the bracket system anteriorly with brakes in Stage II so as to minimise anterior retraction and to lose molar anchorage. Friction in Stage III is only a problem if it confounded uprighting or torque. Stage III set-ups utilise larger and stiffer arch wires (round or rectangular) for support while torque and/or uprighting are added and these increase the friction within the system. Generally, our study found an increase in frictional forces in Stage III for the Tip Edge brackets tested, especially with increased deflection.

Clinically, these uprighting springs tip the tooth (as brakes in Stage II and uprighting in Stage III), but in the experimental situation no tip was possible as the brackets in the present study were glued to the testing unit. As such, the experimental set-up limited the full expression of the mechanics.

Similar limitations apply to the tests with the Tip Edge brackets and side-winders. As the brackets were not tipped to allow full expression of the 0.028" bracket slot, the clinical effects of Stage II and Stage III with braking springs were not expressed. This is a limitation of a laboratory based study. However, the added friction from the vertical action of the hook arm of the spring contacting the arch wire is measured in this set-up.

With the Tip Edge brackets, the difference in frictional characteristics between stages were only evident in higher deflections. With the metal Tip Edge brackets, at higher deflections of 0.50mm and 0.75mm, Stage III produced higher frictional forces than Stage I. This was especially evident with larger round wires and rectangular wires. This may be explained by the larger diameter wires having more contact area and thus more binding and higher frictional forces. This is in agreement with **Vaughan et al, 1995, Tanne et al, 1994, Frank and Nikolai, 1980, Andreasen and Quevedo,1970 and Riley et al, 1979,** who found that an increase in wire size generally increased bracket to wire friction. With the ceramic Tip Edge brackets, at high deflections, the rectangular wires produced significantly higher frictional forces than the round wires used in Stage III. This is in agreement with **Riley et al, 1979** who reported similar results with rectangular wires in edgewise brackets. This was evident from the very scratched and rough surface of the 0.021" x 0.025" stainless steel wire observed with the S.E.M. for the ceramic Tip Edge bracket (see Figure 39). This may be again partly caused by the rougher ceramic brackets. **Siatkowski, 1997** examined stainless steel bracket and arch wire in an S.E.M. after a clinical retraction of canine and found considerable wear and tear on both the bracket and the wire. He then concluded that tooth movement occurred in a ratcheting, 'stick-slip' manner rather than pure sliding as often perceived.

## 6.2 Effect of lubrication

Artificial saliva increased the frictional resistance of the metal Begg bracket system. No studies have been found which compared the effect of a wet environment with Begg or Tip Edge brackets. Our study is the first to study the effect of a wet environment on both the metal and ceramic Begg and Tip Edge brackets. All other studies to date have been laboratory based, and have tested Edgewise brackets and their findings were inconclusive. Some studies (**Kusy et al, 1991, Andreasen and Quevedo, 1970**) have used human saliva while others used artificial saliva (**Pratten et al, 1990, Baker et al, 1987, Stannard et al, 1986, Tselepis et al, 1994, Downing et al, 1995**). Of those using artificial saliva, several different brands have been employed. Different brands of artificial saliva may have different compositions, and this may explain the variation in results. For example, some brands of artificial saliva are more viscous and this may have influenced the frictional resistance measured. Other brands contain carboxymethylcellulose which rapidly desiccates and adheres to the arch wire increasing its stickiness (**Shivapuja and Berger, 1994**). The brand of artificial saliva used in the present study did not contain carboxymethylcellulose but consisted primarily of aqueous solutions of electrolytes.

In previous studies, the testing unit has been immersed in a covered bath of artificial saliva maintained at 37°C (**Baker et al, 1987**). or involves the use of a spray of artificial saliva (**Stannard et al, 1986**). In the present study, the equipment was sprayed before and after each reading to ensure that the testing unit was wet.

Using human saliva as a lubricant, **Kusy et al, 1991** reported mixed results, which indicated that human saliva could both reduce and increase friction depending on the particular bracket/arch wire combination.

