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An in-vitro investigation of frictional resistance of self-ligating and ceramic brackets when subjected to different ligation methods and tipping angles

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**AN IN-VITRO INVESTIGATION OF FRICTIONAL
RESISTANCE OF SELF-LIGATING AND CERAMIC
BRACKETS WHEN SUBJECTED TO DIFFERENT
LIGATION METHODS AND TIPPING ANGLES**

By

Todd S. Bovenizer, D.D.S.

A THESIS

Submitted to
The School of Dentistry
At
West Virginia University

In partial fulfillment of the requirements for
The degree of

Master of Science
In
Orthodontics

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Morgantown, West Virginia
2006

ABSTRACT

AN IN-VITRO INVESTIGATION OF FRICTIONAL RESISTANCE OF SELF-LIGATING AND CERAMIC BRACKETS WHEN SUBJECTED TO DIFFERENT LIGATION METHODS AND TIPPING ANGLES

Todd S. Bovenizer, D.D.S.

Objectives: To investigate the frictional resistance of two new ceramic brackets, two self-ligating bracket, and one standard stainless steel bracket with several methods of ligation. The size and composition of the archwires will also be varied. The wires used are all stainless steel and the sizes are .018, 19X25, and 21X25. The frictional forces obtained in this study will be more useful when compared in a relative manner to one another, as opposed to the actual forces that will be measured. **Methods:** Each bracket and wire was placed in an Instron machine and tested for 120 seconds. During this time period the archwire was pulled superiorly both with and without variable tipping angles introduced to the wire. The bracket and wire combination also had variable methods of ligation, stainless steel, alastic, and self ligation. The data was then analyzed to see the friction averages for each test. **Results:** The data was separated into two groups, Experiment 1 and 2. This was done to compare the non-self ligating brackets to the self ligating brackets since they already have ligation built in. Therefore Experiment 1 included all brackets and Experiment 2 only included the non-self ligating brackets. ANOVA found significant differences in Experiments 1 and 2. Experiment 1 was significant at the wire, bracket ligature system (BLS), wire-bracket ligature system, stage, and wire-stage. Experiment 2 was significant with the bracket and ligation.

DEDICATIONS

To my wife and best friend **Megan McDermott Bovenizer**, who has stood by me. Thank you for everything you have done and continue to do for me. Without you, I know that I could not accomplish what I set out to do each day. Your love and sacrifice has been beyond comprehension, and I love you for supporting me. I cannot thank you enough for being my partner in the foundation that we are creating together and I can't wait for the rest to unfold. I love you so much.

To my daughter, **Caroline Grace**, you are our gift from God. My life changed the instant you were born and you make everyday more fulfilling. To see your smiling face and to know how much I love you makes my journey more satisfying.

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CHAPTER I INTRODUCTION

BACKGROUND

Orthodontists are always seeking to reduce friction. The majority of friction investigations have been in vitro studies which involved pulling a straight wire through a bracket. The bracket had some form of archwire ligation and the mechanical testing machine measured the amount of force or frictional resistance that occurred while the bracket slid along the archwire. This technique does not mimic the clinical situation. To overcome some of these short comings, this research will vary the bracket/archwire angle to better simulate the clinical condition and allow clinicians to minimize friction of these appliances.

This study investigated the frictional resistance of two new ceramic brackets, two self-ligating bracket, and one standard stainless steel bracket with several methods of ligation. The size and composition of the archwires will also be varied. The frictional forces obtained in this study will be more useful when compared in a relative manner to one another, as opposed to the actual forces that will be measured.

STATEMENT OF THE PROBLEM

Do different methods of ligation, such as a stainless steel ligature tie, elastomeric tie, or self ligation with clips influence frictional resistance? Do different bracket slots such as stainless steel bracket slots, or silicated bracket slot influence frictional resistance during tooth movement?

SIGNIFICANCE OF THE PROBLEM

Frictional components have always been a major concern in orthodontics. Its innate ability to impede tooth movements can require greater force to move the teeth, prolong treatment and cause anchorage loss. It is a goal of every orthodontist and manufacturer to reduce the amount of friction, because this allows faster tooth movement and shorter treatment times. This investigation will study friction of stainless steel, ceramic, and self-ligating brackets under clinical simulation using variable tip and different size archwires.

NULL HYPOTHESIS

1) There is no significant difference in frictional resistance among various types of brackets: GAC Mystique brackets with silicated slots, 3M Clarity ceramic brackets with a metal slot, 3M SmartClip with a self ligating clip, GAC microArch (stainless steel twin bracket), or GAC's Inovation R brackets with a self ligating clip. 2) There is no difference in the frictional resistance among brackets with various types of ligation methods: Self ligating brackets of Inovation R and SmartClip, stainless steel tie or elastomeric tie. 3) There is no difference in the frictional resistance among the various types of archwires: 0.018 inch stainless steel, 0.019 inch X 0.025 inch stainless steel and 0.021 inch X 0.025 inch stainless steel archwire sizes.

DEFINITION OF TERMS

apparent stiffness – resistance to moments (stiffness) of an archwire measured when rotating the bracket.

coefficient of friction – the ratio of two forces; the weight (normal force) of an object being moved along a surface and the frictional force that resists

movement. The coefficient is independent of the area of contact and independent of the sliding velocity.

conventional bracket – commonly used stainless steel or ceramic brackets that require the use of a steel or elastic tie to enclose the archwire.

dynamic friction – frictional force that occurs when the applied (normal) force is variable (dynamic load).

dynamic load – variable moment occurring between an archwire and bracket.

friction – the force that retards or resists the relative motion of two objects in contact; the direction is tangential to the common boundary of the two surfaces in contact.

kinetic friction – the force that resists the sliding motion of one solid object over another at a constant speed.

noise – electronic variability within the system.

oscillation – a single swing from one extreme limit to the other and back.

resistance – a force that opposes or slows down another movement.

self-ligating bracket – a bracket that completely encloses the archwire without the need for steel or elastic ties.

sliding – to move over a surface while maintaining smooth, continuous contact.

sliding mechanics – the process of an archwire moving through the slot of a bracket to allow tooth movement.

static friction – the smallest force needed to start the motion of solid surfaces that were previously at rest with respect to each other.¹

stiffness – a combination of modulus of elasticity and moment of inertia

tipping – rotation about an axis perpendicular to the facial surface of a tooth

ASSUMPTIONS

- 1) Brackets, archwires and elastic ties of each type were identical in physical attributes and composition.
- 2) Frictional force needs to be overcome in order to slide brackets along an archwire.
- 3) The brackets and wires were properly aligned in the testing apparatus.

LIMITATIONS

- 1) Force of elastic ties holding the archwire in the bracket slot varies and decays with time.
- 2) The stainless steel metal ligature ties were applied with the same force.
- 3) Application of this *in vitro* study to any *in vivo* situation has limitations.

With any testing situation, it is impossible to reproduce with exact precision the movements that will occur intra-orally. In the oral environment, saliva amount and content, bacteria type and concentration, types of liquids and solids ingested, force of oral musculature upon chewing, and periodontal health are some of the factors not encountered when performing this study *in vitro*.

- 4) Out of plane deformations were not evaluated.

DELIMITATIONS

- 1) Only maxillary first premolar orthodontic brackets with 0.022-inch vertical slot and 0.028-inch slot depth were investigated.
- 2) Only 0.018-inch stainless steel, 0.019 x 0.025-inch stainless steel and 0.021 x 0.025-inch stainless steel were evaluated.

- 3) Only injection molded O-ties (Ormco), which were more consistent in size and force, were used.
- 4) Amount and frequency of variable moments placed at the bracket-archwire interface were 1.00 Hz (60 cycles/minute).
- 5) All tests were run dry without the lubricating effects of saliva.
- 6) The angles were limited to 0, 2.9, 4.7, and 5.4 degrees.

CHAPTER II LITERATURE REVIEW

FRICTION

Friction is defined as the force that resists the motion of a body relative to another, and it operates in an opposite direction of the motion.¹ It acts at the surface between two objects when one of the objects slides in comparison to the other.² As these two surfaces are sliding against each other, two components of the force system are related, the frictional force and the normal force.³ Frictional force is proportional to the normal force acting perpendicular to the direction of motion.^{1,4} When two surfaces contacting are in motion, three forces are present. The first component is the force causing the motion, the second is the frictional force, which is opposite in direction of the motion. The last component is the normal force, which is perpendicular to the two surfaces in contact. It is also perpendicular to the frictional forces and the force causing motion. The magnitude of friction depends on the magnitude of the normal force pushing the two surfaces together. It will also rely on the roughness of the surfaces in contact and the composition of the materials involved.^{5,2} It is well documented by Kapur et al.⁶ that frictional forces in the contact areas between the two materials are greatest when atomic and molecular forces attract. As a result, friction would expect to be greater between two like materials rather than different compositions.

To reiterate from above, three principles have been discussed:^{2,7,8} The frictional force is proportional to normal force $F = \mu N$. F is the frictional force, μ is the coefficient of friction and N is the normal force. The coefficient of friction is always constant with regard to contact area, speed of movement and the normal force. The coefficient may be dependent on the roughness, texture or hardness of the surfaces.

In order for one object to slide against the other the application of the force must overcome the frictional force. A distinction must be made between two types of friction: static and dynamic. Static friction is the smallest force needed to start the motion. Kinetic friction is the force that resists the sliding motion of one object over another which at a constant speed.^{9,10,11} Static friction is the force required for the initial movement and is always greater than the kinetic friction.^{1,4}

Friction can be a major challenge when designing orthodontic appliances. A number of factors, both physical and biological, have been identified in influencing frictional forces during orthodontics:

1. Archwire properties: a) size and shape b) archwire material c) texture of wire d) apparent stiffness of wire.¹²
2. Ligation methods: a) steel ligature wires b) elastics c) ligation variables, operator dependent.¹²
3. Bracket properties: a) material b) manufacturing c) width and depth of the slot d) design e) prescription (bracket archwire angulation).¹²
4. Appliances: a) interbracket distance b) the level of the brackets compared to each other c) force levels used.¹²
5. Biological properties: a) plaque and oral hygiene b) saliva^{12,13,14,15,16} c) acquired pellicle d) corrosion e) food particles. f) temperature g) bite force and tooth mobility.¹⁷

WIRE SIZE

Most investigators agree that frictional resistance increases as the archwire increases in dimension.^{5,18,19,20} This has been noted from Andreasen's¹⁹ classic work in

the area and confirmed by Frank and Nikolai,⁵ whom both ended by stating that with increased wire diameter the friction increased. When shape changes from round, to square, and finally rectangular, friction will increase at the bracket-wire interface.^{21,22,23,24} Moore concluded in his study that movement along a 21x25 inch wire produced almost three times as much friction as 19x25 stainless steel.²⁵ Other researchers have reported archwire size does not necessary contribute to friction. Sims et al.²⁶ reported that resistance did not rise steadily with progressively larger archwires. There is also evidence that while decreasing archwire size may reduce the friction temporarily, however, smaller archwires allow tooth tipping which causes more binding and may increase friction.²⁷ Peterson and Vaughn^{28,29} noted that changing from a round to a rectangular nickel-titanium wire does not necessarily increase the frictional resistance.

WIRE SHAPE

Rectangular archwires generate greater friction than round wires because it has been shown there is more binding occurring at the bracket archwire interface.^{5,27,30,29} Translating teeth along 0.018-inch or 0.016 round wire rather than rectangular wire is often suggested since there is belief that frictional forces are less and anchorage is better maintained.²¹ Frank and Nikolai⁵ in 1980 reported a conflicting study. They found that at binding angulations, stainless steel rectangular wires produced less friction than round wires. This resulted from greater pressures on the point of contact of round wires compared to line contacts of the rectangular.

WIRE MATERIAL

It is well established that the wire material affects the frictional resistance produced.^{15,31} However the debate on archwire friction continues. Stainless steel, nickel

titanium, and beta titanium are three very popular wires. Each of the three wire types have been found to produce the least amount of friction, in at least one study, when compared to the other two wires.³²

A very popular method of pulling a straight piece of wire through orthodontic brackets without any variable moment, found that nickel titanium produced the least amount of friction, then stainless steel and finally beta-titanium wires.^{33,11,34} There are also studies which suggest that stainless steel provides the least amount of friction when compared to the nickel-titanium.^{15,35,30}

Beta-titanium was found to have the greater friction when compared to stainless steel and nickel-titanium.^{10,15} They have postulated that some adhesion occurs between the archwire and the bracket. With laser profileometer, stainless steel was the smoothest, followed by beta-titanium and nickel-titanium.³⁶ Most studies are consistent with the fact however that nickel-titanium provides less friction than the beta-titanium wire.^{35,21}

Mendes³⁷ et al. have shown that significantly lower frictional resistance are provided by certain wires and brackets. He showed that ion implanted nickel- titanium (Bioforce, GAC) and beta- titanium (TMA Colors, Ormco) wires had significant differences in frictional forces. The ion implanted wire had the lowest frictional resistance.³⁷

Differences were also noted between different brackets. An ion implanted bracket (Omni Golden, GAC) demonstrated less friction with the untreated nickel- titanium wire, beta-titanium, and rectangular stainless steel wire.³⁷

LIGATION

Forces of normal ligation techniques can range from 50 to 300 grams.³⁸ There is a wide range of variability that seems to be different from operator to operator. There are

two main types of ligation widely used in orthodontics, elastomeric and stainless steel. Whichever method utilized, the forces that will be present are varied and differ from operator to operator. This variable component will ultimately affect frictional forces.^{33,39}

Elastomeric modules will approximately apply 225 grams of force once activated. Khambay⁴⁰ in his study found significant differences in the mean force of seating the archwire with different ligation methods. The study also measured that grey alastic ligation produced the lowest force on the wire and stainless steel had the highest seating force. The exact opposite was true when a wire was passed through these different ligation methods, stainless steel having the lowest friction.⁴⁰ It is important to note that this amount will invariably decrease because of module decay.⁴¹ This does not necessarily rise steadily with increasing archwire dimensions.³¹ With steel ligatures, seating forces can range from 0 to 300 grams.⁴¹ Schumacher et al.⁴² stated that friction was determined mostly by the nature of ligation and not by the sizes of the various archwires. Satisfying the first law of classical friction, resistance will proportionally increase with larger normal forces that are produced by the ligation.^{5,43,14} Loosely tied steel ligatures are thought to provide less friction than the elastic counterparts.⁴⁴ Elastomerics can be prestretched before use to decrease friction and many advocate doing so.^{45,30} Also many clinicians prefer to “figure-eight” tie elastic ligatures. This will increase frictional resistance levels 70 to 220% depending on the size of the wire.²⁶ Andreasen and Quevedo⁴⁶ concluded that steel ligatures can be very “clinician sensitive”, and that frictional resistance can be increased by increasing ligation forces.^{5,15,47} However, Riley et al.⁴⁸ determined that steel ligatures generated more friction when applied on plastic brackets than elastic ligatures.

Hain⁴⁹ et al. investigated a new elastic module from TP Orthodontics, a new “super slick” module incorporating new technology that is easier to use. They concluded that these modules generated significantly less friction than regular ties and they reduced friction when the modules were soaked in human saliva. The figure-eight ties that have previously reported higher friction, the authors here reported less friction with these new ties in human saliva. Hain⁴⁹ also confirmed previous research that loosely tied stainless steel ligatures still provided the least amount of frictional forces. The debate still exists, Iwasaki⁵⁰ et. al. reported that loose stainless steel ligation was not associated with lower frictional levels.

The permanent deformation of elastomerics is related to time (stress relaxation), how fast they are stretched (strain rate), and hydrolysis due to water and moist heat in the oral environment.⁵¹ Such deformation changes the degree of frictional resistance.⁵² Therefore, static friction decays over time with elastomeric modules.³⁰ As mentioned earlier, the rapid rate of decay for these elastomeric ties and their history sequestering large amounts of plaque, these authors suggests that there is little merit in their use, especially in canine retraction and sliding mechanics.⁵³

BRACKETS

Bracket designs can also be a factor. Wider bracket designs caused more stretching of elastomeric modules and increased the normal forces of friction.⁵⁴ Some bracket designs, such as the Synergy bracket (RMO, Denver, CO), restrict the amount of force placed on the wire by the ligature tie.^{22,55}

STAINLESS STEEL BRACKETS

Stainless steel brackets exhibit lower coefficients of friction than the ceramic brackets.^{16,56} Angolkar²¹ demonstrated in his research that stainless steel slots are relatively smooth as compared to their ceramic counterparts. Stainless steel brackets are manufactured by casting, sintering, and machining.

CERAMIC BRACKETS

Many ceramic brackets are processed by milling the material with diamond tools. This may leave rough edges and sharp angles.²⁹ With many more adults seeking treatment, and the continual rise of esthetics in our culture, ceramic brackets are constantly being updated. Ceramic brackets come in two main types; 1)ceramic slot and 2)stainless steel slot. In most studies the stainless steel slot produced the least amount of friction when compared to the all ceramic bracket.^{57,58} This is most likely due to the increased roughness and porosity of the ceramic surface and a sharp bracket slot edge.^{16,21,44} Rose and Zernik⁵⁹ demonstrated this well in their study. They proved that by rounding the corners of ceramic brackets, this would significantly lower the frictional resistance.^{59,33} Saunders⁶⁰ et al. found that monocrystalline ceramics has a smoother surface than polycrystalline, but the differences in friction are very small. Ceramic brackets have reported to abrade the archwire.⁴³ The ceramic bracket with stainless steel slot showed the surface finish of the slot to be smoother with fewer irregularities than the ceramic bracket slot.²⁴ Significantly higher forces would be needed clinically to overcome this polycrystalline rougher surface as compared to the stainless steel slot. Articolo and Kusy⁶¹ have also investigated the effects of ceramic slots on notching of archwires and inhibiting treatment mechanics. The static and kinetic coefficients of

friction were often higher with ceramic than with stainless steel brackets.⁵⁶ They found a larger percentage of notching for the ceramic brackets compared to the stainless steel.

