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"DIFFERENCE IN FRICTIONAL RESISTANCE BETWEEN LIGATURE WIRE AND ELASTIC MODULE"
(AN IN VITRO STUDY)

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Abstract:
Introduction: The purpose of this in-vitro study was to compare the frictional resistance forces generated by slid low friction elastomeric ligatures and stainless steel ligatures wire during leveling and alignment phase. Methods: The testing metal plates consisted of three stainless steel 0.022-in slot size preadjusted brackets of lateral incisor, canine and first premolar. First comparison were the bracket position vertically adhered to the plates. The second one were the canine bracket was adhered as a high canine in 2 mm. The forces generated by wires (0.014-in superelastic nickel-titanium) with the 2 types of ligatures at different bracket position were recorded. Results and Conclusions: The results of the present study revealed that there was a statistically significant difference in the frictional force between group A and group B with a p-value of 0.047 which is less than 0.05 level of significance, while there was no statistically significant difference in the frictional force between group C and group D with a p-value of 0.56 which is greater than 0.05 level of significance.
Keywords: Anchorage, Frictional Force, Orthodontic Tooth Movement, Resistance.

CHAPTER I

THE PROBLEM AND ITS BACKGROUND

An essential aspect of the scientific revolution that has taken place in biology over the past decade is the broad application of the physical sciences to living tissues. Similarly, physics, mathematics, and engineering can be applied in the field of orthodontics. The basic principles of engineering and physics can pave the way towards enhanced designs of orthodontic appliances. If orthodontists rely only on trial and error procedures for the development of new appliances, the developmental skylines will become sharply limited, most importantly since orthodontic treatment usually involves different techniques and materials such as removable and fixed appliances.

Knowledge of physics may lead to better treatment results. Theoretic mechanics can help clinicians improve and later develop and design new orthodontic materials and appliances based on existing ones that are specific to a specific tooth movement needed in a case. Experimentation in orthodontic design can give way to a new discipline of orderly appliance development using concepts from the physical sciences. Each time clinicians adapt an arch wire or any other orthodontic appliance, certain expectations are made about the relationship between an appliance and the biology of tooth movement.

Tooth movement is determined by the total forces applied to the teeth (Graber, 2011). This includes not only forces from the appliance but also muscular forces that are produced during function. In addition, frictional forces also play a role that can highly alter the force system. During orthodontic treatment with fixed appliances, frictional forces should be kept to a minimum so that lower levels of force can be applied to obtain an optimal biological response for effective tooth movement. Friction can be described as a force opposing the relative motion of two surfaces in contact (Alison, 2011). Friction is a function of the relative roughness of two surfaces in contact. It is the force that resists the movement of one surface past another and acts in a direction opposite the direction of movement. Thus, friction force is produced by many possible appliance activations: buccal, lingual, apical, and occlusal forces. It can produce either good or bad effects depending on its application that with too much friction, force can be lost and tooth movement can be reduced. And according to Burrow (2009), a low friction coefficient is necessary in the retraction of teeth or space closure, whereas for anchorage, a high friction coefficient is more appropriate. On the other hand, if much force is used friction reduces the force to more acceptable biologic levels.

The ligation mechanism produces normal forces adding to the friction force. The purpose of ligation is to keep the archwire from being displaced from the bracket. Any additional ligation force will add to the friction force and usually is not desired. The friction present during orthodontic sliding mechanics represents a clinical challenge to the orthodontists because high levels of friction may reduce the effectiveness of the mechanics, decrease tooth movement efficiency and further complicate anchorage control.

One of the most utilized material in Orthodontics that can produce friction are elastomeric ligatures, whose dimensions can vastly change under load and then return to their original size, or nearly so, when load is removed. Elastomeric ligatures are manufactured in different colors and morphological modules that are either ellipsoid or circular, with different diameter and width. Generally, orthodontic elastomers are made of organic polymers in producing forces for intra-oral or extra-oral use.