**Andreasen and Quevedo, 1970** postulated that an increase in frictional forces with saliva as lubricant could be due to the fact that when the arch wire contacts the bracket surface, the pressure exerted might expel the lubricant. In relation to the Begg bracket system, the tightness of the brass lock pins might have determined the amount of lubricant available thus explaining the results of our study. **Pratten et al, 1990**, also concluded that at high loads, saliva is forced out from the contacts between the brackets and the arch wire thus producing higher friction whereas at lower loads, saliva now acted as a lubricant and could reduce friction.

**Downing et al, 1995,** also found an increase in frictional forces with artificial saliva and they explained that water and other polar liquids (including saliva) were known to increase adhesion or attraction among polar materials and thus increase friction. This phenomenon was thought to occur from increased atomic attraction among ionic species. This behaviour had been observed for several different dental materials in the presence of saliva. They concluded that artificial saliva did not appear to act as a lubricant.

Both **Tselepis et al, 1994** and **Baker et al, 1987,** however reported a decrease in frictional resistance with artificial saliva. **Tselepis et al, 1994,** reported a significant reduction of up to 60.5% and **Baker et al, 1987,** reported a significant reduction of 15-19%.

The effect of saliva on friction is probably a case of whether it can successfully act as a lubricant or not.

## 6.3 Effect of deflection

**Suyama et al, 1995, Ogata et al, 1996 and Rose and Zernik, 1996**, examined 2 or more brackets placed vertically offset. **Suyama et al, 1995 and Ogata et al, 1996** used increments of 0.25mm whereas **Rose and Zernik, 1996** used 1mm increments.

**Ho and West, 1991, Tselepis et al, 1994, Frank and Nikolai, 1980** and **Andreasen and Quevedo, 1970,** had single brackets in their studies, but simulated second order deflections by angulating their brackets instead.

Findings from the present study were similar to **Suyama et al,1995, Ogata et al, 1996 and Rose and Zernik, 1996**. For the 4 types of brackets tested, a significant increase in friction was found with corresponding increase in deflection. Other studies that measured only wire angulation with a single bracket also found an increase in friction with an increase in bracket/wire angulation.

**Frank and Nikolai, 1980**, explained that at higher angulations, the bending stiffness and the wire shape (especially the latter) determines the size of contact area with the bracket and thus the amount of friction generated.

All the studies were in agreement that with increased deflection/angulation of the bracket, there was a greater contact force between arch wire and bracket and this led to an increase in friction. **Frank and Nikolai, 1980,** in their study with Begg brackets found higher frictional forces with more contact area between bracket and arch wire *i.e.* 0.020" arch wire in a 0.020" wide bracket slot. For both the Begg and Tip Edge brackets, increased deflection increased the contact area between the arch wire and the bracket. However, with the Begg ceramic brackets, an initial increase in deflection resulted in a decrease in friction. This may be influenced by the tightness of the brass pins and the smooth and less acute line angles in the bracket (See figure 25). Even with the Tip Edge brackets, increased deflection now deflected the arch wire to contact even the slope of the bracket slot. See illustrated diagram (Figure 54). With the experimental set-up in this study, it does not matter which direction the arch wire is pulled.

**Figure 54 Diagram to show second order deflection with the Tip Edge brackets**

It is possible that increased deflection not only increases the contact area between the arch wire and bracket, but also increases the binding force on the contact area. This is related to the bending stiffness of the arch wire. Results of the present study show that frictional resistance increases with stiffer Stage III rectangular arch wires with increased deflections. There is also an increased likelihood of damage to the bracket and arch wire with these stiffer wires and this may add to frictional resistance (**Siatkowski, 1997**).

**Gibb, 1992**, reported that bracket wing fracture is a frequent and common problem encountered by clinicians. **Karamouzos et al, 1997**, attributed the breakage of ceramic brackets to the low fracture toughness of the aluminium oxide. The ability to resist fracture depends on the type, shape and the bulk of the material present. They also found that second order wire activations do not usually cause ceramic bracket failure unless the bracket has been previously weakened by a direct trauma or by introducing surface defects during treatment. Third order wire activations were more likely to cause ceramic bracket failures. Because of both the stiffness of the Stage III arch wires and the inherent low fracture resistance of the ceramic brackets, no tests were possible with the ceramic Tip Edge brackets at 0.75mm deflection. These may have no clinical relevance as one never engages a stiff arch wire in a clinical situation with crowded or irregularly placed teeth.