Both types of brackets for two studies concluded that there are no frictional differences between ceramic and stainless steel brackets.^{27,62} In a study by Articolo, he discovered that most notching of the wire occurred in the canine area on the lingual surface of the wire.⁶¹ Downing²⁴, mentioned that there would be no disadvantage to using ceramic brackets when teeth require sliding. These studies pulled a straight wire through the bracket, therefore clinical simulations were not utilized, such as tipping and binding of the archwire into the bracket slot. DeFranco³⁴ et al confirmed this theory. At 0° angulation, there is really no room for contact between brackets and archwires, therefore minute changes in frictional forces were noted. With increased angulations and bracket and archwire contact, friction was significantly higher with the ceramic brackets.³²

Ceramic brackets have excellent esthetics but generally have plagued orthodontists with several problems, such as fracture during angular and tipping movements,^{63,64} enamel abrasion,⁶⁵ enamel damage during debonding.^{66,67} Manufacturers have recognized these problems. The advent of the stainless steel slot in a ceramic bracket is one way in which frictional resistance can be reduced to almost a regular stainless steel bracket without compromising esthetics.

SELF LIGATING BRACKETS

Self ligating brackets have been around since 1935 when Stolzenberg described the Russell Lock appliance.⁶⁸ Many designs have been patented but very few make it to the orthodontists office. Stolzenberg's design was then modified by Wildman in the

Edgelok appliance in 1972. The archwire was positioned by sliding a labially cap across the top of the archwire slot and locked. This created a rectangular slot, or tube, and the archwire had total freedom of movement. The Mobil-Lock bracket was introduced in 1980. In 1980 Hanson,^{69,70} created a different appliance consisting of a spring-loaded, self-adjusting ligature less design. This was different in that it could retain and actively influence control of the archwire. This was called the SPEED appliance. Other designs include the Aactiva and active Time bracket were introduced in 1986 and 1994 respectively. Damon⁷¹ in 1996 made a revolutionary passive self-ligating Damon SL bracket. When the slide is closed, the lumen of the slot is full-size, which is critical for rotational control.³² In 1998 Wildman⁷² came out with another appliance called the Timelok. This was three designs in one decade. This trend continued in spite that self-ligating brackets only captured a small percentage of the market. It wasn't until recently when Damon⁷¹ redesigned the Damon SL bracket and introduced the passive Damon System II bracket in 2000. Voudouris also designed a new active self-ligating bracket named In-Ovation in 2000. These latest and most significant changes have been in the last two systems mentioned. Both of these exhibit major advances in the self-ligating system and have gained extreme popularity.⁷³

Haradine⁷³ now feels that self-ligating brackets have reached a stage of design and control, where the advantages far outweigh the remaining imperfections. There are many clinical advantages to the self-ligating system. There is a more certain engagement of the archwire. There is decrease in frictional resistance between the bracket and the archwire,^{73,74} both static and dynamic.⁷⁵ Faster archwire removal and ligation, leading to perhaps the most significant aspect, less chair side assistance.⁷³ The self-ligating bracket

systems are also advantageous in that they generate a healthier tissue response because of better plaque control.^{55,73} The elastomeric ties accumulate plaque more than steel ties, however the ends of steel ties can possibly cause laceration and collect plaque.^{55,73} Harradine⁷³ also mentions that anchorage control is not as important of an issue as compared to the conventional bracket designs. Cacciafesta⁷⁵ et al. also mentioned that from the patient's perspective, self-ligating brackets are more comfortable and also easier to clean.^{55,75}

All the inventors report a significant reduction in friction, as well as shorter treatment time and chair-time, when compared with conventional bracket systems.^{76,72,77} All these opinions were promoted back in 1935 with the advent of the Russell Lock, which may lead to some confidence issues with current brackets.⁶⁸

Sims et al found that self-ligating brackets produced substantially less friction than conventional elastomerically tied brackets, using archwires ranging from 0.016 x 0.022-inch to 0.019 x 0.025-inch.^{26,55} Cacciafesta⁷⁵ concluded that stainless steel self-ligating brackets produced the lowest patterns of static and kinetic friction compared to the stainless steel and polycarbonate self-ligating. Perhaps one of the major differences between stainless steel brackets and self-ligating is the method of ligation. Ligating clips of the self-ligating brackets have a smaller magnitude of force on the archwire into the slot compared to the steel or elastomeric ligatures of the conventional systems.^{78,79} Read-Ward⁸⁰ found some contradictory results. He concluded that self-ligating brackets showed reduced frictional resistance in comparison to steel ligated brackets only under certain conditions.

Berger⁸¹ et al. studied the three major popular uses of ligation; steel ligature, elastomeric, and self-ligating. They found that self-ligating brackets produced the lowest friction than either steel ligatures or elastomerics.

Damon concluded that self-ligating bracket design facilitates rapid leveling because teeth move along the path of least resistance with little or no resistance between the archwire and the slot of the bracket. The hinge mechanism of the self-ligating system eliminates the friction caused by conventional ligation.⁷¹

BRACKET WIDTH

Andreasen and Quevedo⁴⁶ and Peterson²⁸ et al. concluded that bracket width did not affect friction, whereas Nicolls^{48,72} and Frank and Nikolai⁵ found that friction increased with wider brackets. They also maintained that the larger contact surface area of the wire contacting more of the wider bracket resulted in increased friction. As mentioned earlier, wider brackets produce more frictional forces because of the greater stretch of the ligation over the bracket that is involved. Frank and Nikolai⁵ also found that narrower brackets produce less friction because of less binding of the narrower brackets. Yamaguchi⁸³ et al. concluded that for retraction, the closer to the center of resistance, less tipping of the bracket would occur for the narrow bracket and therefore reduce the friction. However, many others such as Nicolls,⁸² Drescher,^{84,27} found that friction decreased as the bracket width increases because tipping and binding were reduced in the wider bracket. Omana, Sims, Moore, et al. also reported that wider brackets have less friction by allowing less angulation change of the archwire, and therefore less binding.^{33,85,86}

Frictional resistance increases as the number of brackets included in the assembly increases.³² The greater the interbracket distance the longer the wire will be between the brackets therefore larger amounts of deflection, and flexibility, hence more leveling.⁸⁷ The effects of bracket width and interbracket distance still remains uncertain, according to Frank and Nikolai, who found interbracket distance to have little if no effect on friction.⁵

BRACKET-ARCHWIRE ANGULATION

As the angle between the bracket and the archwire increases, friction tends to increase, and more rapidly beyond the critical contact angle.⁸⁸ Greater angulation between the archwire and bracket yielded greater friction.^{89,90,26,33} The dependence on angulation is more pronounced in stainless steel than nickel titanium archwires, a possible reason being the lower stiffness of the latter wire.¹⁰ Frank and Nikolai⁵ found that frictional resistance increased in a non-linear manner with increased bracket angulation. This is more correctly attributable to binding rather than true friction.

SURFACE ROUGHNESS

There has been no definite relationship between archwire and bracket surface roughness and friction.^{36,91} Generally, friction tends to be highest for surfaces that are similar. Rough surfaces generate a lot of friction because the peaks in between the roughness cause an interlocking relationship.¹⁸ Smooth surfaces interact via different mechanisms, the flat surfaces allow for a stronger adhesion and thereby increasing friction.

Kusy and Whitley showed that, while the smoothest wire surface did have the lowest coefficient of friction, surface roughness does not necessarily correlate with the

coefficient. Studies using laser spectroscopy and profilometer showed no significant correlation between surface roughness and frictional forces for various kinds of archwires.⁹²

SLIDING MECHANICS

Sliding mechanics involves a relative displacement of wire through bracket slots. The problem still lies, whenever sliding teeth along an archwire, frictional resistance is encountered. The technique is commonly used and orthodontists are constantly striving to level arches to facilitate translation of teeth. It is widely used in achieving closure of extraction sites, distalization of teeth, eruption of high cuspids, rotations, leveling and modifying arch forms. Frictional forces developed between the bracket and archwire opposes such movements.³² Friction will ultimately lead to impaired tooth movements, therefore higher force levels and more anchorage will be needed.^{33,86} Also if extra bracket tip occurs the archwire is more likely to be permanently deformed.⁸⁶ Up to 60% of the applied force to the archwire complex is dissipated as friction,¹⁸ which ultimately reduces the force available for tooth movement.⁹³ Therefore, one can see why it is imperative for orthodontists to constantly seek techniques to reduce or even eliminate friction.

Bourauel⁹⁴ agreed and concluded friction increased appliance inefficiency. The force levels on specific teeth become difficult to access. Root surface area, bone density and occlusal interferences all effect the force on a tooth.²⁸ It is also well documented that increasing force increases the rate of tooth movement only to a certain point. Once excessive force levels have been obtained there is no appreciable increase in tooth movement.⁹⁵ It is counter-productive because it increases friction and has the potential to

lose anchorage.³³ In fact Swartz⁹⁶ stated that a force as light as that of capillary blood pressure (20-26 gm/cm²) would produce tooth movement.

Proffit⁹⁰ in his textbook Contemporary Orthodontics said that the optimum force levels for orthodontic tooth movement would begin cellular activity within the periodontal ligament. If too great a force is used then occlusion of the blood vessels occurs and blood supply is lost. When this occurs the PDL goes through hyalinization and teeth cannot be moved. There is a point to which the PDL can have so much force placed upon it; it becomes necrotic. According to Proffit,⁹⁰ as previously discussed, vascularity is critical to tooth movement. He and many others agree there is no doubt that light, continuous forces produce the most efficient tooth movement.

Static friction is more important in tooth movement than kinetic friction, in that static friction is the force to begin movement. The coefficient of static friction is always larger than kinetic friction. Forces tend to be higher because so much force is lost to the static frictional component. The static and kinetic frictional forces produced between bracket slots and archwires during sliding mechanics should be kept as low as possible to allow optimal tooth movement.⁹⁷ Drescher¹⁸ et al. reported that even under the lowest velocity sliding mechanics, static and kinetic friction will always take place.

Orthodontic forces are usually applied at a distance from the center of resistance of the teeth.¹¹ The orthodontic forces are not at the center of rotation and this causes interaction between tipping and uprighting of the tooth. The bracket will rotate with this movement and the tooth will translate along the wire, although constrained by the friction. In these interactions, the extent of force loss due to friction is proportional to the vertical and horizontal pressure of the archwire in the bracket-archwire complex.⁹⁸ This

pressure will be decided by the amount of force in the archwire. Therefore, a tooth moves along an archwire, tipping and uprighting.

The average PDL space in human beings is about 0.2 mm. The space is larger for teeth receiving orthodontic treatment. During periods of orthodontic tooth movement, the distance between the root surface and the alveolar socket may double or triple in width. Due to the width and compressibility of the PDL, the teeth will tip within this freedom of the PDL until contact is established between the corners of the bracket and the archwire diagonally. These movements occur immediately, once the archwire is tied in, and before movement along the archwire occurs.¹¹ Once the tooth has tipped all further movement will cease until subsequent remodeling occurs in the PDL. Each time the tooth moves, static frictional resistance must be overcome, and then kinetic friction occurs to further move the tooth.⁵ During tooth movement the teeth maintain this tipped position and move parallel to the archwire.

Orthodontists are constantly striving to maintain these light continuous forces; however, remodeling of periodontal tissues is rarely achieved in a healthy way. Tooth movement will change the gingiva, PDL and the bone. Oppenheim⁹⁹ et al. hypothesized that the periodontal ligament will suffocate and this is the mechanism in which changes occur in bone; by undermining and frontal resorption.

Changes in blood supply can be noticed in the gingival tissues when subjected to variable moments, either with tooth brushing¹⁰⁰ or orthodontic tooth movement.¹⁰¹ Tuncay¹⁰² feels that the resistance to remodeling is more important in terms of efficiency of tooth movement than the remodeling of bone. All components are important however in the remodeling process. The ongoing challenge for the orthodontist is to place enough

force to stimulate cellular activity in the periodontium without iatrogenic trauma causing cell death. Beginning the treatment with low force, low friction and small dimension wires will allow teeth to move more individually. They will also begin to level because they are linked together in a group.

There are many other factors which will affect the periodontium and ultimately tooth movement. Many of the studies mentioned were conducted in laboratory experiments, such as the fact that tooth movement occurs at a rate of 1mm per month. There are many other variables intra-orally such as mastication, swallowing, and saliva to name a few have a large impact on tooth movement.

VARIABLE MOMENT

Liew's¹⁰³ study in 1993, changed the way frictional resistance measurements were conducted in a steady state. Most friction tests were absent of any vibrations or disturbances at the bracket-archwire interface that would normally be produced by various everyday oral functions. He placed vertical displacements on the archwire under differing loads using low frequency (91.3 cycles/minute) vibrations. He found that the resistance to archwire movement through an orthodontic bracket was decreased by continuous repeated low frequency vertical displacement of the wire. With loads of 100-250 grams he saw a reduction in friction by 85%. When he used smaller loads of 25 grams, this reduced friction by more than 50%. Therefore, several investigators figured that clinically vibrations must occur due to mastication and tooth mobility during movement. This will mean that friction encountered clinically will be less than measured in the laboratory.⁹¹

O'Reilly⁹ et al. studied 0.022 x 0.028-inch maxillary premolar stainless steel brackets with 0° tip and 0° torque. An alignment fixture was used to determine that the bracket was placed precisely at the center of each block and the slot was at right angles to the surface. The apparatus consisted of two parts: a lower member swivel mounting and an upper member slide, which supported the test bracket that supported the fixed brackets and the test archwire respectively. The distance between the two brackets on either side of the window measured 19.2 mm. This is the average distance between the lateral incisor and the second bicuspid brackets. The test bracket was then placed in the window and the test wire was then placed through all four brackets in series.

A vibrating machine produced the bracket displacement. A frequency of 1.35 Hz (81 cycles/minute) was used, which simulates the normal chewing cycle. The archwire was drawn through the bracket at a crosshead speed of 1 mm/minute. A mechanical universal testing machine was used to measure the forces encountered. Each test run lasted one minute and the loads were recorded in newtons. Four amplitudes were chosen for investigation ranging from 0 mm to 1.0 mm. A total of 16 cohorts (four wires and four amplitudes) with 20 specimens in each group were assembled. This study concluded that the effective sliding resistance between orthodontic brackets and archwires is substantially reduced by repeated displacement. The reduction in sliding resistance noted with displacement, depended on the archwire.

Braun¹⁰⁴ et al. also performed an investigation involving deflection of the archwire in bracket slots. He developed a bracket-holding jig to allow for changes in the bracket angle relative to the archwire. This would simulate clinical activity. The bracket angulations relative to the archwire were tested from 0° (as in translatory movement) to a

maximum of 25.5°, as in dental tipping. The crosshead speed was 0.1 mm/minute and all tests were conducted in a dry environment. Steel ties (0.010-inch) were used to ligate the archwires in the bracket slots. Deflections were applied to the bracket or archwire in random frequencies and in random directions in all three planes of space. The deflections were applied with finger touch, measured by a Correx gauge, to the bracket or archwire with a mean force of 87.2 grams (range 20 to 200 grams). This study concluded that frictional resistance momentarily became zero in 96% of the experiments. This reduction seemed to be independent of the archwire size. The use of steel ligation had no influence. Relative bracket-archwire angulations up to 25.5°, did not increase frictional resistance.

Omana's³³ study compared the frictional effects of seven brands of ceramic brackets to those of a familiar type of metal bracket (Mini Diamond). Each bracket was tested on 0.018 x 0.025-inch straight pieces of nickel titanium and stainless steel wires. Load ranging from 50-150 grams were randomly placed on a 10 mm long counterweight arm to simulate the effects of varying amounts of bracket engagement during tooth movement. As the wire was drawn through the bracket, the static frictional forces were measured by a mechanical testing machine.

The results showed that increasing levels of bracket tip (load) resulted in a corresponding increase in frictional force, there was no appreciable difference between the frictional force values of the stainless steel and nickel titanium wires. In addition, smoother, injection-molded ceramic brackets appear to create less friction than other ceramic brackets, wider metal or ceramic brackets create less friction than narrower brackets of the same material and excessive force is counterproductive because of increased bracket friction and potential loss of posterior anchorage.

In vitro frictional resistance experiments that did incorporate variable moments at the bracket-archwire interface concluded that the relationship between tip and friction appears to be linear. The effect of displacement was shown to have a significant effect on sliding resistance regardless of wire type.

If one considers the clinical situation, where there is intermittent movement between the bracket and archwire, then clinically we may not be looking at true friction, but rather a binding and releasing phenomenon. Kajdas¹⁰⁵ et al. found that repeated displacement of a bracket, equivalent to as little as 0.16 mm of mesio-distal crown movement (which is within the range of normal tooth mobility), could reduce the sliding resistance by as much as 85%. Assuming this fact, it is not unreasonable to conclude that the reduced sliding resistance observed *in vivo* may be a result of this intermittent movement between the bracket and archwire.

CONTACT ANGLE

The angle in the bracket slot before the archwire and bracket bind is called the contact angle. Archwires with smaller dimensions result in larger contact angles than archwires with larger dimensions, when using the same bracket. As the angle between the bracket and archwire increases, the frictional force will increase, more rapidly beyond a certain contact angle.^{88,106} created a formula that would calculate the contact angle.

$$\text{Contact Angle } (\theta_c) = \frac{57.3 [1 - (\text{size/slot})]}{(2^{\text{nd}} \text{ order angulation}) (\text{Width/slot})}$$

Size = the archwire dimension that contacts the floor of the slot

Slot = the bracket dimension at the floor of the slot

Width = the mesial-distal dimension of the bracket

SALIVA

The presence of saliva has an inconsistent effect on the static frictional resistance, in some cases with saliva functioning as a lubricant and at other times acting to increase friction.⁸⁰ Stainless steel brackets have been evaluated with inconsistent results of saliva on frictional properties.^{80,14,82}

Many investigators have found that saliva acts to increase frictional resistance.^{80,14} Most would think that saliva is a natural lubricant. As Stannard¹⁴ mentions, water is made of polar molecules which attract to each other and therefore increase friction.

The greatest difference between dry and wet states occurred with beta-titanium archwires, the friction was reduced to half in the wet state.⁵⁶

CHAPTER III MATERIALS AND METHODS

OVERVIEW

This research study investigated the effects of variable tipping angles and ligation methods on friction using different brackets and archwires, to evaluate the amount of static, kinetic and dynamic friction present. Friction is the force necessary to pull an archwire through a bracket. The force required to tip the bracket to create a constant bracket-archwire angulation was measured. The testing apparatus consisted of a friction-testing apparatus, mechanical testing machine (Figure 1), two load cells, two signal amplifiers, two computers and a rotating cam. The testing machine engaged one end of the vertically oriented archwire, which was inserted in the bracket slot, and pulled the archwire superiorly. Each bracket-archwire and ligation combination was tested 5 times, which yielded friction and load data. During the 120 second trial, the archwire was pulled with and without any variable moments. The data was analyzed to determine which brackets, archwires, and ligation method yielded the least static, kinetic and dynamic friction.