In Orthodontics, the most widely used elastomers are made from polyurethanes although polyurethanes are not considered ideal elastic materials because they are easily pigmented and susceptible to degradation during tensile load applied on teeth. Polyurethanes can be tailored to have high strength, high rigidity, or high flexibility and toughness. Viscoelastic behavior shows marked structural relaxation mechanical properties that are subjected to changes depending on time and temperature (Ahrari, 2010). The time-dependent force decay may be attributed to variation in manufacturing techniques such as dying, cut stamping or injection molding, effect due to additives, different morphological or dimensional characteristics of the chains (Watts, 1999).

The purpose of this study was to compare the frictional forces between slide low friction ligatures and stainless steel ligature wires in reference to their effects on frictional forces in fixed orthodontic treatment.

Statement of the Problem

Frictional forces and treatment efficiency are subjects discussed in different articles and literary publications. This study was undertaken to determine the difference in the frictional force between slide low friction ligatures and stainless steel ligature wires.

Specifically, this study sought to answer the following questions:

1)What is the frictional force of slide low friction ligatures in vertical positioned brackets?
2)What is the frictional force of stainless steel ligatures wires in vertical positioned brackets?
3)Is there a significant difference in the frictional force between slide low friction ligatures and stainless steel ligature wires in high bracket position?

Significance of Study

This study will be beneficial to the following:

For Orthodontists: To identify the effect of frictional forces during levelling and alignment stage which can help them decide what type of ligation to use with low friction during treatment.

For MSD Students: To serve as a guide to help students in learning and understanding better the ligating methods that can be used during orthodontic treatment.

.For Orthodontic Material Manufacturers: To help companies in producing and developing better products to lessen frictional forces in ligation methods.

For Patients: To provide awareness of the available orthodontics materials that can increase patient's comfort and decrease the treatment time consumed in orthodontic treatment.

For Future Researchers: To introduce new and effective low frictional ligation materials in the field of orthodontics.

Conceptual Framework

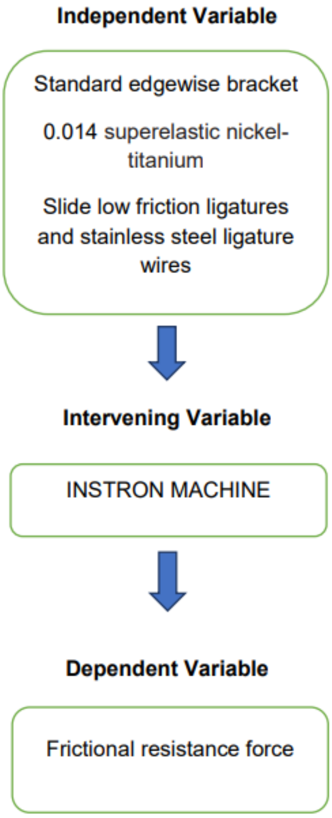

Figure 1: Paradigm of the Study

Hypothesis

Ho: There is no significant difference in the frictional force between slide low friction ligatures and stainless steel ligature wires in high bracket position.

Scope and Limitations

This study focused on the frictional resistance between slide low friction elastomeric ligatures and stainless steel ligature wires 0.010" in size. The main materials used in this study were one hundred twenty standard edgewise brackets with 0.022 x 0.028-in slot, forty straight 0.014" superelastic nickel- titanium wires, forty metal plates with three different brackets lateral, canine,1st premolar attached to them, forty acrylic blocks and straight 0.014" superelastic nickel-titanium wire settled passively in the bracket slots attached in the metal plates. The ligatures that were tested include the slide low friction elastomeric ligatures and 0.010" stainless steel ligature wires.

Definitions of Terms

The following terms were defined contextually and operationally in this study:

Anchorage: is a way of resisting movement of a tooth or number of teeth by using different techniques (Nanda - Temporary Anchorage Devices, 2008).

Frictional Force :refers to the force generated by two surfaces that contact and slide against each other.