## 6.4 Effect of ligation

Elastomeric and stainless steel ligation methods of engaging wires in bracket slots result in varying ligation force levels and this may affect frictional values (**Bazakidou et al, 1997, Frank and Nikolai, 1980, Omana et al, 1992**). **Bazakidou et al, 1997** quoted the unpublished research project of Riley (1977) who evaluated frictional forces between plastic and metal Edgewise brackets and found that stainless steel ligation could actually compress the plastic bracket slot and, therefore, increase friction. The present study, however, did not find steel ligation to significantly increase friction with the ceramic brackets. To the contrary, steel ligation significantly increased the frictional forces with the metal Tip Edge brackets. This is in accordance to the findings of **Riley et al, 1979** who also reported higher friction with steel ligatures and metal Edgewise brackets in their study. It is possible that the amount of frictional force is proportional to the tightness of the ligature tie and the lock pin.

**Andreasen and Quevedo, 1970**, concluded that friction increased as steel ligatures are tightened. **Bazakidou et al , 1997**, reported a great variability in friction with steel ligation approximately 2.7 to 3 times more variable compared with elastomeric modules. **Taylor and Ison, 1996**, reported lower friction with loosely ligated steel ligatures and stretched elastomeric modules. **Omana et al, 1992**, reported a variation in their results comparing the 2 forms of ligatures and attributed it to the inability to standardize the tightness of the steel ligature ties.

**Bazakidou et al, 1997**, attempted to standardize both the methods and force of ligation in their study. They used a ligature gun (Straight Shooter, TP Orthodontic) that limited the possible stretching differences between elastomeric modules and tightened their steel ligatures seven times with a Mathieu ligature tying pier, simulating the clinical method. They claimed that with less than seven turns of the ligature tie, a 0.016" wire in a 0.018" slot bracket and the 0.018" wire in the 0.022" slot bracket would slip out of the bracket under their own weight. Turning more than seven turns resulted in the ligature wire turning on itself. Despite standardizing their ligation method, they observed more variable frictional forces with steel ligatures such that the values measured could be either more or less than elastomeric ligation. **Edwards et al, 1995**, studied the frictional resistance generated by 4 methods of ligation with metal Edgewise brackets and arch wires. They standardized their method of steel ligation with the use of a digital strain gauge to ensure a more reproducible force level for each test sample. They found that elastomeric modules tied in a figure of 8 pattern produced significantly more friction than the other 3 methods. No significant differences were found in conventionally tied elastomeric modules and steel ligatures. Their last method was the use of Teflon-coated ligatures in a conventional tie and found that to be associated with the lowest frictional forces.

With reference to the graphic recordings, combinations with steel ligation displayed a more spiky pattern than the elastomeric ligation. This may be attributed to the inconsistent ligating force with the steel ligatures compared with the elastomeric modules. The spikes in the graph may represent the binding and release patterns with the steel ligatures whereas a less irregular graph pattern is observed with the alastik modules which are less stiff. **Taylor and Ison, 1996**, observed that elastomeric modules produced a more consistent force. The current study found an increase in frictional force with Tip Edge ceramic brackets and 0.020" SS, sidewinders and alastik modules. These, however, were not statistically significant. Perhaps the compression of the alastik modules against the arch wire and the bracket may have increased the friction.

In view of the inconsistencies from the results of these studies, it is obvious that standardizing the method of ligation is very difficult to do accurately.