Figure 1. Friction-testing apparatus.

MATERIALS

Maxillary right first premolar brackets with 0.022 x 0.028-inch slots were selected for this study. The brackets were chosen because of the increase in popularity of ceramic and self ligating brackets. The brackets were:

- 1) Mystique (GAC) -7° torque, 0° tip (Lot #16378) (**Figure 2**)

- 2) Clarity (Unitek) -7° torque, 0° tip (Lot #016525400) (**Figure 3**)

- 3) MicroArch (GAC) -7° torque 0° tip (Lot #15767) (**Figure 4**)

- 4) SmartClip (Unitek) -7° torque, 0° tip (Lot #G1068BN) (**Figure 5**)

- 5) Inovation R (GAC) -7° torque, 0° tip (Lot #0904) (**Figure 6**)

Open and Closed

All the archwires used in this study were provided by GAC:

- 1) 0.018 inch stainless steel (Lot #02F10).
- 2) 0.019 x 0.025-inch stainless steel (19x25ss) (Lot #024448).
- 3) 0.021 x 0.025-inch stainless steel (21x25ss) (Lot #021308)

LIGATION METHODS

- 1) Elastomeric tie fromOrmco
- 2) .009 Stainless steel ligature tie from Masel
- 3) Self ligation bracket from Unitek-SmartClip
- 4) Self-ligation bracket from GAC-Inovation-R

TEST BRACKET-ACRYLIC ROD ASSEMBLY

A dental surveyor was utilized to align and mount the test brackets onto the ends of fabricated acrylic rods. The acrylic rods were 6 mm in diameter and were 12.6 mm in

length. A rectangular acrylic block, with a 6mm diameter hole drilled in its center, was secured to the base of the surveyor table with caulking paste. This block will be used to center the acrylic rod beneath the pin of the surveyor. Gel superglue was placed on the mesh retention side of the bracket. The bracket was then inserted onto the rod on the surveyor to position it over the center of the acrylic rod and perpendicular to the long axis of the rod. The surveyor pin used to secure the bracket was ground into the shape of a blade, with its width equaling the bracket slot (.022). The pin was then inserted into the bracket slot to align and center the bracket on the acrylic rod surface: the bracket was held on the pin with a friction fit. The surveyor and plate negated the -7° torque prescription in the brackets (Figure 7). Isopropyl alcohol (200 Catalyst-C, M-Line Accessories, Measurements Group, Inc., Raleigh, N.C.) was painted onto the bracket-rod interface to accelerate bonding.

Figure 7. Surveyor pin aligning test bracket mounted on acrylic rod.

APPARATUS SETUP

The bracket/rod assembly was mounted to the test apparatus by sliding the rod into a sleeve with a locking set screw (Figure 8). The sleeve was free to rotate in the plane of the bracket slot. The angle of rotation was recorded via an electronic angle gauge. The sleeve was rigidly attached to a lever arm, see Figure 8. The lever arm was connected to a rotating cam.

All brackets were orientated in the same direction, with the distogingival dot positioned superiorly and to the right. As a result, all bracket slots were vertically orientated.

Wires were rigidly fixed to a rod connected to the movable cross head and the load cell of the testing machine. The position of the bracket was adjusted by moving the

test apparatus left and right, forward and back via an adjustable platform. This positioning and wire connection resulted in the wire being passively aligned through the bracket slot. After the bracket was properly positioned, ligation was engaged. Testing procedures pulled the wire through the bracket/ligature while monitoring the load.

Rotation of the cam moved one end of the lever arm up and down. The other end of the lever arm was fixed but allowed to rotate. Rotation of this end of the lever arm, rotated the rod/bracket assembly. (Figure 9) As the bracket rotated, the wire came into contact with the bracket slot. Rotation of the wire was limited by two low friction guide bearing (Figure 8). The force to rotate the bracket was recorded via the second load cell.

Figure 8. Archwire in mounting plate.

LOAD CELLS AND COMPUTER SETUP

Prior to data collection, a 50-gram weight was used to calibrate the 250-gram load cell (Sensotec, Inc. Model 31/1435-03). This load cell measured the load required to tip

the bracket/archwire to a predetermined angle. It was interfaced with a custom built computer containing an Intel Celeron processor and Labtech software (Laboratory Technologies Corporation © 1999, Labtech Control Version 11, Universal) recording the data. It was attached superiorly to the lever arm and inferiorly to the rotating cam, which created the variable moments. The load cell was attached to the lever arm at a distance from the lever arm's center of rotation, which was directly behind the test bracket-rod assembly.

The second load cell, ± 1 kN (Instron, UK 598) located on top of the Instron machine, was calibrated with a 1000-gram weight. This load cell recorded the force to pull the wire through the bracket, and friction at the bracket-archwire interface. This load cell was also interfaced with the same custom built computer utilizing the Labtech software. A Gateway E3000 system containing Merlin software (Instron Merlin Program, Version 3.23) controlled the crosshead speed of the archwire (5mm/min).

ROTATING CAM

A DC Power Supply (Maxtel International Corporation, BK Precision, and Triple Output DC Power Supply 1651) powered the rotating cam. The cam was attached with a rod and load cell to a lever arm. The rotation of the cam oscillated the lever arm which rotated the bracket/rod assembly to produce the variable moments. The power was set to 11 volts, which correlated to 1 Hertz or 60 cycles/minute. As the rotating cam moved cyclically, the measured load would cyclically change. When the cam rotated to the highest vertical dimension, the minimum load was applied. Conversely, when the cam was rotated to its smallest vertical dimension, the maximum load was applied. The connection of the lever arm to the rotating cam was positioned to vary the rotation angle

from zero to the maximum. Before the archwire was engaged in the test bracket, the rotating cam was turned until the 250-gram load cell was at its most superior position, to apply the minimum load, at zero degrees (Figure 9).

FIGURE 9. LEVER ARM TO SET ANGLE.

BRIDGE AMPLIFIERS

Two bridge amplifiers were used in this study to provide stimulation in the load cells and to amplify the signal voltage (proportional to load) (Figure 10). The Signal Conditioning Amplifier (Measurements Group, Instruments Division, Model 2311)

attached to the ± 1 kN load cell, to measure friction, was reset to zero prior to each trial. The second amplifier (Sensotec, Inc., Signal Conditioner-Indicator, Model GM), used to measure load and connected to the 250-gram load cell, was not reset to zero prior to each trial.

Figure 10. DC power supply and two bridge amplifiers.

TEST TRIAL INTERVALS

Each trial will consist of 120 seconds in length and the intervals are provided below:

0-15 seconds	noise /offset (no archwire pull and no variable moments)
15 seconds	begin archwire pull superiorly at a crosshead speed of 5 mm/min
30 seconds	bracket angle turned to 2.7 degrees
45 seconds	bracket angle turned to 4.9 degrees
60 seconds	bracket angle turned to 5.4 degrees
75 seconds	Motor to rotating cam turned on.
105 seconds	Instron machine stopped and only rotating cam on.
120 seconds	All data collection finished.

At each of the time changes above, a trigger was used to identify points on the data screen.

After each trial, the archwire and bracket-rod assembly were removed and replaced with new ones. Ligation was also replaced each time.

DATA COLLECTION AND EVALUATION

As stated above, all data was collected (DC voltages) and scaled by the computer using Labtech software. Each bracket-archwire combination was tested 5 times. Measurements were taken every tenth of a second (0.10 seconds/measurement) for 120 seconds for both load and friction values. Load was in units of gram-centimeters, due to the lever arm length, while friction was in units of grams. The raw data was transferred to Microsoft Excel 2000, where the appropriate titles for archwires, brackets and trial number were placed. Headings for each of the 4 columns (time, load, friction, and

trigger) were also assigned. The first 10 seconds of the load data was averaged and this value was then subtracted from all the load data and multiplied by 10 to obtain the true load. This was necessary because the amplifier connected to the 250-gram load cell recording the load data was not reset to zero prior to each trial. However, the friction data was not adjusted because the amplifier connected to the ± 1 kN load cell used to measure friction was reset to zero prior to each trial. An example is shown below (Table 1).

0.019X0.025" SS, Mystique, alastic, Trial #1

Time seconds	torque gm-cm	friction gm	trigger	angle degrees
0	-1.9453	-4.8828	0	58.2563
0.1	-1.7021	-4.8828	0	58.3555
0.2	-1.9453	-4.8828	0	58.1572
0.3	-1.7021	-4.8828	0	58.2563
0.4	-1.9453	-4.8828	0	58.2563
0.5	-2.1885	-4.8828	0	58.2563
0.6	-1.9453	-4.8828	0	58.1572
0.7	-1.9453	-4.8828	0	58.2563
0.8	-1.9453	-4.8828	0	58.0581
0.9	-2.1885	-4.8828	0	58.2563
1	-1.7021	-4.8828	0	58.2563

Table 1: Sample of data.

Data from every trial was graphed using Microsoft Excel 2000. Two y-axes were placed on each graph. Friction (gm) was on the left y-axes and Load (gm-cm) was on the right y-axes. The x-axis was labeled Time (seconds). An example is shown below in Figure 11.

For each trial of bracket/wire/ligature, static friction was calculated as the maximum friction value between 14 and 16 seconds. Kinetic friction was calculated at each test angle by averaging data for a ten second interval. Dynamic friction was calculated by averaging data for a ten second interval while the cam rotated.

Figure 11. Sample graph of raw data.

DATA ANALYSIS

Data was analyzed to compare:

- 1) static, kinetic and dynamic friction
- 2) dynamic friction and dynamic load
- 3) dynamic load and apparent stiffness
- 4) ligation method
- 5) archwire sizes
- 6) contact angles

STATISTICS

JMP version 3.1.5 statistical analysis software was used to calculate ANOVA ($p < 0.0001$) and Tukey-Kramer Honest Significant Difference (HSD) ($p < 0.05$). Microsoft Excel 2000 was used to calculate the average friction and standard deviation.

STANDARDIZATION OF THE TESTING MACHINE

A preliminary standardizing technique was conducted to determine:

- 1) if the apparatus and data collection software were functioning properly
- 2) if the frictional resistance at the bracket-archwire interface was proportional to the load
- 3) to see if the brackets being tested had indeed differing amounts of friction
- 4) if the cyclic rotating variable moment at the bracket-archwire interface influenced friction.

Brackets used in the standardization were: Transcend (Unitek), Mystique (GAC), Clarity (Unitek), and MicroArch (GAC). The pilot study did not use any method of ligation. Two archwires were used: .014 Round Nickel-Titanium and 18X25 Stainless Steel, with upper bicuspid brackets with .022 slots. Four brackets were tested: GAC's Mystique and MicroArch along with Unitek's Clarity and Transcend. The Transcend bracket was added as a positive control, a bracket with a significant friction and antidotal prolonged treatment times. The metal MicroArch bracket served as a negative control, a bracket with minimal friction.

Brackets were bonded to one end of a quarter inch diameter acrylic rods with cyanoacrylate cement. A dental surveyor and modified pin were utilized to position the bracket slot in the middle of the acrylic rod. In addition, the surveyor pin positioned each bracket's slot perpendicular to the long axis of the acrylic rod negating the effects of bracket prescription.

The testing apparatus of Mah et al (Mah J Dent Res, 2003) was modified to enable the application of a variable tipping torque to be applied to the bracket while recording the friction, tipping torque and angle similar to Omana (Omana JCO, 1992).

The bracket-acrylic rod assembly was mounted in the test fixture. The archwire was inserted into the bracket slot and attached to the crosshead of the testing machine. The wire was guided by the bearing of the test fixture. No ligatures were used. Ligatures are a confounding variable. Without ligatures, an extraneous variable is eliminated. The measurements focused on the friction of the bracket/wire interface. In the test fixture, the acrylic rod was connected to the lever arm of the offset cam. The rotating cam moved the lever up and down on one end, rotating the acrylic rod and the bracket on the other end.

The bracket was tipped to four fixed angles: 0, 2.7, 4.9, and 5.9 degrees by hand and friction measured by pulling the wire through the bracket. After measuring friction at each fixed angle, variable cyclical tipping angle and torque from 0 to 5.9 degrees was applied via the rotating cam and lever arm, and dynamic friction measured. Each combination of bracket and archwire was tested three (Ni-Ti) or five (SS) times. Each test run utilized a new bracket and wire segment.

Multiple data channels were recorded via an analog to digital conversion board in a PC. Data was analyzed with the MS Excel spreadsheets and JUMP statistical software. The information obtained from the pilot study enabled us to replicate results of previous research and to predict the data obtained when the remaining brackets and archwires were studied.

The wires were pulled through the bracket without any ligation first to establish a baseline. The ligation methods were then employed in the following order:

1)Elastomeric 2) .009 Stainless steel ligature wires 3) self ligation. Each combination was run 5 successive times, changing the ligation method and wire each time.

The ceramic brackets were selected due to their popularity and the original Transcend ceramic bracket for its alleged high friction. The SmartClip self-ligating brackets were chosen due to their new design, a nickel-titanium clip that requires no opening or closing. Perhaps most important with this bracket is the familiar twin bracket design that lets orthodontist keep their preferred treatment mechanics. The wires were chosen due to their popularity and frequent use in sliding mechanics.

CHAPTER IV RESULTS AND DISCUSSION

INTRODUCTION

The main objective of this project was to study friction between brackets, wires, and ligation methods. There are three types of friction. Static friction is the smallest force needed to begin the movement of an object across another that was previously at rest with each other; kinetic friction is the force that resists the sliding of these objects past one another at a constant speed; dynamic friction was defined in this study as the frictional force that occurs when the applied (normal) force is variable (dynamic load). Static and kinetic frictions were very similar and were combined and presented as a zero degree angle data. Friction was measured and analyzed for each combination of bracket, wire, ligation method, and angle.

OVERALL RESULTS

The results of the entire study are presented in Table 2. Each bracket and wire combination for both the self ligating brackets and the non-self ligating brackets/(BLS) are shown with data for all angles averaged. The BLS had two different methods of ligation: stainless steel and alastic o-rings, both of which are presented. The table indicates that with each bracket the friction increased with increasing wire size (018, 19X25, and 21X25). The friction of the 018 wire, was the lowest with the SmartClip and highest with the Clarity ligated bracket. With the 19X25 stainless steel wire, the friction was again lowest for the SmartClip and highest for the Clarity ligated bracket. Lastly, for the 21X25 wire, the metal bracket with the stainless steel ligature had the lowest amount of friction and the Mystique bracket with stainless steel ligation had the highest.

Bracket Types	Wire Size	<u>Alastic Ligation</u> Mean Friction (grams)	S.E.	<u>SS Ligation</u> Mean Friction (grams)	S.E.
Clarity	18	150	46	58	50
Clarity	19X25	182	60	404	117
Clarity	21X25	293	92	296	88
Metal	18	150	81	59	58
Metal	19X25	130	145	185	172
Metal	21X25	217	92	343	257
Mystique	18	94	56	93	55
Mystique	19X25	229	139	371	279
Mystique	21X25	422	247	439	298
SmartClip self ligating	18	43	59		
SmartClip	19X25	120	142		
SmartClip	21X25	347	315		
InvR self ligating	18	70	95		
InvR	19X25	299	193		
InvR	21X25	417	301		

Table 2. Overall Results (all brackets and ligation with all angles averaged).

OVERVIEW OF THE PROJECT

The results were separated into two experiments (Experiment 1 and Experiment 2), since two types of bracket/ligation systems were used in this study; self ligating and

non-self ligating brackets. With the increasing popularity of self ligating brackets, two brackets of this group were used. Self ligating brackets have a method of securing the wire into place incorporated into the bracket system. They are noted for reducing friction during tooth movement.⁷³ Three non-self ligating brackets were used; GAC MicroArch metal (control), 3M Unitek Clarity, and GAC Mystique. The latter two are ceramic brackets which are increasing in popularity with treatment of the adult population. The non-self ligation brackets were used with two ligation techniques, alastic and stainless steel ligation.

Experiment 1 analyzed all BLS. The rationale for including all systems was to compare the self ligating brackets with the non-self ligating brackets. The non-self ligating brackets had to be ligated, hence bracket ligature system, (BLS) were analyzed in Experiment 1.

Experiment 2 analyzed data from only the non-self ligating brackets to focus on the effects of ligation method. It was designed to compare the importance of the bracket with the ligature factor.

EXPERIMENT 1 (ALL BRACKET LIGATURE SYSTEMS)

ANOVA showed significant differences among the: wire size, bracket-ligature system (BLS), wire-BLS interaction, stage (tipping angle), and wire-stage interaction. Dynamic friction was not considered.

GENERAL RESULTS FOR EXPERIMENT 1

Mean differences in friction were grouped by wire size, Table 3. Significant differences were found at $p < .0001$. All wire sizes were significantly different from the others based on the Tukey-Kramer analysis. Generally, as wire size increased the mean

friction also increased. The 018 stainless steel wire had the lowest mean friction and the 21X25 stainless steel wire had the highest friction. The data range was 257 grams. There was a wide range of friction between the wire sizes, indicating that there was a significant friction component depending on the wire used.

Wire Size	Mean Friction (grams)	S.E.	Level
21X25	347	13	A
19X25	240	13	B
018	90	13	C

Levels not connected by same letter are significantly different
Table 3. Mean friction for each wire, all BLS and stages averaged.

The BLS was also a significant factor at $p < .0001$. The brackets with the stainless steel ligature system on the average had a higher friction than those with the alastic method of ligation. All wires at every stage in the testing procedure were averaged together in table 4. The data range from the 018 stainless steel to the 21X25 stainless steel wires was 135 grams within the BLS for eight different bracket combinations. The significance was not as much for the bracket ligation systems as was seen with the wire sizes only.

Bracket Ligature System	Mean Friction (grams)	S.E.	Level
MystiqueSS	301	21	A
InvRselflig	262	21	A B
ClaritySS	248	21	A B C
MystiqueAlastic	209	21	A B C
ClarityAlastic	209	21	B C
MetalSS	196	21	B C
SmartClipsselflig	170	21	C
MetalAlastic	166	21	C

Levels not connected by same letter are significantly different

Table 4. Mean friction for each BLS.