Instron: is a test equipment machine designed to evaluate the mechanical properties of materials and components.

Kinetic Friction: is a force that acts between moving surfaces (Elena Cox, 2010).

Ligation: refers to the way by which an archwire is held inside the bracket. Conventionally, elastic or metallic ties were used to secure the archwire in place (Seru Surbhi, et al., 2014).

Muscular Force: is the force that is created through the use of muscles.

Orthodontic Tooth Movement: is the interaction between the periodontal ligament and both tooth and bone when a force is applied to the tooth.

Reciprocal Forces: are forces whereby the resistance of one or more teeth is used to move one or more opposing teeth.

Resistance: is the position or counteracting force as opposition of a conductor to passage of electricity or other energy or substance.

Root Resorption: is the progressive loss of dentine and cementum by the action of osteoclasts (Pitt, et al., 2007).

Static Friction: is a force that keeps an object at rest.

Theoretical Mechanics: is the simplest form of motion of material bodies – mechanical motion. Mechanical motion is defined as that phenomenon in which a body or a part from a body modifies its position with respect to another body considered as reference system (Walter, 2003).

CHAPTER II

REVIEW OF RELATED LITERATURE AND STUDIES

This chapter presents a review or related literature and studies taken from books, journals, and other library materials which guided the researcher in the conduct of the present study.

Relationship between Friction and Material Used

According to Luca Pizzoni, et al. (1998), orthodontic tooth movement can be regarded as teeth sliding on a wire like pearls on a string, the force being supplied by springs or elastics. The movement implies friction between wire and bracket, taking up part of the force and leaving an uncontrolled amount to act on the teeth. The friction is likely to depend on bracket construction and wire material. In this investigation the friction of self-ligating brackets and beta- titanium wires was evaluated, as opposed to more conventional configurations. Carried by low-friction linear ball bearings, a bracket was made to slide along an outstretched archwire with minimal basic friction, either parallel or at an angle to the wire. Two self-ligating brackets were used in their closed position without any normal force. Friction was tested against four wires: stainless steel and beta-

titanium, both in round and rectangular cross-sections. The self-ligating brackets had a markedly lower friction than conventional brackets at all angulations, and self-ligating brackets, closed by the capping of a conventional design, exhibited a significantly lower friction than self-ligating brackets closed by a spring. The selection of bracket design, wire material, and wire cross-section significantly influences the forces acting in a continuous arch system.

Camporesi, et al. (2007) stated that two of the qualities most desired in the contemporary use of fixed appliances are good aesthetics and low friction. In modern society, the aesthetic aspect of orthodontic therapy is important because of the increasing numbers of adult patients. Ceramic brackets were developed to improve aesthetics during orthodontic treatment. However, they tend to have high frictional resistance to sliding mechanics when compared with stainless steel brackets. Frictional forces can be reduced by means of either passive self- ligating brackets or low-friction ligatures. Ideally, it would be favorable to have an aesthetic system that allows for low-friction biomechanics. Two innovative types of aesthetic brackets with aesthetic low-friction ligature systems were introduced: ceramic brackets with nonconventional elastomeric ligatures and ceramic brackets with low-friction clip ligatures. Camporesi analyzed the forces released by orthodontic archwires during the levelling and aligning phase of fixed appliance therapy with the two new types of aesthetic brackets with low friction ligature systems compared with the forces released by the same brackets with conventional elastomeric ligatures (CEL). The comparison between the two esthetic low friction systems showed that the forces available for tooth movement were not significantly different at any amount of canine misalignment. With CEL, the two aesthetic systems did not show a significant difference. These results indicate that when a slight amount of tooth alignment is needed, for example, 1.5 mm, the differences in the performance of conventional from low-friction ligatures associated with aesthetic brackets are minimal, but these differences become significant for misalignments greater than 3 mm. These findings are similar to those of stainless steel brackets with both low-friction and conventional ligatures with misaligned canine brackets. A remarkable amount of friction leading to an almost null amount of force available for alignment was actually recorded with CEL when the misalignment was equal to or greater than 3.0 mm.