The many variations within these studies: the materials tested, the methodology of the experimental procedures, the recording technique and the different types of lubricant, all combine to make comparisons very difficult and may well explain the inconsistent results. The design of the present study was similar to **Ogata et al, 1997** with the intention to compare findings. The decision to test 4 anterior brackets was to simulate a clinical condition of 4 anterior teeth with malocclusion expressed with second order deflections in the experimental set-up. The rate of 5mm/minute was selected in this study as it was used in **Ogata et al, 1997** and also because **Ireland et al, 1991** reported in their pilot study to determine the effect of different sliding velocities of 50mm/minute, 20mm/minute, 10mm/minute, 5mm/minute, 1mm/minute and 0.5mm/minute, and found no difference between 5mm/minute, 1mm/minute and 0.5mm/minute, no matter what combination of bracket and arch wire used.

The only other study allowing comparison of the actual mean frictional value is **Ogata et al, 1997** who tested Tip Edge metal brackets ligated with alastik modules in a dry condition. The results between the 2 studies are very similar both for the round wires (0.016" SS) and rectangular wires. **Ogata et al, 1997** found the mean frictional value with round wires to be 2.92N (compared to 1.73N in the present study) at 0.00mm deflection and increased to 4.50N (compared to 3.43N in the present study) at 0.75mm deflection. For the rectangular wires, they found the mean frictional value to be 7.37N (compared to 1.66N in the present study) at 0.00mm deflection and increased to 15.14N (compared to 15.59N in the present study) at 0.75mm deflection. Comparing with other studies that examined Edgewise metal brackets, **Kapila et al, 1990**, found frictional values for 0.016" SS and NiTi to be between 1-2N and 2.5-3.3N for 0.017"x 0.025" dimension arch wire. **Tselepis et al, 1994,** found the frictional forces of 0.016" SS and NiTi to be 2.25N and 1.84N respectively. These values were comparable to our study except for the higher values we found with our Australian stainless steel arch wires. **Frank and Nikolai, 1980,** reported frictional forces of 0.18N and 0.38N for 0.016" SS and 0.019"x0.025" SS respectively with Begg metal brackets. These are lower values compared with our study. These studies are not directly comparable as it differs in experimental design.

The disadvantages of the present experimental design included the inability to simulate a clinical rounded arch form for the attachment of the brackets and testing a simulated malocclusion in the first order. The brackets were also fixed and thus were unable to simulate clinical tooth tipping in the presence of periodontal ligament especially important with uprighting springs and sidewinder springs. As mentioned, this is more critical for the Tip Edge bracket which is designed to tip for the full expression of its 0.028" slot. Further study is required to test the effect of tipping of the Tip Edge bracket on friction.

It is also difficult to measure the amount of deflection accurately because although the testing apparatus is adjustable, and every effort was made to align the brackets accurately, human error leads to some uncertainty.

The statistical analysis with repeated measures analysis of variance has its inaccuracy as it is merely an estimate of an average obtained from sets of 3 readings which are averages in themselves

With regard to clinical relevance of the present study, the recommended use of Co-Ax wires as an initial aligning arch wire may be substantiated by the results of the present study considering other variables, such as tightness of the lock pins. The low frictional values obtained for the Stage II set-up may be clinically advantageous in space closure mechanics. However, it is really also in Stage II where we want the brakes placed, for molar mesial space closure clinically. The higher frictional values obtained in Stage III set-ups with uprighting springs in Begg brackets and rectangular wires both with and without sidewinder springs may be clinically advantageous as brakes and in anchorage control. With the metal Tip Edge brackets, fixation with alastik modules may be recommended as they were found to have a lower frictional value than steel ligatures. However, the tightness of the steel ligatures and the lock pins or T pins (in Begg brackets) are important clinically. As with the results from the S.E.M., possible manufacturing imperfections in the brackets and arch wires may be related to binding and thus have an effect on the frictional value. However, this may not be clinically significant. It would be worthwhile to conduct a clinical study, inspecting new brackets and arch wires (Begg or Tip Edge) in the S.E.M. and again at the end of treatment, to examine any surface changes during treatment.

It is always very difficult to simulate clinical conditions in laboratory studies and thus care must be taken in evaluating these in vitro results and extrapolating them to in vivo or clinical situations. Hence the relative rankings of the arch wires and brackets are considered to be more meaningful than the actual force values recorded for a given experimental set-up.