The wire-bracket ligature system (BLS) interaction was also found to be significant at $p < .0001$ (Figure 12). The differences in the mean friction between the wires depended on different bracket ligature system used. When using the 21X25 stainless steel archwire generally experienced higher friction regardless of the bracket ligature system. The Clarity with stainless steel ligation had a lower friction with the 21X25 wire than the 19X25 wire. Figure 12 shows the different wire sizes with each bracket ligature system.

Figure 12. Wire-BLS graph.

The stage or the tipping angle factor that was used was also significant at $p < .0001$. As the angle increased from 0 degrees to 5.4 degrees, the mean friction gradually increased as seen in Figure 13. Certain angles were significantly different than others when analyzed with the Tukey-Kramer. For 0 to 2.7 degrees there was no significance and from 4.9 to 5.4 degrees there was also no significance in the angle. All other angles were significant from one another. The range for the stage factor was 131 grams, although statistically significant the range was not as great as with other factors, Figure 13.

Figure 13. Stage and mean friction for all wires and bracket ligature systems.

The wire-stage interaction was significant at $p < .0006$. As mentioned before the wire size and the angle both increased the friction. There were differences in the friction between the wires used depending on the angle that was involved. When the wire increased in size and at the same time increased to a larger angle, the friction increased gradually. Figure 14 shows the lowest friction to be the 018 stainless steel wire at 0 degrees. The 21X25 stainless steel wire had the highest friction at 5.4 degrees.

Figure 14. Wire-stage interaction.

WIRE-BLS INTERACTION

Since there was a significant BLS- wire interaction, each wire/bracket ligature system (BLS) combination was analyzed. This included all the brackets, self ligating and non-self ligating brackets. Mean friction for each BLS was compared for each wire size. Wire size as mentioned previously is essential to maintain lower friction during tooth

movement. The range of friction in grams for wire size has had the greatest impact of all other factors and interactions, therefore each wire will be analyzed within each BLS.

018 STAINLESS STEEL WIRE

For the .018 stainless steel wire, the alastic method of ligation had a higher friction when compared to the stainless steel ligation for all brackets. The Metal bracket with the alastic ligation had the highest friction. The SmartClip bracket had the lowest mean friction. The range in the friction averages was 92 grams. The results of the Tukey-Kramer are shown below in Table 5.

Bracket Ligature System	Mean Friction (grams)	S.E.	Level
MetalAlastic	151	14	A
ClarityAlastic	150	14	A
MystiqueAlastic	94	14	A B
MystiqueSS	93	14	A B
InvRselfligation	70	14	B
MetalSS	59	14	B
ClaritySS	58	14	B
SmartClip selfligation	43	14	B

Levels not connected by same letter are significantly different

Table 5. 018wire-BLS Tukey-Kramer.

19X25 STAINLESS STEEL WIRE

The Clarity with stainless steel ligation had the highest friction and the SmartClip self ligation had the lowest. There was also a broad range of 284 grams in the mean friction. As can be seen in Table 6, the range for this wire was not as large as it was between some of the other bracket ligature systems. The results of the Tukey-Kramer are shown in Table 6.

Bracket Ligature System	Mean Friction (grams)	S.E.	Level
ClaritySS	404	37	A
MystiqueSS	371	37	A B
InovationRselfligation	299	37	A B C
MystiqueAlastic	229	37	B C
MetalSS	185	37	C D
ClarityAlastic	182	37	C D
MetalAlastic	130	37	D
SmartClipsselfligation	120	37	D

Levels not connected by same letter are significantly different

Table 6. 19X25 Tukey Kramer.

21X25 STAINLESS STEEL WIRE

The one way ANOVA showed a significant difference among BLS for this wire. However no significant differences were found with the Tukey-Kramer. A Student's test did yield significant differences. Again, like the 19X25 stainless steel wire group the stainless steel method of ligation yielded the higher friction compared to the alastic. The Mystique with the stainless steel ligation exhibited the highest friction and the metal with

the alastic had the lowest friction. The range here was also very large at 222 grams of friction between the highest friction and the lowest friction. Some of the bracket ligature systems however were very comparable in the amounts of mean friction. Results of the Tukey-Kramer and Students' t test are shown in Table 7.

Bracket Ligature System	Mean Friction (grams)	S.E.	Level
MystiqueSS	439	52	A
MystiqueAlastic	422	52	A B
InovationRselfligation	417	52	A B
SmartClipselfligation	347	52	A B C
MetalSS	343	52	A B C
ClaritySS	296	52	A B C
ClarityAlastic	293	52	B C
MetalAlastic	217	52	C

Levels not connected by same letter are significantly different

Table 7. 21X25 Students' t test.

EXPERIMENT 2 (NON-SELF LIGATING BRACKETS)

Friction was analyzed to compare two factors, ligation and bracket.

It was important to compare the two ligation components where they could be changed. The two ligation methods were stainless steel and alastic rubber bands.

Brackets were two ceramics, Clarity and Mystique, and one metal bracket (control).

ANOVA analyzed the bracket and the ligation factors only.

BRACKET FACTOR

The ANOVA and Tukey Kramer analyses showed significant differences between the brackets. The Mystique bracket overall had the highest friction. The metal bracket had the lowest overall friction. The range for these three brackets was not that large, approximately 94 grams of friction. The results of the different bracket types are seen in Table 8.

Bracket	Mean Friction (grams)	S.E.	Level
Mystique	275	13	A
Clarity	231	13	B
Metal	181	13	C

Levels not connected by same letter are significantly different

Table 8. Bracket Factor Tukey-Kramer.

LIGATION

The ligation component was also significant with the ANOVA and Tukey Kramer analysis. The stainless steel method of ligation had the highest overall friction and the alastic had the lowest. The range was approximately 42 grams of friction. The results are described in Table 9.

Ligation Component	Mean Friction (grams)	S.E.	Level
SS	250	11	A
Alastic	208	11	B

Levels not connected by the same letter are significantly different.

Table 9. Ligation Factor Tukey-Kramer.

COMPARISONS OF LIGATION METHOD FOR EACH WIRE

All the brackets and all the tipping angles averaged together to compare the friction utilizing each ligation method in the three different wire sizes. The 018 stainless steel archwire exhibited the highest amount of friction in the alastic method of ligation and the self ligation had the lowest amount of friction. The overall results can be seen in Figure 15.

Figure 15. All brackets and ligation with 018 wire.

When the 19X25 stainless steel archwire was compared utilizing all brackets and tipping angles the results were different than the 018 stainless steel archwire. The stainless steel method of ligation had the highest friction and the alastic had the lowest, however the self ligation was also low in friction. These results can be seen in Figure 16.

Figure 16. All brackets and ligation with 19X25 wire.

The 21X25 wire had different results also. The self ligating group of brackets had the highest amount of friction and the alastic method of ligation had the lowest. The range between the groups here was very small. The results can be seen in Figure 17.

Figure 17. All brackets and ligation with 21X25 wire.

DISCUSSION

INTRODUCTION

Many studies have been done involving friction and archwires. Most of these studies rely on simply pulling an archwire superiorly and quantifying the friction present in the wire.^{11,33,39} The focus of this study was to simulate a more realistic setup with archwires ligated to the brackets and then placing variable moments on bracket and wire. The angulations that was present of the wire/bracket imitated movement of teeth. More specifically, three stainless steel archwires were tested with five different brackets, and four different angles. In addition, the ligation factor included: self-ligation, alastic, and stainless steel ligation.

FRICTION TYPES

Static friction and kinetic friction in this study were similar. Previous research stated that static friction was greater than kinetic friction^{1,4} however this amount was negligible and was not presented in the results section. The difference when evaluated by the Tukey-Kramer HSD analysis, at an alpha level of 0.05, was not statistically significant.

These results are clinically significant during tooth movement. There is always static friction present between the archwire and bracket and this force must be overcome if a tooth is allowed to move. Once this initial tooth movement has occurred, the kinetic friction must be overcome to allow the tooth to continue to move.¹ This is most often accomplished with orthodontic devices such as rubber bands, power chain, nickel-titanium coils, or closing loops incorporated into the archwire.

A tooth does not translate linearly along an archwire. Tooth movement occurs by a process of the crown tipping then crown uprighting. The tooth tips and uprights along the archwire, therefore archwire binding occurs during various times along the wire. This is an extremely important concept and must be recognized. When the crown tips it will bind to the archwire and at that point increase friction.⁵ Tooth movement during that binding moment, the friction is the greatest and must be overcome. In a clinical setting, friction is a dynamic phenomena. Dynamic friction is overcome and a force must be placed on the tooth that is greater than the binding force that impedes tooth movement.

Variable moments tipped the bracket to a total range of 0 to 5.4°, creating a variable bracket-archwire angle to study dynamic friction. The archwire was subjected to cyclical binding and releasing actions against the bracket slot, due to bracket tipping. As binding occurred, the friction increased until the moment (angulation) was rotated back to zero degrees. Clinically, this tooth movement would occur if 1) a release of any binding present at the bracket-archwire interface and 2) if the bracket ligation system was deemed to have lower friction so kinetic friction could be overcome sooner.

This study attempted to clarify the effects of bracket, ligation, angle, and archwire on friction. Actually, if the right combination is used at the right time, friction will be reduced significantly. Elastomeric and stainless steel ties along with self-ligating clips were investigated. The results of this study were similar to those earlier done by O'Reilly, Braun and Liew.^{9,104,103} They stated that with variable archwire deflection, frictional resistance was either reduced or momentarily became zero, due to the release of binding. This was evident when the angle was reduced, when the angle was 5.4 degrees the most binding occurred and when it was 0 degrees the friction was the lowest.

EXPERIMENT 1

WIRES

When all of the brackets were grouped together to compare the non-self ligating brackets to the self ligating brackets, self ligating brackets had lower friction. This was consistent with previous research.⁷³ The smaller the wire size had the lower mean friction within the bracket system. The friction steadily increased with the larger archwires used in the study 19X25, and 21X25 stainless steel. This is consistent with previous studies including the classic work by Frank and Nikolai when they stated that increased wire diameter increased friction.^{5,18,19,20} At the same time this study contradicted the results of Sims study where he found that archwire size does not necessarily contribute to friction.²⁶ Therefore in an ideal situation tooth movement should occur with a smaller round wire and have the least amount of binding within the bracket. This opposes the idea of Tidy et al, he stated that decreasing archwire size allowed more tipping and causes more binding to occur.²⁷

Friction has always been a factor during tooth translation. Most orthodontists will work up to a larger rectangular stainless steel archwire to translate teeth. There is a larger frictional value with increasing wire size, therefore the clinician must overcome this increase in friction with larger forces in order to successfully move teeth. There are some benefits to the larger archwire. When teeth are being translated the torque, tip, and angulation are prebuilt into the bracket prescription. Also, the more the archwire fills the slot size of the bracket the more the expression of the prescription will be seen. Therefore, if there is a larger distance for tooth translation to occur, and torque and angulation is of concern to the clinician, a higher friction 19X25 or 21X25 wires should

be used. On the other hand, if the movement is minimal and these factors are not a concern, the 018 wire would clearly be the better choice due to lower friction.

BLS

When all the bracket systems were compared with all types of ligation (alastic, stainless steel, and self ligation) the results were variable.

The stainless steel method of ligation was the most variable during the laboratory simulation. This was consistent with previous reports by Nanda, he stated ligation techniques can range from 50 to 300 grams.³⁸ Braun's et al study was also done with variable tipping angles and he found that steel ligation had no influence on the friction.^{104,33} The operator tried to be consistent on tying each archwire into the bracket, regardless of the attempted consistency; the alastic and self ligation were much more consistent. The orthodontist will face this same situation clinically where friction can be increased or reduced depending on how the bracket was tied in with the stainless steel method of ligation. These findings in the laboratory are similar to those found by Bednar⁴⁴, he stated that loosely tied ligatures are thought to provide less friction than the elastic counterparts. Therefore the operator can increase or decrease the friction that is placed on the wire by the technique that is used.

The twin metal bracket with alastic ligation, which served as our control, had the lowest friction. The self ligation brackets as well as the ceramic brackets had a higher amount of friction. This was consistent with the previous results done by Pratten and Kusy, they stated that stainless steel brackets had lower friction than the ceramic brackets.^{16,56} This friction takes into account all methods of ligation analyzed together. With the increased awareness of ceramic brackets and esthetic brackets the orthodontist

must recognize that ligation affects the friction. Depending on the bracket and ligation method used the friction can increase significantly. With self ligating brackets, chair time will be reduced because the orthodontist does not have to take the time to ligate every bracket to the wire. Whereas simply using a self ligating bracket may not reduce friction.

WIRE-BLS INTERACTION

This perhaps is the most important interaction measured in Experiment 1 with all the brackets. Differences between BLS depended on the wire used. Although a system was created with multiple variables, wire, bracket, angle, and ligation; the most important factor still is the wire size. Clinically smaller round wires will reduce friction significantly more than larger rectangular stainless steel ones. For simplicity the bracket ligature systems were analyzed by the different wire sizes. This takes into account tooth movement in the mouth without the tipping of the brackets. Although this is not realistic clinically, it is reliable from the standpoint of the wire being seating into the bracket slot by the ligation method.

018 WIRE

The size of the wire has already proven to be significant when translating teeth. In an ideal situation teeth would be translated on an 018 stainless steel wire because the friction is significantly reduced. The results were then broken into wire types with the different ligation methods.

For simplicity all the brackets were grouped together with all three ligation methods. This allows the orthodontist to evaluate which of the ligation methods had the highest friction. Therefore it can be helpful when choosing a ligation component for the

018 wire. Overall the alastic method of ligation in general had the higher friction when compared to the stainless steel and the self ligation. This agreed with the results found by Khambay⁴⁰ where he stated that stainless steel ligation methods had the lowest amount of friction when compared to alastic. It was interesting to note that the stainless steel method of ligation was the lowest for the 018 wire and highest for the 19X25 and 21X25 wires. These results contradicted those results found by Ireland³¹, he found that friction did not raise steadily with increasing archwire dimensions. The results of this study found that with increasing wire size with the stainless steel method of ligation the friction also increased more than the alastic counterpart. The alastic was the lowest with the latter two. Therefore when using the lower wire size stainless steel ligation may be more beneficial because of it lack of contact with the wire.

19X25 WIRE

The 19X25 wire showed different results compared to the 018 stainless steel wire. The stainless steel method of ligation compared with the alastic ligation, generally had a higher friction, except as mentioned before with the 018 stainless steel. Again this could be related to the operator and how the stainless steel ligature is tied into place. The self ligation group exhibited a higher overall friction than the alastic group in this wire group. This study contradicted previous results found by Harradine and Cacciafesta. They found that there was a decrease in frictional resistance between the bracket and archwire.^{73,74,75} There is a drastic difference in the ligation method between the 018 and the 19X25 wire sizes, this may be of importance to the operator as they would increase in wire size. Sims et al showed that less friction occurred in archwires ranging from 16X22 inch to 19X25 with self ligating brackets compared to alastic tied conventional brackets.^{26,53,75} These

results contradict those results. The Inovation-R bracket becomes an active appliance as the progression through the archwires and the SmartClip remains passive. Both brackets have a beneficial component; the Inovation-R will express more torque and tip and the SmartClip will have less friction.

21X25 WIRE

In the 21X25 stainless steel wire group the results were similar to the 19X25 in terms of the stainless steel method of ligation having an overall higher friction when compared to the alastic method of ligation. The striking difference when progressing up in wire size is the increasingly more friction in the self ligating brackets. This group exhibits the higher friction, more than stainless steel and alastic ligation methods. This is important clinically because the operator may want to have a lower friction in the beginning of treatment to correct rotations and leveling the curve of spee, in the final stages of treatment when translating teeth some friction is wanted. Friction can be good to build up anchorage units to move other teeth too. The other issue is the increased friction in relation to the overall tooth movement. Most orthodontists will wait until they get into a rectangular stainless steel to translate teeth, therefore friction has to be considered.

WIRE AND STAGE

As discussed previously the increase in wire size will invariably increase the friction. With that said the friction also will increase with increasing tip on the wire bracket interface. Braun, Omana and others found similar results with increasing tip the friction will also increase. Although the angles in these studies were different than the angles presented here, the friction invariably increases.^{104,33} Therefore the friction will be

the highest with the 21X25 stainless steel wire and 5.4 degrees of angulation. The more rotated a tooth during the initial stages of treatment the more friction will be placed on that bracket ligature system to unravel this tooth crowding. Smaller round wires will be the method of choice.

EXPERIMENT 2

The results were also analyzed to compare the effects of bracket and ligation in the non-self ligating brackets. The self ligating brackets were intentionally deleted from this part of the study to examine fairly the effect of bracket and ligation alone since the ligation factor could be removed and interchanged in these three non-self ligating brackets.

BRACKET FACTOR

The Mystique ceramic bracket with the silicated slot had the highest amount of friction compared with the Clarity and metal brackets. This was clinically significant even though the range is only 45 grams. The Clarity bracket has a stainless steel slot and may mimic the properties of the twin metal bracket. The effect of the bracket slot could have increased the friction significantly in this study and this agrees with previous studies. Ceramic material has been reported to abrade the archwire and actually notch the stainless steel wire.³⁹ Cacciafesta and others found that the stainless steel slot had a lower amount of friction than the others and this could be related to the surface roughness and porosity of the ceramic slots.^{57,58,16,21,44} The silicated slot here in the Mystique bracket did not seem to reduce friction as well as the stainless steel slot of the Clarity. The twin metal bracket proved to have the least amount of friction and the range is broader, almost 100 grams between the Mystique bracket and the twin metal bracket. Clinically when

choosing between metal and ceramic brackets, the metal and the Clarity will provide the least amount of clinically significant friction.

Ligation

The stainless steel method of ligation had the higher amount of friction than the alastic tie. These results are similar to those found in experiment 1 with the self ligating brackets included. The stainless steel method of ligation here also had the highest amount of friction compared to the alastic counterpart. The range was approximately 40 grams. This was clinically significant from one another. This was different from previous research where stainless steel ligation had generally the least amount of friction.⁴⁰ This could be operator error in how tight the ligature wire was ligated. Friction could actually be increased or decreased depending on how tight the ligature was tied to the bracket.

As previously stated, the ligation component in the BLS was not as relevant as the wire size. The wire size seemed to have the most effect on friction. Although the clinician must also consider the ligation method used and attempt to reduce friction if that is the treatment plan.