Anchorage and Friction

The initiation of tooth movement by orthodontic forces may be either desirable or undesirable. Anchorage, used in an orthodontic context, is defined as "resistance to unwanted tooth movement" (Proffit, 1986). In canine-retraction procedures, for example, increased friction in the canine bracket-slot/ archwire/ ligation system necessitates the use of greater applied force to cause the desired tooth movement. The accompanying larger responsive force acting on the posterior anchorage teeth can, in turn, cause undesirable movements of these teeth in an anterior direction producing loss of anchorage. The awareness and management of frictional force is, therefore, an important consideration when planning orthodontic tooth movement (Proffit, 1986).

Friction reduces the efficiency of fixed appliances so that more force is required to achieve the desired result (Kusy, 1999). However, low forces are considered desirable in conserving anchorage when they keep reciprocal forces low and facilitate release of binding forces between archwires and brackets, thus the presence of sliding mechanics. In addition, low forces might increase patient comfort and reduce the risk of root resorption (Sims, et al., 1982). Between 12% and 60% of the applied force in fixed appliances is lost to friction (Kusy, 1997). The nature of friction in orthodontics is multifactorial, derived from both a multitude of mechanical and biological factors. A combination of mechanical and chemical factors determines friction at the archwire-bracket-ligature interface. Magnitude of friction depends on the amount of normal force pushing the two surfaces together which is decided by the method of ligation, the surface roughness and the nature of materials from which the surfaces are made.

Friction is created when two contacting surfaces slide or attempt to slide with respect to one another. Frictional force is at least part of the responsive counterpart to some initial force causing or attempting to cause motion, and the magnitude of the frictional resistance is influenced by the nature of the contacting surfaces and the normal forces action-reaction components perpendicular to the contact plane termed as exerted on the contacting areas (Nikolai, 1985).

Variable Factors Affecting Level of Friction

Rossouw (2003) concluded that binding of the bracket on the guiding archwire occurs through a series of tipping and uprighting movements. It signifies orthodontic tooth movement, moreover, it creates friction. Friction is a clinical challenge, particularly with sliding mechanics and must be dealt with efficiently to provide optimal orthodontic results. The orthodontic literature notes numerous variables that affect the levels of friction at the bracket-archwire interface. In addition, experimental protocol and design often affect the outcome of in vitro frictional studies. The nature of friction in orthodontics is multi-factorial, derived from both a multitude of mechanical or biological factors. Some of the variables have been assessed using a variety of model systems with nearly equally varying results. Two variables affecting frictional resistance in orthodontic sliding mechanics include physical and mechanical factors such as archwire properties which include the type of material, cross sectional shape, size, surface texture and stiffness and bracket to archwire ligation like ligature wires, and elastomerics method of ligation. Other bracket properties include material, surface treatment, manufacturing process, slot width and depth, bracket design, and bracket prescription. Orthodontic appliances such as interbracket distance, level of bracket slots between teeth and forces applied for retraction. Last are biological factors such as saliva, plaque, and acquired pellicle, corrosion and food particles.

Laws of Friction

Rossouw, et al. (2003) argued that canine distalization using sliding mechanics is possibly one of the most frequently executed tooth movements. It is not uncommon to also find canine retraction in the latter mode as the choice for testing a model in in vitro experiments. During canine distalization with sliding mechanics, a significant amount of the applied force to move the tooth may be lost because of frictional resistance. Minimizing frictional resistance during canine retraction allows most of the applied force to be transferred to the teeth while optimizing orthodontic tooth movement and decreasing undesirable anchorage loss. Classically, the gold standard for sliding mechanics had been established as couples between stainless steel arch wires and brackets, laboratory experiments. Reduction in the applied force because of friction during sliding mechanics has been recognized for some time. More importantly, to prevent undesirable tooth movement and to ensure optimal tooth movement, friction must be understood and controlled. The laws of friction were derived from the straight-line sliding of materials in the dry state and there are three basic principles to consider first, friction is proportional to the force acting at right angles to the contact and it is independent of both contact area and sliding velocity (O'Reilly, et al., 1999).