Further research will be required to test the frictional characteristics of Edgewise brackets with a similar experimental set-up to allow comparison of the Begg and Tip Edge brackets with the Edgewise bracket systems.

# 7. Conclusions

**1. Begg bracket**

a) Metal bracket

- Stage I with Co-Ax wires produced the lowest frictional resistance.
- Comparing the various stages of treatment, Stage I with Australian SS and NiTi wires produced higher frictional resistance than Stage II or Stage III set-ups.
- A wet environment with artificial saliva as lubricant significantly increased the frictional resistance.
- Frictional resistance increased with increased deflections.

b) Ceramic bracket

- Stage I with Australian SS wire produced significantly more friction than Stage I with Co-Ax or NiTi wires.
- Comparing the various stages of treatment, Stage I with Australian SS wire produced higher frictional resistance than in Stage II or Stage III with auxiliary but was comparable with Stage III with uprighting springs.
- There was no statistical significance lubricating with artificial saliva.
- With increased deflection, there was an increase in frictional resistance.

**2. Tip Edge bracket**

a) Metal bracket

- There was no statistically significant difference detected between the 3 Stage I alignment wires.
- Comparing the various stages of treatment, Stage III set-up produced statistically higher frictional resistance only at higher deflections.
- Lubrication was not statistically significant.
- An increase in deflection increased the frictional resistance.

•Steel ligatures produced a significantly higher frictional resistance than elastomeric modules.

b) Ceramic bracket

•Stage I with the 3 different alignment wires revealed no statistically significant differences, indicating that it does not matter which type of aligning wire is used initially.

•At higher deflections, Stage III with rectangular wire produced higher frictional resistance than Stage III with round wire.

•Effect of a wet environment was not statistically significant.

•An increase in deflection increased the frictional resistance especially with rectangular wire.

•Method of ligation did not play a significant role in the frictional characteristics of this bracket system.

Stage I with Australian stainless steel wires produced higher frictional values in this study. This is not clinically desirable as it may lead to loss of anchorage. Thus the recommendation is made for the use of Co-Ax for Stage I alignment. If stainless steel wire is necessary for bite opening, use of Stage I lock pins (not pinned too tightly) may be desirable.

Clinically, T pins and uprighting springs were used in Stage II as brakes. However, this study found a lower frictional value for these set-ups. This may be explained by the experimental design. It did not allow full expression of the springs, and the tightness of the pins was variable. Stage III frictional values increased with deflection and this may indicate the inadvisability of engaging Stage III wires when alignment is incomplete.

In section 2.3, the null hypothesis that, 1) Begg brackets do not exhibit any difference in frictional resistance compared with Tip Edge brackets in the various simulated stages of treatment and 4) increase in wire deflection does not increase the frictional resistance, were not verified. The second hypothesis that effect of a wet environment on both bracket systems is negligible was verified except for the Begg metal bracket. The third hypothesis that effect of ligation on the frictional characteristics with the Tip Edge brackets is negligible was verified only with the Tip Edge ceramic brackets.

There are many variables affecting an in vitro study on friction which made the design of these studies so varied. It is also difficult to design an in vitro study and extrapolate its results to an in vivo or clinical situation. However, the present study is an acceptable study designed to measure the frictional characteristics of brackets and arch wires despite the disadvantages mentioned. Further research may extend into testing with Edgewise brackets allowing a direct comparison between various brackets under the same test conditions. Tests may also allow tipping effects of the Begg and especially Tip Edge brackets to be re-tested. To study the wear and damage of brackets and arch wires clinically, tests with S.E.M. examination prior to and after treatment may be conducted. Understanding the limitations of these in vitro studies, improvements in methodology may include a modified design of the testing apparatus to better simulate the arch form and malocclusion presented clinically. The testing apparatus should also be able to accurately tip the brackets to various angulations for measurement. A standardized approach towards the method of fixation with the use of a strain gauge may be advantageous. Ultimately, if a testing device can be developed to measure frictional forces directly intraorally, it would be most useful.

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