CHAPTER V SUMMARY AND CONCLUSIONS

SUMMARY

Objectives: To 1) determine if self ligating brackets have a comparable friction to the conventional metal twin brackets; 2) determine if the type of slot in the ceramic bracket decreases friction; 3) determine if the ligation component that is utilized had an effect on friction; 4) determine what wires produce the greatest and least amount of friction during tooth movement.

The study utilized four different brackets, microArch twin metal (GAC), Clarity ceramic (3M Unitek), Mystique ceramic (GAC), and two self ligating brackets SmartClip (3M Unitek) and Inovation R (GAC). Three wires, 018, 19X25, and 21X25 stainless steel were utilized. The ligation component was also important and consisted of three different methods; alastic o-rings, stainless steel, and self ligating. The bracket/wire/ligation combination was then placed in a mechanical testing apparatus and subjected to various tipping angles (0, 2.7, 4.9, and 5.4 degrees) to evaluate the friction involved with each bracket system. The bracket, wire, and ligation method were all analyzed to determine any significant differences.

CONCLUSIONS

The smaller the archwire size typically had the lowest amount of friction. This ultimately among all other factors was the most clinically significant. The 018 stainless steel wire had the lowest and the 21X25 wire had the highest friction. The Mystique ceramic bracket on the average had a higher friction than the Clarity bracket. The SmartClip self ligating bracket had lower friction generally when compared to the Inovation R. The alastic method of ligation showed the lowest amount of friction when

compared to the stainless steel, however the self ligating had the lowest friction when compared to the lower wires, and increased with increasing wire size. When looking at the results as a whole the self ligating brackets had a higher friction in the larger archwire sizes however this was most likely due to the Inovation-R being an interactive appliance. This seemed to increase the levels of friction for the self ligating appliances.

RECOMMENDATIONS

Future studies could further investigate the use of new self ligating brackets, such as the Damon 3, ceramic Inovation R, and Time 2. Many self ligation systems claim to be passive, active, or interactive. It can be determined by another in vitro investigation the amount of friction present. Another project could be done in vivo, with the extraction of teeth. It would be beneficial to utilize a split arch technique and use different bracket systems while retracting canines and quantifying how much tooth movement occurred during a specified period of time. There have been very few studies done in vivo on the friction involved with different bracket systems. There are many claims that note that self ligating brackets have less friction, a clinical study would be beneficial to verify these claims.

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APPENDIX B

FRICTION AVERAGES

Clarity	18	alastic	1	static	-0.16121	4.668264	-0.00979
Clarity	18	alastic	1	kinetic/0	-0.30997	107.9585	-0.00762
Clarity	18	alastic	1	2.7 deg	5.956182	104.739	1.998758
Clarity	18	alastic	1	4.9 deg	23.10326	162.8499	4.452811
Clarity	18	alastic	1	5.4 deg	29.37476	175.8349	5.250157
Clarity	18	alastic	1	dyn frict	7.621587	82.8904	2.654491
Clarity	18	alastic	1	appar stiff	7.444855	48.17844	2.522619
Clarity	18	alastic	2	static	0.040079	5.634	0.010525
Clarity	18	alastic	2	kinetic/0	4.21396	101.8952	-0.75919
Clarity	18	alastic	2	2.7 deg	10.92103	184.3128	1.883304
Clarity	18	alastic	2	4.9 deg	16.12367	181.6836	3.750265
Clarity	18	alastic	2	5.4 deg	20.98693	194.454	4.595526
Clarity	18	alastic	2	dyn frict	6.352513	118.959	1.956469
Clarity	18	alastic	2	appar stiff	5.624954	85.45112	1.886646
Clarity	18	alastic	3	static	-0.06948	4.024286	-0.06173
Clarity	18	alastic	3	kinetic/0	-0.0187	63.90586	0.026141
Clarity	18	alastic	3	2.7 deg	2.428967	75.28117	2.345131
Clarity	18	alastic	3	4.9 deg	14.31728	120.9972	4.443021
Clarity	18	alastic	3	5.4 deg	17.66547	141.6016	5.371062
Clarity	18	alastic	3	dyn frict	1.465376	63.12824	2.745503
Clarity	18	alastic	3	appar stiff	0.788651	31.87086	2.726888
Clarity	18	alastic	4	static	-0.08106	6.3852	0.015966
Clarity	18	alastic	4	kinetic/0	0.382103	200.8928	-0.02723
Clarity	18	alastic	4	2.7 deg	-1.81438	167.6253	1.99004
Clarity	18	alastic	4	4.9 deg	4.630804	177.1763	4.544302
Clarity	18	alastic	4	5.4 deg	16.11563	190.376	5.209857
Clarity	18	alastic	4	dyn frict	-0.59072	135.8891	2.664976
Clarity	18	alastic	4	appar stiff	-0.21806	95.001	2.661914
Clarity	18	alastic	5	static	-0.06947	4.99021	0.034493
Clarity	18	alastic	5	kinetic/0	0.836386	97.11972	-0.0109
Clarity	18	alastic	5	2.7 deg	11.56232	135.6457	2.16323
Clarity	18	alastic	5	4.9 deg	29.01134	207.2245	4.522527
Clarity	18	alastic	5	5.4 deg	38.60698	214.4682	5.327496
Clarity	18	alastic	5	dyn frict	13.92534	102.5007	2.759718
Clarity	18	alastic	5	appar stiff	14.09492	60.77994	2.767916
Clarity	18	ss	1	static	0.00892	5.741314	-0.03451
Clarity	18	ss	1	kinetic/0	-1.90523	56.17923	-0.01526
Clarity	18	ss	1	2.7 deg	4.048287	50.11597	2.704574
Clarity	18	ss	1	4.9 deg	8.427908	53.12077	4.64342

Clarity	18	ss	1	5.4 deg	18.64614	66.96431	5.478881
Clarity	18	ss	1	dyn frict	0.969289	41.57295	2.512919
Clarity	18	ss	1	appar stiff	0.334043	25.61103	2.449181
Clarity	18	ss	2	static	0.174588	4.990114	-0.00944
Clarity	18	ss	2	kinetic/0	-0.00802	5.2584	0.014164
Clarity	18	ss	2	2.7 deg	5.726369	9.980229	2.467133
Clarity	18	ss	2	4.9 deg	11.19356	29.2969	4.411431
Clarity	18	ss	2	5.4 deg	16.35879	38.36496	5.310065
Clarity	18	ss	2	dyn frict	2.834171	11.52482	2.711144
Clarity	18	ss	2	appar stiff	2.702978	5.183493	2.745392
Clarity	18	ss	3	static	-0.01158	-0.05366	-0.05337
Clarity	18	ss	3	kinetic/0	-0.29662	22.91167	-0.06862
Clarity	18	ss	3	2.7 deg	12.70332	80.59323	2.494374
Clarity	18	ss	3	4.9 deg	26.6091	163.0645	4.481152
Clarity	18	ss	3	5.4 deg	34.95684	202.5026	5.217477
Clarity	18	ss	3	dyn frict	11.69607	67.30971	2.62135
Clarity	18	ss	3	appar stiff	11.80911	38.62208	2.589253
Clarity	18	ss	4	static	-0.30284	4.346229	-0.01744
Clarity	18	ss	4	kinetic/0	-1.80101	9.819257	-0.03813
Clarity	18	ss	4	2.7 deg	9.007774	33.4285	2.548829
Clarity	18	ss	4	4.9 deg	11.12945	74.63729	4.555218
Clarity	18	ss	4	5.4 deg	22.83873	89.55397	5.24798
Clarity	18	ss	4	dyn frict	4.430488	20.33076	2.71316
Clarity	18	ss	4	appar stiff	3.885876	-4.40415	2.716048
Clarity	18	ss	5	static	0.038293	2.897486	-0.00146
Clarity	18	ss	5	kinetic/0	0.040079	18.72637	-5.5E-06
Clarity	18	ss	5	2.7 deg	7.687731	20.81903	2.446431
Clarity	18	ss	5	4.9 deg	16.39354	68.94963	4.499663
Clarity	18	ss	5	5.4 deg	21.94355	75.28117	5.286098
Clarity	18	ss	5	dyn frict	4.801169	27.4816	2.682915
Clarity	18	ss	5	appar stiff	4.762739	0.383566	2.630189
Clarity	1925	alastic	1	static	0.06146	1.502431	0.03632
Clarity	1925	alastic	1	kinetic/0	-1.13834	220.1021	0.009808
Clarity	1925	alastic	1	2.7 deg	4.884644	186.4054	2.347326
Clarity	1925	alastic	1	4.9 deg	15.57318	194.1857	4.379851
Clarity	1925	alastic	1	5.4 deg	23.88084	186.6737	5.276301
Clarity	1925	alastic	1	dyn frict	3.294818	202.4751	2.661928
Clarity	1925	alastic	1	appar stiff	3.37529	112.4534	2.638882
Clarity	1925	alastic	2	static	0.044536	0	0.043214
Clarity	1925	alastic	2	kinetic/0	-0.95395	163.7083	-0.01852
Clarity	1925	alastic	2	2.7 deg	7.583516	177.7129	2.213348
Clarity	1925	alastic	2	4.9 deg	25.39863	314.2707	4.303597
Clarity	1925	alastic	2	5.4 deg	35.28552	359.1818	5.164108
Clarity	1925	alastic	2	dyn frict	11.86384	158.0476	2.636138

Clarity	1925	alastic	2	appar stiff	11.37305	59.41559	2.550348
Clarity	1925	alastic	3	static	0.184368	4.1316	-0.01052
Clarity	1925	alastic	3	kinetic/0	-0.52372	148.6307	-0.04357
Clarity	1925	alastic	3	2.7 deg	7.989679	133.7677	2.561905
Clarity	1925	alastic	3	4.9 deg	10.4801	150.0794	4.290525
Clarity	1925	alastic	3	5.4 deg	25.95709	171.3278	5.158653
Clarity	1925	alastic	3	dyn frict	5.789245	113.9585	2.630588
Clarity	1925	alastic	3	appar stiff	6.162355	62.33865	2.585031
Clarity	1925	alastic	4	static	0.142511	7.619314	-0.03449
Clarity	1925	alastic	4	kinetic/0	-0.72414	154.5866	-0.08387
Clarity	1925	alastic	4	2.7 deg	3.043553	143.3186	2.412675
Clarity	1925	alastic	4	4.9 deg	10.89696	127.3824	4.391827
Clarity	1925	alastic	4	5.4 deg	18.23195	115.6851	5.246886
Clarity	1925	alastic	4	dyn frict	0.422834	77.58204	2.691515
Clarity	1925	alastic	4	appar stiff	0.206938	27.77909	2.637899
Clarity	1925	alastic	5	static	-0.11045	5.794971	-0.00508
Clarity	1925	alastic	5	kinetic/0	-0.86043	161.9377	0.023958
Clarity	1925	alastic	5	2.7 deg	11.22563	135.9676	2.484556
Clarity	1925	alastic	5	4.9 deg	19.49053	198.1563	4.517096
Clarity	1925	alastic	5	5.4 deg	20.76247	200.5173	5.28392
Clarity	1925	alastic	5	dyn frict	5.413887	133.0153	2.683589
Clarity	1925	alastic	5	appar stiff	5.351168	66.12918	2.615853
Clarity	1925	ss	1	static	-0.49524	2.307257	0.029418
Clarity	1925	ss	1	kinetic/0	-0.41953	449.3261	0.013066
Clarity	1925	ss	1	2.7 deg	7.412492	301.5002	2.493274
Clarity	1925	ss	1	4.9 deg	20.49259	316.7926	4.465887
Clarity	1925	ss	1	5.4 deg	24.09997	330.6361	5.351451
Clarity	1925	ss	1	dyn frict	4.07269	203.7658	2.716734
Clarity	1925	ss	1	appar stiff	3.596139	111.953	2.648609
Clarity	1925	ss	2	static	0.138048	1.663371	0.011259
Clarity	1925	ss	2	kinetic/0	-3.3081	734.4072	-0.02723
Clarity	1925	ss	2	2.7 deg	5.290813	585.8839	2.541195
Clarity	1925	ss	2	4.9 deg	28.29254	516.2904	4.481133
Clarity	1925	ss	2	5.4 deg	29.67135	486.2423	5.30788
Clarity	1925	ss	2	dyn frict	11.86523	383.1301	2.723237
Clarity	1925	ss	2	appar stiff	11.65848	177.8797	2.68182
Clarity	1925	ss	3	static	-0.09977	0.965829	-0.03849
Clarity	1925	ss	3	kinetic/0	0.109548	469.7695	-4.4E-06
Clarity	1925	ss	3	2.7 deg	5.956168	438.4873	2.423555
Clarity	1925	ss	3	4.9 deg	20.29485	316.3633	4.426677
Clarity	1925	ss	3	5.4 deg	26.67588	331.602	5.340558
Clarity	1925	ss	3	dyn frict	7.039609	208.3518	2.744365
Clarity	1925	ss	3	appar stiff	6.539148	94.8512	2.672077

Clarity	1925	ss	4	static	0.096194	1.073143	-0.06791
Clarity	1925	ss	4	kinetic/0	-0.12558	280.1447	0.016335
Clarity	1925	ss	4	2.7 deg	16.98142	285.7251	2.755768
Clarity	1925	ss	4	4.9 deg	25.92504	365.8354	4.52361
Clarity	1925	ss	4	5.4 deg	23.79268	361.6501	5.283922
Clarity	1925	ss	4	dyn frict	13.82297	197.8675	2.715165
Clarity	1925	ss	4	appar stiff	13.34538	106.7063	2.668042
Clarity	1925	ss	5	static	0.077488	1.395086	-0.03667
Clarity	1925	ss	5	kinetic/0	-0.60659	305.0417	0.051201
Clarity	1925	ss	5	2.7 deg	9.918953	326.3973	2.562992
Clarity	1925	ss	5	4.9 deg	23.30634	472.7207	4.520347
Clarity	1925	ss	5	5.4 deg	31.06621	408.7075	5.337303
Clarity	1925	ss	5	dyn frict	7.307775	201.7119	2.719697
Clarity	1925	ss	5	appar stiff	6.498806	94.21692	2.702597
Clarity	2125	alastic	1	static	0.033855	1.5024	-0.00834
Clarity	2125	alastic	1	kinetic/0	-1.26125	154.5866	-0.04466
Clarity	2125	alastic	1	2.7 deg	8.884842	206.3122	2.717669
Clarity	2125	alastic	1	4.9 deg	29.57517	310.3537	4.39402
Clarity	2125	alastic	1	5.4 deg	37.48201	292.2176	5.178263
Clarity	2125	alastic	1	dyn frict	5.884647	86.13781	2.628546
Clarity	2125	alastic	1	appar stiff	6.053332	11.8965	2.696014
Clarity	2125	alastic	2	static	0.130936	0	0.02651
Clarity	2125	alastic	2	kinetic/0	-0.75621	403.5028	0.013074
Clarity	2125	alastic	2	2.7 deg	48.72634	291.4127	2.384363
Clarity	2125	alastic	2	4.9 deg	59.75956	397.8688	4.609688
Clarity	2125	alastic	2	5.4 deg	68.21954	382.6301	5.215298
Clarity	2125	alastic	2	dyn frict	39.81144	260.1252	2.650237
Clarity	2125	alastic	2	appar stiff	39.78593	157.9905	2.653902
Clarity	2125	alastic	3	static	0.02048	4.131621	-0.02324
Clarity	2125	alastic	3	kinetic/0	0.916535	130.7091	0.034857
Clarity	2125	alastic	3	2.7 deg	15.68007	141.2796	2.571715
Clarity	2125	alastic	3	4.9 deg	38.89556	350.704	4.578104
Clarity	2125	alastic	3	5.4 deg	40.18619	446.7505	5.300256
Clarity	2125	alastic	3	dyn frict	14.07371	112.2094	2.743635
Clarity	2125	alastic	3	appar stiff	14.20952	25.83835	2.696308
Clarity	2125	alastic	4	static	0.042752	4.077943	-0.0777
Clarity	2125	alastic	4	kinetic/0	-1.79834	230.8873	-0.02723
Clarity	2125	alastic	4	2.7 deg	10.0499	259.8622	2.506358
Clarity	2125	alastic	4	4.9 deg	18.29076	293.5054	4.497504
Clarity	2125	alastic	4	5.4 deg	24.40192	278.9106	5.232718
Clarity	2125	alastic	4	dyn frict	1.495874	166.5955	2.67586
Clarity	2125	alastic	4	appar stiff	1.247235	112.3701	2.652647
Clarity	2125	alastic	5	static	0.010678	7.780286	-0.03595
Clarity	2125	alastic	5	kinetic/0	0.379426	227.5069	-0.03158