Second, the ease with which brackets slide along an archwire is influenced by the wire material, its cross-sectional size and shape, the material and design of the brackets, and the ligation method (Ghosh, 1997). Third, the proportion of applied force that is translated into tooth movement decreases as friction increases so that the force required to overcome friction may be up to 60% (Drescher, et al., 1989) or half of the total force applied to a bracket (Fields, 2000).

Ligation and Friction

Chimenti (2005) stated that the method of archwire ligation has been investigated in relatively few studies. The majority of the authors agree that loosely tied stainless steel ligatures produce less friction than standard elastomeric ligatures. According to other studies, frictional forces produced by elastomeric ligatures and stainless steel ligatures are similar, whereas others found that friction caused by elastomeric ligatures was less than that generated by steel ligatures. These differences in results may be ascribed to the different forces used to tie the stainless steel ligatures. Although loose stainless steel ligatures produce less friction compared with elastomeric modules, the convenience and speed of application of elastomeric rings are likely to ensure their continued popularity among clinicians. In addition, the low force exerted by loose steel ligatures may be inadequate to ensure torque expression because of incomplete adaptation of the archwire inside the bracket slot. Frictional forces produced by elastomeric modules may vary from 50 g to 150 g. Elastomeric ligatures consists of polyurethane polymers that are subject to permanent deformation with time and they also deteriorate in moist environment as a result of slow hydrolysis.

Hain, et al. (2006) demonstrated that when the bracket and archwire angulation is carefully controlled, friction is significantly affected by the ligation method. They compared two self-ligating brackets Damon 2 and Speed with four conventional ligatures, TP Orthodontics regular, conventional, 3M Unitek Easy- To-Tie, American Orthodontic's standard

and two nonconventional ligatures by (SuperSlick TP and Sili-Ties). The study found that the SuperSlick ligatures produced 50% less friction than all of the other ligation methods except Damon
2. Damon 2 had no recordable friction of ligation. There was no statistical difference between the Sili-Ties, Easy-To-Tie and TP regular. The AO standard and 3M Unitek conventional produced statistically more friction than all of the others. Sixty minutes of exposure to saliva significantly reduced friction in coated modules. Prolonged exposure to saliva as in one week reduced friction in regular uncoated modules, but they still had 50% more friction than coated modules. There was no statistical difference between sixty minutes and one week of saliva exposure for coated modules.

In a prior study, Hain et al. (2003) compared conventional ligatures, stainless steel ligatures, and SuperSlick (TP) on twin, miniature twin, and metal- reinforced brackets. Also included was the friction produced by the Speed self- ligating bracket. They found that the loosely tied (tied tightly and unwound three times) stainless steel ligatures produced almost no friction, followed by the Speed brackets. The SuperSlick modules reduced static friction by up to 60% as compared with the conventional ligatures regardless of the bracket system used. The reduction of friction when lubricated was greater for the SuperSlick ligatures 50-60% than for the conventional modules 10%-30%. While the results looked promising for the stainless steel ligatures, the authors note that this may be negated by the amount of time needed to tie all of the brackets in with this method and problems associated with an archwire that is not completely engaged in the slot.

Static Friction and Kinetic Friction

Friction is determined in two ways. Static friction is the smallest force needed to start movement while kinetic friction is the force that resists the sliding motion of one solid object over another at a constant speed (Omana, et al., 1992). According to the laws of physics, static friction is always greater than kinetic friction (Ghosh, 1997) but the situation is more complicated when brackets are moved along an orthodontic wire in the mouth since teeth move in a series of short jumps (Read-Ward, et al.,1997).