Clarity	2125	alastic	5	2.7 deg	19.05228	295.8126	2.744903
Clarity	2125	alastic	5	4.9 deg	22.61959	369.4304	4.55414
Clarity	2125	alastic	5	5.4 deg	38.93829	401.5175	5.264304
Clarity	2125	alastic	5	dyn frict	10.66512	198.04	2.735575
Clarity	2125	alastic	5	appar stiff	10.24764	107.2253	2.761325
Clarity	2125	ss	1	static	0.138063	5.151181	0.041399
Clarity	2125	ss	1	kinetic/0	1.589934	271.0766	-0.0196
Clarity	2125	ss	1	2.7 deg	30.95401	246.7699	2.568462
Clarity	2125	ss	1	4.9 deg	33.44443	243.8188	2.643618
Clarity	2125	ss	1	5.4 deg	47.8499	254.6575	4.981119
Clarity	2125	ss	1	dyn frict	26.4487	158.486	2.535709
Clarity	2125	ss	1	appar stiff	24.345	115.0869	2.535134
Clarity	2125	ss	2	static	-0.17726	2.038971	-0.02795
Clarity	2125	ss	2	kinetic/0	2.209842	254.8184	0.006535
Clarity	2125	ss	2	2.7 deg	8.526769	208.8878	2.675203
Clarity	2125	ss	2	4.9 deg	28.72275	302.1441	4.575926
Clarity	2125	ss	2	5.4 deg	35.27749	331.4947	5.227278
Clarity	2125	ss	2	dyn frict	11.37191	159.3092	2.699888
Clarity	2125	ss	2	appar stiff	10.7093	94.66734	2.706689
Clarity	2125	ss	3	static	0.027622	0.7512	-0.02143
Clarity	2125	ss	3	kinetic/0	-0.86312	205.722	0.006535
Clarity	2125	ss	3	2.7 deg	14.84902	226.0581	1.73298
Clarity	2125	ss	3	4.9 deg	39.98043	390.5713	3.907119
Clarity	2125	ss	3	5.4 deg	57.03933	454.3162	4.566096
Clarity	2125	ss	3	dyn frict	16.8232	147.6485	2.075118
Clarity	2125	ss	3	appar stiff	16.13398	42.42429	2.044595
Clarity	2125	ss	4	static	0.098879	1.23414	-0.03267
Clarity	2125	ss	4	kinetic/0	0.037415	166.2303	-0.00435
Clarity	2125	ss	4	2.7 deg	18.25067	249.3454	2.407236
Clarity	2125	ss	4	4.9 deg	27.02862	260.5597	4.193602
Clarity	2125	ss	4	5.4 deg	34.77781	284.1153	5.161924
Clarity	2125	ss	4	dyn frict	6.267838	101.8055	2.615633
Clarity	2125	ss	4	appar stiff	6.044526	30.24092	2.652014
Clarity	2125	ss	5	static	0.147854	3.863314	0.033037
Clarity	2125	ss	5	kinetic/0	1.902568	254.8184	0.015248
Clarity	2125	ss	5	2.7 deg	14.75285	429.5265	2.55863
Clarity	2125	ss	5	4.9 deg	28.01731	462.6331	4.450643
Clarity	2125	ss	5	5.4 deg	35.04503	419.9219	5.28064
Clarity	2125	ss	5	dyn frict	3.26095	161.3765	2.795252
Clarity	2125	ss	5	appar stiff	1.924421	25.28001	2.772021
Metal	18	alastic	1	static	0.099767	4.936457	-0.01125
Metal	18	alastic	1	kinetic/0	-0.34472	55.5889	0.003267
Metal	18	alastic	1	2.7 deg	17.59865	108.1194	2.853811
Metal	18	alastic	1	4.9 deg	26.54496	169.7179	4.829685

Metal	18	alastic	1	5.4 deg	37.5969	187.2639	5.813271
Metal	18	alastic	1	dyn frict	11.49372	57.96721	2.936025
Metal	18	alastic	1	appar stiff	11.30192	-6.56958	3.003407
Metal	18	alastic	2	static	-0.16122	8.263201	0.023611
Metal	18	alastic	2	kinetic/0	-0.43288	66.91056	0.009805
Metal	18	alastic	2	2.7 deg	22.88681	172.1325	2.84621
Metal	18	alastic	2	4.9 deg	39.05321	244.3016	4.940805
Metal	18	alastic	2	5.4 deg	44.40284	277.0325	5.871023
Metal	18	alastic	2	dyn frict	18.54099	138.6416	3.082203
Metal	18	alastic	2	appar stiff	18.39927	39.44551	3.152538
Metal	18	alastic	3	static	0.11	2.63	0.05
Metal	18	alastic	3	kinetic/0	0.22	117.56	-0.01
Metal	18	alastic	3	2.7 deg	14.19	193.33	2.56
Metal	18	alastic	3	4.9 deg	31.51	278.21	4.81
Metal	18	alastic	3	5.4 deg	38.74	300.70	5.74
Metal	18	alastic	3	dyn frict	12.28	148.31	2.90
Metal	18	alastic	3	appar stiff	12.14	84.33	2.96
Metal	18	alastic	4	static	0.071256	5.043771	-0.02432
Metal	18	alastic	4	kinetic/0	-0.11758	62.61808	-0.0098
Metal	18	alastic	4	2.7 deg	3.762352	60.0962	2.760155
Metal	18	alastic	4	4.9 deg	10.91566	72.06174	4.823152
Metal	18	alastic	4	5.4 deg	17.70019	81.77369	5.753369
Metal	18	alastic	4	dyn frict	3.380321	50.44665	2.932398
Metal	18	alastic	4	appar stiff	2.503463	3.545105	2.989632
Metal	18	alastic	5	static	0.350953	4.346229	0.027973
Metal	18	alastic	5	kinetic/0	0.342044	76.40797	0.004358
Metal	18	alastic	5	2.7 deg	19.04429	100.3392	2.740546
Metal	18	alastic	5	4.9 deg	37.2816	190.376	4.940795
Metal	18	alastic	5	5.4 deg	43.79626	194.3467	5.81656
Metal	18	alastic	5	dyn frict	18.73136	82.27694	3.00709
Metal	18	alastic	5	appar stiff	18.60488	7.101914	3.061414
Metal	18	ss	1	static	0.03921	-0.59023	0.030136
Metal	18	ss	1	kinetic/0	0.136287	-0.3756	0.007625
Metal	18	ss	1	2.7 deg	13.4034	68.57403	2.780832
Metal	18	ss	1	4.9 deg	27.06335	152.2794	4.672838
Metal	18	ss	1	5.4 deg	29.05676	179.6446	5.609602
Metal	18	ss	1	dyn frict	9.254528	51.27446	2.683711
Metal	18	ss	1	appar stiff	8.955648	15.31516	2.545122
Metal	18	ss	2	static	-0.06947	3.595029	0.007993
Metal	18	ss	2	kinetic/0	-0.10422	46.41353	0.018524
Metal	18	ss	2	2.7 deg	13.66797	106.0268	2.62833
Metal	18	ss	2	4.9 deg	17.06158	136.8261	4.693529
Metal	18	ss	2	5.4 deg	26.97785	154.372	5.543146
Metal	18	ss	2	dyn frict	7.420742	52.18025	2.787176

Metal	18	ss	2	appar stiff	7.446593	28.10579	2.715422
Metal	18	ss	3	static	-0.07393	1.448743	0.000367
Metal	18	ss	3	kinetic/0	0.053438	0.965829	0.049011
Metal	18	ss	3	2.7 deg	10.35985	2.414571	2.488902
Metal	18	ss	3	4.9 deg	14.05274	43.73067	4.520332
Metal	18	ss	3	5.4 deg	21.82063	79.09083	5.375398
Metal	18	ss	3	dyn frict	5.585552	17.6762	2.702828
Metal	18	ss	3	appar stiff	5.578113	8.216994	2.74789
Metal	18	ss	4	static	0.128252	5.473042	-0.06609
Metal	18	ss	4	kinetic/0	0.146963	12.77041	0.009804
Metal	18	ss	4	2.7 deg	8.109914	-8.69254	2.405044
Metal	18	ss	4	4.9 deg	12.77814	22.16041	4.600937
Metal	18	ss	4	5.4 deg	18.08499	27.52613	5.421155
Metal	18	ss	4	dyn frict	5.003468	2.436436	2.75883
Metal	18	ss	4	appar stiff	5.243643	-25.2259	2.853757
Metal	18	ss	5	static	-0.05523	4.775486	-0.00508
Metal	18	ss	5	kinetic/0	0.061459	1.180457	0.005446
Metal	18	ss	5	2.7 deg	9.814747	31.1749	2.75032
Metal	18	ss	5	4.9 deg	11.43407	60.1498	4.590055
Metal	18	ss	5	5.4 deg	22.35239	70.18374	5.463637
Metal	18	ss	5	dyn frict	5.557775	17.06754	2.791159
Metal	18	ss	5	appar stiff	4.756935	8.449686	2.854615
Metal	1925	alastic	1	static	0.187053	0.3756	-0.00508
Metal	1925	alastic	1	kinetic/0	-2.25795	159.845	0.005446
Metal	1925	alastic	1	2.7 deg	7.391109	108.817	2.75032
Metal	1925	alastic	1	4.9 deg	12.09139	126.0946	4.590055
Metal	1925	alastic	1	5.4 deg	22.05845	150.0258	5.463637
Metal	1925	alastic	1	dyn frict	5.719507	44.36949	2.791159
Metal	1925	alastic	1	appar stiff	5.494007	2.841166	2.854615
Metal	1925	alastic	2	static	0.109568	2.6292	-0.00508
Metal	1925	alastic	2	kinetic/0	0.09353	1.609714	0.005446
Metal	1925	alastic	2	2.7 deg	16.03011	-119.602	2.75032
Metal	1925	alastic	2	4.9 deg	22.01034	-101.573	4.590055
Metal	1925	alastic	2	5.4 deg	27.98256	-103.666	5.463637
Metal	1925	alastic	2	dyn frict	13.76596	-66.7019	2.791159
Metal	1925	alastic	2	appar stiff	13.50489	-65.6335	2.854615
Metal	1925	alastic	3	static	-0.11936	5.2584	-0.00508
Metal	1925	alastic	3	kinetic/0	-2.21253	180.4495	0.005446
Metal	1925	alastic	3	2.7 deg	5.379015	104.2561	2.75032
Metal	1925	alastic	3	4.9 deg	15.10824	80.64689	4.590055
Metal	1925	alastic	3	5.4 deg	22.72916	75.17386	5.463637
Metal	1925	alastic	3	dyn frict	6.700136	53.11484	2.791159
Metal	1925	alastic	3	appar stiff	6.904316	-7.98804	2.854615

Metal	1925	alastic	4	static	0.034741	1.770722	-0.00508
Metal	1925	alastic	4	kinetic/0	-0.88181	117.0802	0.005446
Metal	1925	alastic	4	2.7 deg	10.52019	85.58338	2.75032
Metal	1925	alastic	4	4.9 deg	24.9203	220.746	4.590055
Metal	1925	alastic	4	5.4 deg	35.67831	264.5304	5.463637
Metal	1925	alastic	4	dyn frict	10.39694	103.5081	2.791159
Metal	1925	alastic	4	appar stiff	10.63731	14.87209	2.854615
Metal	1925	alastic	5	static	-0.02673	3.541371	-0.00508
Metal	1925	alastic	5	kinetic/0	-0.46763	163.1182	0.005446
Metal	1925	alastic	5	2.7 deg	15.29526	285.8324	2.75032
Metal	1925	alastic	5	4.9 deg	33.46845	389.2299	4.590055
Metal	1925	alastic	5	5.4 deg	45.26857	416.4342	5.463637
Metal	1925	alastic	5	dyn frict	10.68424	207.1863	2.791159
Metal	1925	alastic	5	appar stiff	10.65666	102.1646	2.854615
Metal	1925	ss	1	static	0.061467	7.726646	-0.01889
Metal	1925	ss	1	kinetic/0	0.323314	60.52537	-0.01198
Metal	1925	ss	1	2.7 deg	39.48609	296.4564	2.894119
Metal	1925	ss	1	4.9 deg	63.69562	489.0324	4.797012
Metal	1925	ss	1	5.4 deg	68.94101	533.0314	5.70328
Metal	1925	ss	1	dyn frict	28.39758	151.7332	2.787226
Metal	1925	ss	1	appar stiff	28.11302	5.261046	2.796001
Metal	1925	ss	2	static	0.032067	2.360914	-0.01997
Metal	1925	ss	2	kinetic/0	0.072141	21.8922	0.018519
Metal	1925	ss	2	2.7 deg	15.85108	9.443704	2.906095
Metal	1925	ss	2	4.9 deg	19.27409	102.7537	4.691356
Metal	1925	ss	2	5.4 deg	32.46371	177.2837	5.632469
Metal	1925	ss	2	dyn frict	9.8191	31.02621	2.851449
Metal	1925	ss	2	appar stiff	10.10289	-0.15298	2.885059
Metal	1925	ss	3	static	-0.09175	7.780286	0.002178
Metal	1925	ss	3	kinetic/0	-6.6E-06	40.02833	0.015244
Metal	1925	ss	3	2.7 deg	15.22046	31.38952	2.95619
Metal	1925	ss	3	4.9 deg	21.31291	118.0997	4.742545
Metal	1925	ss	3	5.4 deg	26.76139	140.3674	5.709801
Metal	1925	ss	3	dyn frict	9.075541	42.81022	2.899723
Metal	1925	ss	3	appar stiff	8.994615	27.11816	2.998802
Metal	1925	ss	4	static	0.034736	18.35081	0.050117
Metal	1925	ss	4	kinetic/0	0.018708	55.15971	0.033773
Metal	1925	ss	4	2.7 deg	28.53304	228.7946	3.155518
Metal	1925	ss	4	4.9 deg	56.04264	398.5663	4.983273
Metal	1925	ss	4	5.4 deg	69.63846	486.135	5.902596
Metal	1925	ss	4	dyn frict	23.4478	136.7529	3.210276
Metal	1925	ss	4	appar stiff	21.77884	53.40069	3.211744
Metal	1925	ss	5	static	-0.09263	5.312057	-0.02868
Metal	1925	ss	5	kinetic/0	-0.05612	5.204743	-0.0109

Metal	1925	ss	5	2.7 deg	15.21512	69.59351	2.728545
Metal	1925	ss	5	4.9 deg	27.01526	188.6054	4.740366
Metal	1925	ss	5	5.4 deg	39.34714	250.2039	5.482157
Metal	1925	ss	5	dyn frict	10.92182	53.41142	2.851465
Metal	1925	ss	5	appar stiff	10.58125	11.88695	2.759977
Metal	2125	alastic	1	static	0.065908	5.2584	-0.02868
Metal	2125	alastic	1	kinetic/0	-1.5498	194.132	-0.0109
Metal	2125	alastic	1	2.7 deg	9.413936	119.4411	2.728545
Metal	2125	alastic	1	4.9 deg	22.53411	118.7436	4.740366
Metal	2125	alastic	1	5.4 deg	33.50857	192.1467	5.482157
Metal	2125	alastic	1	dyn frict	11.73435	105.0281	2.851465
Metal	2125	alastic	1	appar stiff	12.42385	13.91207	2.759977
Metal	2125	alastic	2	static	0.026712	3.326743	-0.02868
Metal	2125	alastic	2	kinetic/0	-4.34221	348.2894	-0.0109
Metal	2125	alastic	2	2.7 deg	15.6694	200.1954	2.728545
Metal	2125	alastic	2	4.9 deg	28.48495	274.2961	4.740366
Metal	2125	alastic	2	5.4 deg	37.63166	315.6122	5.482157
Metal	2125	alastic	2	dyn frict	12.71205	172.9863	2.851465
Metal	2125	alastic	2	appar stiff	14.4226	102.2884	2.759977
Metal	2125	alastic	3	static	-0.17902	0.536571	-0.02868
Metal	2125	alastic	3	kinetic/0	-3.65545	289.6957	-0.0109
Metal	2125	alastic	3	2.7 deg	14.78762	153.2989	2.728545
Metal	2125	alastic	3	4.9 deg	38.67914	335.0361	4.740366
Metal	2125	alastic	3	5.4 deg	48.9909	372.5425	5.482157
Metal	2125	alastic	3	dyn frict	18.24667	125.4978	2.851465
Metal	2125	alastic	3	appar stiff	19.36182	39.45408	2.759977
Metal	2125	alastic	4	static	0.032066	4.1316	0.036309
Metal	2125	alastic	4	kinetic/0	-0.75889	186.1907	0.027226
Metal	2125	alastic	4	2.7 deg	11.66384	79.89568	2.576059
Metal	2125	alastic	4	4.9 deg	23.34107	81.66637	4.876522
Metal	2125	alastic	4	5.4 deg	37.96031	114.3437	5.745754
Metal	2125	alastic	4	dyn frict	11.72053	57.67247	2.902362
Metal	2125	alastic	4	appar stiff	11.17049	-26.3739	2.850025
Metal	2125	alastic	5	static	0.014252	4.185255	0.011623
Metal	2125	alastic	5	kinetic/0	-2.68285	329.5094	0.02723
Metal	2125	alastic	5	2.7 deg	10.41059	223.3216	2.916987
Metal	2125	alastic	5	4.9 deg	18.53924	186.1908	4.961478
Metal	2125	alastic	5	5.4 deg	29.82899	234.7506	5.766447
Metal	2125	alastic	5	dyn frict	8.563167	207.7087	2.956786
Metal	2125	alastic	5	appar stiff	9.04615	130.9934	2.925613
Metal	2125	ss	1	static	-0.2102	18.88739	0.029414
Metal	2125	ss	1	kinetic/0	-0.42218	125.3971	0.030496
Metal	2125	ss	1	2.7 deg	28.19635	184.903	2.605466
Metal	2125	ss	1	4.9 deg	53.00442	353.8161	4.541045

Metal	2125	ss	1	5.4 deg	61.53654	395.7761	5.396108
Metal	2125	ss	1	dyn frict	24.08684	99.49022	2.755698
Metal	2125	ss	1	appar stiff	23.78439	16.66352	2.800733
Metal	2125	ss	2	static	-0.11223	6.116908	0.039203
Metal	2125	ss	2	kinetic/0	-0.68673	115.8997	-0.00327
Metal	2125	ss	2	2.7 deg	18.79579	84.2956	2.419195
Metal	2125	ss	2	4.9 deg	29.60191	156.7329	4.319918
Metal	2125	ss	2	5.4 deg	40.11941	204.1123	5.202221
Metal	2125	ss	2	dyn frict	12.21553	56.8156	2.537663
Metal	2125	ss	2	appar stiff	11.95038	1.669246	2.494521
Metal	2125	ss	3	static	-4.08571	7.941357	0.012712
Metal	2125	ss	3	kinetic/0	-3.94675	232.819	-0.0207
Metal	2125	ss	3	2.7 deg	49.56538	415.0927	2.621795
Metal	2125	ss	3	4.9 deg	66.78728	535.9826	4.295978
Metal	2125	ss	3	5.4 deg	77.90335	605.6298	5.292635
Metal	2125	ss	3	dyn frict	28.77274	250.0657	2.59436
Metal	2125	ss	3	appar stiff	27.54661	124.307	2.623174
Metal	2125	ss	4	static	0.105096	4.775486	0.001818
Metal	2125	ss	4	kinetic/0	-0.24852	-0.3756	0.023967
Metal	2125	ss	4	2.7 deg	51.77255	44.26725	2.728551
Metal	2125	ss	4	4.9 deg	75.68547	565.3331	4.724032
Metal	2125	ss	4	5.4 deg	76.91198	631.3852	5.6292
Metal	2125	ss	4	dyn frict	29.71909	260.9166	2.735295
Metal	2125	ss	4	appar stiff	25.45997	-155.632	2.788658
Metal	2125	ss	5	static	0.011584	5.258409	0.033033
Metal	2125	ss	5	kinetic/0	0.227122	106.5633	-0.02396
Metal	2125	ss	5	2.7 deg	39.98845	434.5166	2.504171
Metal	2125	ss	5	4.9 deg	71.32187	789.6742	4.655413
Metal	2125	ss	5	5.4 deg	81.8955	873.0576	5.436419
Metal	2125	ss	5	dyn frict	28.25592	204.3362	2.79336
Metal	2125	ss	5	appar stiff	27.71312	-28.8246	2.820393
Mystique	18	alastic	1	static	0.048981	9.604631	-0.03086
Mystique	18	alastic	1	kinetic/0	-0.38213	38.20396	-0.01525
Mystique	18	alastic	1	2.7 deg	18.14111	111.8753	2.712231
Mystique	18	alastic	1	4.9 deg	32.61873	195.5271	4.582456
Mystique	18	alastic	1	5.4 deg	39.83081	221.2826	5.574765
Mystique	18	alastic	1	dyn frict	16.05478	96.79075	2.665712
Mystique	18	alastic	1	appar stiff	14.80542	18.88678	2.54625
Mystique	18	alastic	2	static	0.041855	2.307257	0.0639
Mystique	18	alastic	2	kinetic/0	-1.85714	184.2055	0.016336
Mystique	18	alastic	2	2.7 deg	2.420946	129.6361	2.569542
Mystique	18	alastic	2	4.9 deg	10.46675	105.061	4.539984
Mystique	18	alastic	2	5.4 deg	15.78429	95.24173	5.433146
Mystique	18	alastic	2	dyn frict	1.767686	99.89068	2.805624

Mystique	18	alastic	2	appar stiff	1.979496	49.92681	2.705923
Mystique	18	alastic	3	static	0.055225	4.560951	-0.0127
Mystique	18	alastic	3	kinetic/0	-2.98211	45.71608	-0.04031
Mystique	18	alastic	3	2.7 deg	3.254649	29.13592	1.972625
Mystique	18	alastic	3	4.9 deg	10.45337	23.71655	4.070508
Mystique	18	alastic	3	5.4 deg	16.68747	33.69678	5.111818
Mystique	18	alastic	3	dyn frict	4.915904	4.901002	2.456304
Mystique	18	alastic	3	appar stiff	5.26129	-16.324	2.377748
Mystique	18	alastic	4	static	-0.05343	23.6629	0.014156
Mystique	18	alastic	4	kinetic/0	0.8631	82.5249	-0.03813
Mystique	18	alastic	4	2.7 deg	3.219922	66.21311	2.278719
Mystique	18	alastic	4	4.9 deg	6.79524	59.93523	4.426708
Mystique	18	alastic	4	5.4 deg	6.218049	56.5548	5.228386
Mystique	18	alastic	4	dyn frict	-1.10819	26.72374	2.628241
Mystique	18	alastic	4	appar stiff	-0.63779	-3.8936	2.693112
Mystique	18	alastic	5	static	-0.09798	6.063282	0.053005
Mystique	18	alastic	5	kinetic/0	-1.94532	84.13463	0.031581
Mystique	18	alastic	5	2.7 deg	9.119986	75.92508	2.399616
Mystique	18	alastic	5	4.9 deg	15.70677	100.9293	4.394019
Mystique	18	alastic	5	5.4 deg	26.06396	134.948	5.245799
Mystique	18	alastic	5	dyn frict	3.880945	52.19492	2.636648
Mystique	18	alastic	5	appar stiff	3.831958	10.7527	2.572217
Mystique	18	ss	1	static	-0.2592	3.863314	0.052636
Mystique	18	ss	1	kinetic/0	-2.05755	124.2703	0.034852
Mystique	18	ss	1	2.7 deg	1.905227	105.1683	2.290693
Mystique	18	ss	1	4.9 deg	4.702943	69.75449	4.341735
Mystique	18	ss	1	5.4 deg	7.933541	84.1347	5.220747
Mystique	18	ss	1	dyn frict	-3.87643	67.33993	2.591974
Mystique	18	ss	1	appar stiff	-3.32885	13.48395	2.699392
Mystique	18	ss	2	static	0.187056	21.24833	0.00945
Mystique	18	ss	2	kinetic/0	-2.31139	17.49233	-0.02287
Mystique	18	ss	2	2.7 deg	11.14014	3.541371	2.354956
Mystique	18	ss	2	4.9 deg	21.92217	40.61856	4.240437
Mystique	18	ss	2	5.4 deg	31.85717	66.32043	5.233815
Mystique	18	ss	2	dyn frict	9.273652	1.49842	2.655501
Mystique	18	ss	2	appar stiff	9.463408	-53.4442	2.71722
Mystique	18	ss	3	static	-0.13183	-0.48291	0.010525
Mystique	18	ss	3	kinetic/0	-1.88653	28.9213	-0.00762
Mystique	18	ss	3	2.7 deg	13.53969	54.03294	2.375648
Mystique	18	ss	3	4.9 deg	21.00029	127.1141	4.367875
Mystique	18	ss	3	5.4 deg	28.82162	139.5626	5.224012
Mystique	18	ss	3	dyn frict	8.115873	-0.50717	2.670251
Mystique	18	ss	3	appar stiff	8.443461	-40.609	2.612738

Mystique	18	ss	4	static	-0.0472	1.234114	0.067895
Mystique	18	ss	4	kinetic/0	0.077491	59.23767	-0.01416
Mystique	18	ss	4	2.7 deg	8.302319	106.2414	2.44971
Mystique	18	ss	4	4.9 deg	24.71991	133.9286	4.482241
Mystique	18	ss	4	5.4 deg	30.77763	166.4449	5.28501
Mystique	18	ss	4	dyn frict	9.370866	57.17997	2.721348
Mystique	18	ss	4	appar stiff	9.713864	26.8568	2.753749
Mystique	18	ss	5	static	-0.26186	-2.03902	-0.05553
Mystique	18	ss	5	kinetic/0	-1.10091	47.6477	-0.0294
Mystique	18	ss	5	2.7 deg	9.967068	117.0802	2.178512
Mystique	18	ss	5	4.9 deg	26.56101	173.6886	4.316689
Mystique	18	ss	5	5.4 deg	29.94125	200.41	5.084595
Mystique	18	ss	5	dyn frict	8.476321	77.05774	2.531056
Mystique	18	ss	5	appar stiff	7.803482	15.80022	2.505211
Mystique	1925	alastic	1	static	0.043629	5.526715	0.001816
Mystique	1925	alastic	1	kinetic/0	-0.61727	176.7471	-0.03485
Mystique	1925	alastic	1	2.7 deg	16.60463	293.8809	2.470404
Mystique	1925	alastic	1	4.9 deg	49.91543	486.9935	4.575907
Mystique	1925	alastic	1	5.4 deg	58.59987	524.5536	5.318782
Mystique	1925	alastic	1	dyn frict	23.43301	214.6374	2.70838
Mystique	1925	alastic	1	appar stiff	23.05939	65.61912	2.689393
Mystique	1925	alastic	2	static	0.03295	-0.96583	0.005087
Mystique	1925	alastic	2	kinetic/0	-2.33012	281.5397	-0.01199
Mystique	1925	alastic	2	2.7 deg	10.27166	221.8728	2.358204
Mystique	1925	alastic	2	4.9 deg	30.12828	364.0646	4.462626
Mystique	1925	alastic	2	5.4 deg	41.08402	403.0735	5.278475
Mystique	1925	alastic	2	dyn frict	12.15192	215.9185	2.686986
Mystique	1925	alastic	2	appar stiff	12.30785	132.7072	2.730935
Mystique	1925	alastic	3	static	0.08996	-0.16098	-0.05592
Mystique	1925	alastic	3	kinetic/0	-1.27729	125.9874	-0.01742
Mystique	1925	alastic	3	2.7 deg	7.751855	191.2883	2.386533
Mystique	1925	alastic	3	4.9 deg	32.1805	262.1695	4.238245
Mystique	1925	alastic	3	5.4 deg	48.29078	346.1432	5.12163
Mystique	1925	alastic	3	dyn frict	14.33571	133.7642	2.509397
Mystique	1925	alastic	3	appar stiff	13.3263	35.56579	2.441414
Mystique	1925	alastic	4	static	0.099759	2.682857	0.008706
Mystique	1925	alastic	4	kinetic/0	-1.39754	182.6494	-5.5E-06
Mystique	1925	alastic	4	2.7 deg	2.447668	160.9183	2.405041
Mystique	1925	alastic	4	4.9 deg	14.63259	134.2506	4.459357
Mystique	1925	alastic	4	5.4 deg	18.97215	136.7188	5.323134
Mystique	1925	alastic	4	dyn frict	5.822495	117.1982	2.707802
Mystique	1925	alastic	4	appar stiff	5.365555	40.5368	2.654136
Mystique	1925	alastic	5	static	-0.06235	14.38012	0.027238
Mystique	1925	alastic	5	kinetic/0	-5.85999	60.90096	0.016332

Mystique	1925	alastic	5	2.7 deg	-0.49168	32.67721	2.368007
Mystique	1925	alastic	5	4.9 deg	16.58859	63.63747	4.571553
Mystique	1925	alastic	5	5.4 deg	27.83025	120.0313	5.415727
Mystique	1925	alastic	5	dyn frict	4.522333	20.35609	2.809109
Mystique	1925	alastic	5	appar stiff	5.350081	-44.262	2.823513
Mystique	1925	ss	1	static	-0.26454	52.10119	0.040673
Mystique	1925	ss	1	kinetic/0	-3.24129	702.8567	-0.0196
Mystique	1925	ss	1	2.7 deg	17.91132	651.8823	2.433369
Mystique	1925	ss	1	4.9 deg	25.65783	688.3693	4.328653
Mystique	1925	ss	1	5.4 deg	38.78068	685.4718	5.121625
Mystique	1925	ss	1	dyn frict	10.77377	496.753	2.556028
Mystique	1925	ss	1	appar stiff	10.29402	319.544	2.488031
Mystique	1925	ss	2	static	-0.18527	1.341429	0.021416
Mystique	1925	ss	2	kinetic/0	-0.38746	74.63726	-0.01198
Mystique	1925	ss	2	2.7 deg	17.31808	23.23359	2.855986
Mystique	1925	ss	2	4.9 deg	24.62904	19.26291	4.698982
Mystique	1925	ss	2	5.4 deg	29.07816	71.4715	5.530081
Mystique	1925	ss	2	dyn frict	11.37099	-60.3375	2.974618
Mystique	1925	ss	2	appar stiff	10.84986	-138.955	2.996825
Mystique	1925	ss	3	static	-0.08016	3.273086	0.023606
Mystique	1925	ss	3	kinetic/0	-1.34406	278.9642	0.002178
Mystique	1925	ss	3	2.7 deg	33.80784	573.2744	2.497627
Mystique	1925	ss	3	4.9 deg	55.30782	779.4793	4.482232
Mystique	1925	ss	3	5.4 deg	76.5566	854.8678	5.266491
Mystique	1925	ss	3	dyn frict	25.80585	274.4514	2.723112
Mystique	1925	ss	3	appar stiff	25.58174	66.94302	2.744958
Mystique	1925	ss	4	static	0.187934	121.8557	-0.03884
Mystique	1925	ss	4	kinetic/0	-1.8598	301.2856	0.010895
Mystique	1925	ss	4	2.7 deg	26.51824	242.2626	2.490005
Mystique	1925	ss	4	4.9 deg	29.95728	266.1938	4.361327
Mystique	1925	ss	4	5.4 deg	38.87152	273.8668	5.165197
Mystique	1925	ss	4	dyn frict	17.43651	76.40425	2.577748
Mystique	1925	ss	4	appar stiff	17.72167	-65.8183	2.573956
Mystique	1925	ss	5	static	0.007126	0.053663	0.015982
Mystique	1925	ss	5	kinetic/0	-0.68674	51.02805	0.005438
Mystique	1925	ss	5	2.7 deg	15.27391	115.8997	2.384351
Mystique	1925	ss	5	4.9 deg	44.91588	330.6361	4.361322
Mystique	1925	ss	5	5.4 deg	61.36552	430.2777	5.155382
Mystique	1925	ss	5	dyn frict	16.68607	56.94688	2.591356
Mystique	1925	ss	5	appar stiff	16.02076	-109.302	2.560262
Mystique	2125	alastic	1	static	0.130935	5.687657	-0.03377
Mystique	2125	alastic	1	kinetic/0	-0.06681	259.5403	-0.01199
Mystique	2125	alastic	1	2.7 deg	50.63423	538.7191	2.578237
Mystique	2125	alastic	1	4.9 deg	59.50838	688.6912	4.360235

Mystique	2125	alastic	1	5.4 deg	69.7667	719.1685	5.288278
Mystique	2125	alastic	1	dyn frict	41.90624	407.876	2.691891
Mystique	2125	alastic	1	appar stiff	39.56959	218.791	2.65947
Mystique	2125	alastic	2	static	0.048981	1.395086	0.009428
Mystique	2125	alastic	2	kinetic/0	1.918576	277.891	-0.03268
Mystique	2125	alastic	2	2.7 deg	61.40559	573.8109	2.516151
Mystique	2125	alastic	2	4.9 deg	72.97594	731.5633	4.2829
Mystique	2125	alastic	2	5.4 deg	59.56717	711.0663	5.184799
Mystique	2125	alastic	2	dyn frict	43.23748	431.5441	2.605256
Mystique	2125	alastic	2	appar stiff	40.34864	166.057	2.583033
Mystique	2125	alastic	3	static	0.111333	-2.36091	0.037407
Mystique	2125	alastic	3	kinetic/0	0.489003	144.6064	0.026147
Mystique	2125	alastic	3	2.7 deg	37.5408	344.1578	1.824487
Mystique	2125	alastic	3	4.9 deg	84.41534	675.7598	4.421237
Mystique	2125	alastic	3	5.4 deg	98.0753	787.6889	5.243618
Mystique	2125	alastic	3	dyn frict	47.48133	308.3415	2.707258
Mystique	2125	alastic	3	appar stiff	47.53785	98.9212	2.685533
Mystique	2125	alastic	4	static	0.228911	6.385201	-0.00363
Mystique	2125	alastic	4	kinetic/0	-0.32332	117.6704	-0.00872
Mystique	2125	alastic	4	2.7 deg	29.58853	260.3987	2.507438
Mystique	2125	alastic	4	4.9 deg	67.18277	480.2326	4.485509
Mystique	2125	alastic	4	5.4 deg	78.50994	516.022	5.208762
Mystique	2125	alastic	4	dyn frict	30.95227	217.0506	2.690742
Mystique	2125	alastic	4	appar stiff	31.33626	69.52333	2.695302
Mystique	2125	alastic	5	static	0.10064	-1.66336	-0.00036
Mystique	2125	alastic	5	kinetic/0	0.029387	71.84705	-0.01089
Mystique	2125	alastic	5	2.7 deg	19.19659	42.38925	2.103331
Mystique	2125	alastic	5	4.9 deg	38.83676	232.5506	4.367863
Mystique	2125	alastic	5	5.4 deg	51.83402	264.3694	5.280655
Mystique	2125	alastic	5	dyn frict	19.86122	50.51709	2.710851
Mystique	2125	alastic	5	appar stiff	19.70051	-70.0711	2.721423
Mystique	2125	ss	1	static	0.142526	3.595031	0.03594
Mystique	2125	ss	1	kinetic/0	-0.61993	385.1519	0.047924
Mystique	2125	ss	1	2.7 deg	43.32596	608.8491	2.635969
Mystique	2125	ss	1	4.9 deg	76.44705	774.3282	4.367859
Mystique	2125	ss	1	5.4 deg	94.37972	869.0333	5.230547
Mystique	2125	ss	1	dyn frict	33.24204	415.1359	2.751313
Mystique	2125	ss	1	appar stiff	32.66058	131.4667	2.726516
Mystique	2125	ss	2	static	-0.01783	6.653486	-0.01997
Mystique	2125	ss	2	kinetic/0	-0.46763	416.3805	0.014156
Mystique	2125	ss	2	2.7 deg	61.3201	695.1838	2.547741
Mystique	2125	ss	2	4.9 deg	93.55939	874.0771	4.338444
Mystique	2125	ss	2	5.4 deg	111.7192	1012.191	5.203311
Mystique	2125	ss	2	dyn frict	48.81598	530.4749	2.686378

Mystique	2125	ss	2	appar stiff	46.00669	199.1137	2.659893
Mystique	2125	ss	3	static	0.273452	4.936457	0.011256
Mystique	2125	ss	3	kinetic/0	-0.49434	99.85621	0.005449
Mystique	2125	ss	3	2.7 deg	16.85047	70.55934	2.540123
Mystique	2125	ss	3	4.9 deg	26.27241	105.0073	4.390738
Mystique	2125	ss	3	5.4 deg	44.49635	172.1326	5.282835
Mystique	2125	ss	3	dyn frict	13.765	41.32679	2.694219
Mystique	2125	ss	3	appar stiff	13.01819	-32.6757	2.687013
Mystique	2125	ss	4	static	0.145185	0.7512	-0.03522
Mystique	2125	ss	4	kinetic/0	-1.70216	235.4481	0.003265
Mystique	2125	ss	4	2.7 deg	18.80914	201.8587	1.925775
Mystique	2125	ss	4	4.9 deg	45.31936	351.0796	4.30141
Mystique	2125	ss	4	5.4 deg	60.95668	417.9902	5.152115
Mystique	2125	ss	4	dyn frict	19.0368	163.876	2.564042
Mystique	2125	ss	4	appar stiff	18.97727	42.23094	2.562903
Mystique	2125	ss	5	static	-0.14251	0.912191	-0.02434
Mystique	2125	ss	5	kinetic/0	-0.14696	35.68207	-0.01634
Mystique	2125	ss	5	2.7 deg	47.58533	292.6468	2.481293
Mystique	2125	ss	5	4.9 deg	86.60113	533.6753	4.368947
Mystique	2125	ss	5	5.4 deg	100.229	637.8777	5.174999
Mystique	2125	ss	5	dyn frict	37.01475	188.1109	2.630736
Mystique	2125	ss	5	appar stiff	37.56534	-4.88922	2.664371
SmartClip	18	selfligation	1	static	0.061468	4.99012	0.020701
SmartClip	18	selfligation	1	kinetic/0	1.237195	56.93033	0.013079
SmartClip	18	selfligation	1	2.7 deg	14.21041	39.49176	2.497635
SmartClip	18	selfligation	1	4.9 deg	15.88583	45.34039	4.328656
SmartClip	18	selfligation	1	5.4 deg	15.5812	52.53045	5.169558
SmartClip	18	selfligation	1	dyn frict	6.40429	23.16096	2.533524
SmartClip	18	selfligation	1	appar stiff	5.923877	4.699998	2.527319
SmartClip	18	selfligation	2	static	0.073041	3.219492	-0.00944
SmartClip	18	selfligation	2	kinetic/0	0.03741	11.64366	0.037041
SmartClip	18	selfligation	2	2.7 deg	15.44761	91.86129	2.655584
SmartClip	18	selfligation	2	4.9 deg	23.79266	166.123	4.436496
SmartClip	18	selfligation	2	5.4 deg	29.10755	213.2341	5.219664
SmartClip	18	selfligation	2	dyn frict	6.818381	46.53315	2.67621
SmartClip	18	selfligation	2	appar stiff	7.112193	19.94671	2.680903
SmartClip	18	selfligation	3	static	-0.03206	4.077943	0.024325
SmartClip	18	selfligation	3	kinetic/0	-2.17245	2.736514	-0.00545
SmartClip	18	selfligation	3	2.7 deg	6.912802	2.6292	2.356024
SmartClip	18	selfligation	3	4.9 deg	9.729241	8.316857	4.546481
SmartClip	18	selfligation	3	5.4 deg	16.07288	20.33606	5.484342
SmartClip	18	selfligation	3	dyn frict	3.554037	5.316863	2.712006
SmartClip	18	selfligation	3	appar stiff	3.426574	7.945508	2.792469