Kusy (1999) partitioned the resistance to tooth movement into three separate components. The first component is classical friction that occurs between the wire and bracket surfaces and is further divided into static and kinetic friction. The second component is binding that occurs when a tooth is tipped or a wire is flexed so that the wire contacts the corner of the bracket. The third component is notching. This is permanent deformation of the wire at the wire-bracket interface that stops tooth movement until the notch is released. Thus, resistance to tooth movement is equal to the sum of friction, binding and notching and this is applicable in both passive and active configurations.

Limitations in in vitro Studies

According to Burrow (2009), friction can be a simple component of orthodontics to study, but it is difficult to do so in a way that emulates the true intraoral experience. Methods to study friction in vivo have been developed, but the preponderance of the evidence consists of in vitro studies due to their simpler design. There are numerous limitations to in vitro studies. First, the majority of investigations are passive systems in which the binding and notching components have been removed, leaving only a study of pure friction. These studies mount a bracket so that the wire is pulled through it completely parallel to the slot without introducing any angulation between the wire and the bracket. They measure only the amount of friction that is between the wire, bracket and the ligature or self-ligating apparatus. The advantage to these studies is they determine the amount of friction contributed by the type of ligature, bracket and wire without other variables involved. The disadvantage is that in many clinical situations, the brackets are placed in positions that are far from passive to one another. A second limitation to the passive in vitro friction studies is the absence of minor perturbations or disturbances that are normally produced by various oral functions. When a person speaks, chews and swallows or when tissues or food contact the dentition or orthodontic appliance, random minute movements occur within the appliance and shift the archwire in the bracket slot. This shifting has been shown to alter the friction in the appliance.

Braun in 1999 completed pilot study attempting to measure this aspect. They found that perturbations of 87.2gm applied to the bracket or arch wire by finger pressure caused the frictional resistance to momentarily become zero in 95.8% of their 48 experiments. Factors such as the ligature, archwire slot clearances and bracket angulation did not have a measureable effect on friction when stimulated with these perturbations. If the average frequency of masticatory contacts is 32 to 80 cycles per minute, these reductions in friction may be a significant part of the equation. It was noted that the resistance was reduced to zero because the binding and notching occurring at the bracket archwire interface was released temporarily. Their findings demonstrated that a preponderance of in vitro frictional resistance experiments conducted in the past do not reflect the mode of frictional resistance that may actually occur in the oral cavity, and that random, intermittent, repeated, minute relative motions at the bracket/arch wire interface significantly decreased, if not completely eliminated frictional resistance. This occurs on a cyclical basis as one chews, speaks, swallows, and as the tissues, food, etc contact the orthodontic appliance.

In another in vitro study, Franchi, et al. (2006) attempted to reproduce the right buccal segment of the maxillary arch to compare a nonconventional elastomeric ligature (Slide, Leone Orthodontic Products) with a conventional elastomeric ligature. Five stainless steel 0.022 x 0.028” preadjusted brackets were mounted in 8.5 mm apart, with the canine bracket welded to a sliding bar. The study then tested the forces released by the system after 1.5 mm, 3 mm, 4.5 mm and 6 mm of vertical canine displacement. The authors noted that the major limitation to this study was the inability of the other brackets contiguous to the misaligned bracket to move, mimicking an absolute anchorage scenario.