SmartClip	18	selfligation	4	static	0.126484	0.965829	-0.03594
SmartClip	18	selfligation	4	kinetic/0	-1.31202	1.609714	-0.00871
SmartClip	18	selfligation	4	2.7 deg	5.851964	28.38472	2.532476
SmartClip	18	selfligation	4	4.9 deg	13.16292	65.40826	4.782859
SmartClip	18	selfligation	4	5.4 deg	19.71232	69.70083	5.587807
SmartClip	18	selfligation	4	dyn frict	-0.01265	10.99868	2.835316
SmartClip	18	selfligation	4	appar stiff	0.016528	-0.82291	2.789349
SmartClip	18	selfligation	5	static	-0.11223	3.541371	-0.01089
SmartClip	18	selfligation	5	kinetic/0	-2.26329	11.69736	0.005445
SmartClip	18	selfligation	5	2.7 deg	-1.68344	-9.44366	2.549889
SmartClip	18	selfligation	5	4.9 deg	8.740548	-11.3753	4.717498
SmartClip	18	selfligation	5	5.4 deg	13.02132	-13.5753	5.579091
SmartClip	18	selfligation	5	dyn frict	-1.19549	-9.16361	2.816541
SmartClip	18	selfligation	5	appar stiff	-1.06046	-17.6819	2.908893
SmartClip	1925	selfligation	1	static	-0.08105	6.599829	0.050094
SmartClip	1925	selfligation	1	kinetic/0	-6.72043	410.4246	0.025046
SmartClip	1925	selfligation	1	2.7 deg	10.45335	313.6805	2.364738
SmartClip	1925	selfligation	1	4.9 deg	23.29562	249.9893	4.444075
SmartClip	1925	selfligation	1	5.4 deg	27.81421	242.6382	5.240334
SmartClip	1925	selfligation	1	dyn frict	9.615065	211.3136	2.494512
SmartClip	1925	selfligation	1	appar stiff	10.48906	194.1772	2.572976
SmartClip	1925	selfligation	2	static	-0.01514	4.8828	-0.02469
SmartClip	1925	selfligation	2	kinetic/0	-3.59935	315.6122	-0.0098
SmartClip	1925	selfligation	2	2.7 deg	15.37546	218.7608	2.676241
SmartClip	1925	selfligation	2	4.9 deg	23.19946	145.4649	4.87978
SmartClip	1925	selfligation	2	5.4 deg	32.24197	128.5629	5.693462
SmartClip	1925	selfligation	2	dyn frict	13.00719	147.0674	2.958219
SmartClip	1925	selfligation	2	appar stiff	13.06975	129.4187	2.945045
SmartClip	1925	selfligation	3	static	-0.45427	6.277886	-0.00762
SmartClip	1925	selfligation	3	kinetic/0	-0.60123	132.4262	-0.04684
SmartClip	1925	selfligation	3	2.7 deg	11.27104	51.08173	2.580381
SmartClip	1925	selfligation	3	4.9 deg	18.24532	-20.7653	4.794825
SmartClip	1925	selfligation	3	5.4 deg	28.76551	-40.6722	5.768607
SmartClip	1925	selfligation	3	dyn frict	10.29939	7.492548	2.987542
SmartClip	1925	selfligation	3	appar stiff	11.69912	-53.8145	2.969349
SmartClip	1925	selfligation	4	static	-0.13359	3.970629	-0.0069
SmartClip	1925	selfligation	4	kinetic/0	-0.14964	32.51628	0.002175
SmartClip	1925	selfligation	4	2.7 deg	13.37671	-65.8375	2.713282
SmartClip	1925	selfligation	4	4.9 deg	14.89985	-70.452	4.851462
SmartClip	1925	selfligation	4	5.4 deg	21.93022	-69.3252	5.740293
SmartClip	1925	selfligation	4	dyn frict	8.066758	-58.1941	2.985243
SmartClip	1925	selfligation	4	appar stiff	7.996411	-73.5259	3.020503
SmartClip	1925	selfligation	5	static	-0.05256	4.829143	0.014527
SmartClip	1925	selfligation	5	kinetic/0	-2.30872	203.1465	0.020693

SmartClip	1925	selfligation	5	2.7 deg	17.26733	136.8261	2.707857
SmartClip	1925	selfligation	5	4.9 deg	27.30919	55.05243	4.824234
SmartClip	1925	selfligation	5	5.4 deg	33.41768	40.51124	5.617225
SmartClip	1925	selfligation	5	dyn frict	13.60507	54.96911	2.85211
SmartClip	1925	selfligation	5	appar stiff	13.60361	38.86383	2.875899
SmartClip	2125	selfligation	1	static	0.144297	5.043771	-0.04611
SmartClip	2125	selfligation	1	kinetic/0	-5.05299	920.4906	-0.03376
SmartClip	2125	selfligation	1	2.7 deg	26.44611	600.0494	2.793919
SmartClip	2125	selfligation	1	4.9 deg	49.73908	741.3826	4.507296
SmartClip	2125	selfligation	1	5.4 deg	64.05369	767.9967	5.289374
SmartClip	2125	selfligation	1	dyn frict	20.06458	357.7723	2.745135
SmartClip	2125	selfligation	1	appar stiff	20.02426	143.2129	2.73316
SmartClip	2125	selfligation	2	static	-0.02405	7.8876	0.039933
SmartClip	2125	selfligation	2	kinetic/0	-0.1336	18.45807	0.032677
SmartClip	2125	selfligation	2	2.7 deg	8.307647	12.0192	2.560821
SmartClip	2125	selfligation	2	4.9 deg	25.89563	170.7911	4.604242
SmartClip	2125	selfligation	2	5.4 deg	41.60777	279.769	5.490876
SmartClip	2125	selfligation	2	dyn frict	10.95704	51.22561	2.807655
SmartClip	2125	selfligation	2	appar stiff	11.23612	-4.68202	2.849215
SmartClip	2125	selfligation	3	static	0.105103	5.043771	0.019963
SmartClip	2125	selfligation	3	kinetic/0	-0.66803	79.03719	0.040315
SmartClip	2125	selfligation	3	2.7 deg	15.53578	27.95547	2.909397
SmartClip	2125	selfligation	3	4.9 deg	19.62681	71.14957	4.897265
SmartClip	2125	selfligation	3	5.4 deg	34.3182	154.4257	5.710911
SmartClip	2125	selfligation	3	dyn frict	11.0385	48.91625	3.042017
SmartClip	2125	selfligation	3	appar stiff	11.97314	28.92608	3.04526
SmartClip	2125	selfligation	4	static	-0.06768	1.878	0.042845
SmartClip	2125	selfligation	4	kinetic/0	-0.13895	2.790171	0.011982
SmartClip	2125	selfligation	4	2.7 deg	22.3043	127.0068	2.787379
SmartClip	2125	selfligation	4	4.9 deg	29.98133	246.7162	4.637999
SmartClip	2125	selfligation	4	5.4 deg	43.49165	261.5256	5.546407
SmartClip	2125	selfligation	4	dyn frict	10.86968	26.31638	2.892974
SmartClip	2125	selfligation	4	appar stiff	11.41731	-13.5923	2.952167
SmartClip	2125	selfligation	5	static	-0.0294	4.453633	0.005089
SmartClip	2125	selfligation	5	kinetic/0	-1.47234	279.6082	-0.02723
SmartClip	2125	selfligation	5	2.7 deg	42.29184	700.8714	2.559704
SmartClip	2125	selfligation	5	4.9 deg	47.91935	725.9294	4.730588
SmartClip	2125	selfligation	5	5.4 deg	61.64342	748.3581	5.474508
SmartClip	2125	selfligation	5	dyn frict	12.25359	148.6059	2.842323
SmartClip	2125	selfligation	5	appar stiff	12.24987	46.07836	2.872252
InvR	18	selfligation	1	static	0.132722	0.268286	0.049751
InvR	18	selfligation	1	kinetic/0	-0.07482	-0.3756	-0.00108
InvR	18	selfligation	1	2.7 deg	4.096355	-3.91697	3.055354
InvR	18	selfligation	1	4.9 deg	9.015774	-2.30726	5.245813

InvR	18	selfligation	1	5.4 deg	15.02807	-4.18526	6.317644
InvR	18	selfligation	1	dyn frict	4.930315	-5.82914	3.128506
InvR	18	selfligation	1	appar stiff	4.656749	-4.90458	3.053773
InvR	18	selfligation	2	static	0.220901	-0.05366	-0.00544
InvR	18	selfligation	2	kinetic/0	0.128279	19.85316	0.025048
InvR	18	selfligation	2	2.7 deg	1.138332	21.7312	2.603276
InvR	18	selfligation	2	4.9 deg	9.445997	25.75552	4.835131
InvR	18	selfligation	2	5.4 deg	16.65807	59.29127	5.776247
InvR	18	selfligation	2	dyn frict	2.044546	12.04405	2.991288
InvR	18	selfligation	2	appar stiff	2.044691	-8.22392	2.907056
InvR	18	selfligation	3	static	-0.00356	2.843829	0.008715
InvR	18	selfligation	3	kinetic/0	-0.5478	39.11616	0.031582
InvR	18	selfligation	3	2.7 deg	7.965609	37.34547	2.398516
InvR	18	selfligation	3	4.9 deg	6.185978	39.59907	4.714243
InvR	18	selfligation	3	5.4 deg	13.90843	59.7206	5.683669
InvR	18	selfligation	3	dyn frict	2.203908	14.45569	2.89929
InvR	18	selfligation	3	appar stiff	2.221242	-14.9954	2.905933
InvR	18	selfligation	4	static	-0.1532	4.829143	0.024695
InvR	18	selfligation	4	kinetic/0	-0.06145	18.67269	-0.00218
InvR	18	selfligation	4	2.7 deg	1.068862	23.60922	2.456237
InvR	18	selfligation	4	4.9 deg	12.65523	64.12048	4.734936
InvR	18	selfligation	4	5.4 deg	18.44841	93.73923	5.650999
InvR	18	selfligation	4	dyn frict	3.00621	30.555	2.890042
InvR	18	selfligation	4	appar stiff	3.327688	10.2921	2.835922
InvR	18	selfligation	5	static	0.029394	-0.21464	0.005816
InvR	18	selfligation	5	kinetic/0	-0.30195	88.58824	-0.00436
InvR	18	selfligation	5	2.7 deg	16.99476	197.6735	2.497621
InvR	18	selfligation	5	4.9 deg	30.05614	303.271	4.852574
InvR	18	selfligation	5	5.4 deg	36.69906	321.3535	5.732697
InvR	18	selfligation	5	dyn frict	11.90123	157.4444	2.961414
InvR	18	selfligation	5	appar stiff	12.1649	61.66661	2.913875
InvR	1925	selfligation	1	static	-0.19863	4.614515	0.046114
InvR	1925	selfligation	1	kinetic/0	-0.41953	243.765	0.00763
InvR	1925	selfligation	1	2.7 deg	7.115888	197.9954	2.268903
InvR	1925	selfligation	1	4.9 deg	14.8357	206.9561	4.602065
InvR	1925	selfligation	1	5.4 deg	29.22512	245.9649	5.450599
InvR	1925	selfligation	1	dyn frict	11.16131	144.2969	2.699567
InvR	1925	selfligation	1	appar stiff	11.40332	89.74947	2.744735
InvR	1925	selfligation	2	static	-0.03474	13.36063	0.001445
InvR	1925	selfligation	2	kinetic/0	-0.05611	8.960743	0.004351
InvR	1925	selfligation	2	2.7 deg	9.002423	-21.141	2.488907
InvR	1925	selfligation	2	4.9 deg	12.09676	-24.9507	4.852559
InvR	1925	selfligation	2	5.4 deg	23.48539	9.0144	5.695647
InvR	1925	selfligation	2	dyn frict	6.719257	-43.9456	2.94682

InvR	1925	selfligation	2	appar stiff	6.821338	-70.0823	3.047456
InvR	1925	selfligation	3	static	-0.11135	0.804857	0.01415
InvR	1925	selfligation	3	kinetic/0	-3.67153	428.8826	0.042476
InvR	1925	selfligation	3	2.7 deg	13.51564	376.5131	2.713289
InvR	1925	selfligation	3	4.9 deg	22.94293	471.0036	4.270912
InvR	1925	selfligation	3	5.4 deg	38.46535	615.127	5.09548
InvR	1925	selfligation	3	dyn frict	10.23203	238.0707	2.553823
InvR	1925	selfligation	3	appar stiff	8.919538	79.60665	2.454887
InvR	1925	selfligation	4	static	-0.05521	4.292571	-0.00617
InvR	1925	selfligation	4	kinetic/0	-1.90254	508.6174	0.004357
InvR	1925	selfligation	4	2.7 deg	17.09899	473.2572	2.593467
InvR	1925	selfligation	4	4.9 deg	20.60483	531.9583	4.386366
InvR	1925	selfligation	4	5.4 deg	25.37191	464.8867	5.238174
InvR	1925	selfligation	4	dyn frict	9.137146	307.0027	2.684037
InvR	1925	selfligation	4	appar stiff	8.304308	177.2699	2.616018
InvR	1925	selfligation	5	static	-0.04364	1.609714	-0.0185
InvR	1925	selfligation	5	kinetic/0	-0.68408	335.4653	-0.04247
InvR	1925	selfligation	5	2.7 deg	17.90328	307.2952	2.473666
InvR	1925	selfligation	5	4.9 deg	20.78918	295.9199	4.24042
InvR	1925	selfligation	5	5.4 deg	23.27695	296.4565	5.005088
InvR	1925	selfligation	5	dyn frict	7.857195	144.2316	2.50087
InvR	1925	selfligation	5	appar stiff	7.163116	31.92181	2.54658
InvR	2125	selfligation	1	static	-0.02494	4.721831	-0.05118
InvR	2125	selfligation	1	kinetic/0	-0.73215	110.7486	-0.04901
InvR	2125	selfligation	1	2.7 deg	48.5954	438.9702	2.445347
InvR	2125	selfligation	1	4.9 deg	77.00285	773.3087	4.236059
InvR	2125	selfligation	1	5.4 deg	96.91557	908.3641	5.088949
InvR	2125	selfligation	1	dyn frict	41.44827	193.4267	2.643526
InvR	2125	selfligation	1	appar stiff	42.49357	-134.608	2.675962
InvR	2125	selfligation	2	static	-0.0374	1.878	-0.02905
InvR	2125	selfligation	2	kinetic/0	-1.0475	402.2687	0.023959
InvR	2125	selfligation	2	2.7 deg	18.64613	451.5797	2.559696
InvR	2125	selfligation	2	4.9 deg	46.69284	670.8233	4.367846
InvR	2125	selfligation	2	5.4 deg	55.35322	709.9395	5.20549
InvR	2125	selfligation	2	dyn frict	17.94705	360.3882	2.657498
InvR	2125	selfligation	2	appar stiff	16.61571	223.0549	2.642353
InvR	2125	selfligation	3	static	0.100651	7.941257	-0.04138
InvR	2125	selfligation	3	kinetic/0	-0.56648	233.0872	-0.02179
InvR	2125	selfligation	3	2.7 deg	28.09748	411.6586	2.446425
InvR	2125	selfligation	3	4.9 deg	57.80624	725.0172	4.4931
InvR	2125	selfligation	3	5.4 deg	79.194	800.8349	5.141229
InvR	2125	selfligation	3	dyn frict	26.63924	371.0185	2.639022
InvR	2125	selfligation	3	appar stiff	24.79837	188.6053	2.702433

InvR	2125	selfligation	4	static	-0.05613	4.829143	-0.00544
InvR	2125	selfligation	4	kinetic/0	0.472965	185.5469	0.0305
InvR	2125	selfligation	4	2.7 deg	24.08392	300.1588	2.370184
InvR	2125	selfligation	4	4.9 deg	47.20322	521.0122	4.227347
InvR	2125	selfligation	4	5.4 deg	59.21179	671.3599	5.075881
InvR	2125	selfligation	4	dyn frict	20.10887	176.3835	2.535493
InvR	2125	selfligation	4	appar stiff	20.00578	32.96575	2.617973
InvR	2125	selfligation	5	static	0.130931	1.663371	0.010525
InvR	2125	selfligation	5	kinetic/0	-0.72415	80.91516	0.006533
InvR	2125	selfligation	5	2.7 deg	11.86962	6.599829	2.493257
InvR	2125	selfligation	5	4.9 deg	18.85725	-25.7019	4.352601
InvR	2125	selfligation	5	5.4 deg	24.11599	-38.6869	5.155387
InvR	2125	selfligation	5	dyn frict	9.114011	-84.794	2.643603
InvR	2125	selfligation	5	appar stiff	9.553804	-208.201	2.683381

CURRICULUM VITAE

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