Slide Low Friction Ligature

Most recently, Franchi, et al. (2009) tested an even greater range of materials with seven bracket-ligature combinations. He utilized four passive self- ligating brackets including Carriere (Ortho Organizers), Damon 3 MX (SDS Ormco), SmartClip (3M Unitek), and Opal-M (Ultradent Products), Synergy brackets with Synergy low-friction ligatures (Rocky Mountain Orthodontics), Logic Line conventional stainless steel brackets with Slide ligatures (Leone Orthodontic Products) and conventional stainless steel brackets with conventional elastomeric ligatures (Leone Orthodontic Products).0.012” and 0.014” nickel-titanium wires were tested. The canine bracket was displaced by the Instron machine at four different levels of buccal misalignment: 1.5 mm, 3.0 mm, 4.5 mm and 6.0 mm. Each combination was tested 20 times. A similar result was found to the previous study demonstrating that with both types of wire all low friction systems (self-ligating brackets, Synergy and Slide ligatures) produced significantly greater forces for tooth alignment than the conventional systems at all amounts of canine displacement above 1.5 mm. When the displacement was greater (4.5 and 6.0 mm), the low friction systems produced a significant amount of force, but the conventional systems dropped to 0 g. They concluded that for buccal misalignments of 1.5 and 3.0 mm, both low friction and conventional systems are effective in releasing forces for tooth movement (30 to 60 g.). However, when the displacement is larger than this, the forces for alignment are greater with low friction systems.

Tecco (2009) stated that low-friction ligatures with round archwires showed statistically significantly lower frictional resistance than did conventional ligatures. When coupled with 0.016 x 0.022-in NiTi and SS, no statistically significant difference was observed. When coupled with 0.017 x 0.025-in archwires, low-friction ligatures showed statistically significantly greater frictional resistance than was seen with conventional ligatures. When coupled with 0.019 x 0.025-in NiTi, low-friction ligatures showed statistically significantly greater frictional resistance than did conventional ligatures. In his study, low-friction and conventional ligatures demonstrated different trends of results for archwires of various cross-sections either round or rectangular and sizes, the design of low friction ligatures allows low friction only when they are coupled with round archwires and not when they are coupled with most rectangular archwires. About rectangular archwires may be explained by the design of low-friction ligatures.

Their shape, with the elastic device built in to transform the slot into a tube and to close off the archwire in the slot However, the results observed with rectangular archwires could be related to the vertical dimension and the type of alloy in the archwires. The larger contact area between the wire and the slot and the surface texture of the wire surface are factors that can affect the magnitude of frictional forces, in that friction was observed to increase with an increase in wire size. The use of several types of archwires led to the inclusion of many variables that could have influenced the frictional force, such as arch size (6 thickness), arch cross-section (round and rectangular), and wire surface roughness (SS, NiTi, TMA).

In 2006, Franchi and Baccetti tested the forces generated by three sizes of wire (0.012-in, 0.014-in, and 0.016-in superelastic NiTi) with two types of elastomeric ligature (conventional and low friction) at different amounts of upward canine misalignment (1.5, 3, 4.5, and 6 mm) in a segment of five stainless steel 0.022-in preadjusted brackets.

In 2007, Camporesi, et al. using the Franchi and Baccetti model, evaluated the frictional force generated by preadjusted 0.022-in ceramic brackets with low-friction esthetic ligatures and confirmed what had been found with metal brackets in 2006.

Recently, Tecco, et al. (2007) evaluated the FR generated by conventional ligatures, self-ligating Damon SL II brackets (Ormco, Glendora, Calif), self-ligating Time Plus brackets (American Orthodontics, Sheboygan, Wis), and low-friction ligatures coupled with various SS, NiTi, and beta-titanium (titanium molybdenum alloy [TMA]) archwires, using a new experimental method to investigate the FR generated during the slidingof an archwire along a group of
10 aligned brackets. When coupled with 0.016-in NiTi, low-friction ligatures generated greater FR compared with Damon SL II (P_ .001); when coupled with
0.016 x 0.022-in NiTi, low-friction ligatures generated significantly greater FR (P
_ .001) compared with all self-ligating brackets. It was only when low-friction ligatures were coupled with 0.019 x 0.025-in stainless steel (SS) or 0.019 x 0.025-in NiTi that low-friction ligatures generated significantly lower FR than was produced by self-ligating brackets and conventional ligatures. No difference was observed among the low-friction ligatures, the conventional ligatures, and the self-ligating brackets when coupled with a 0.017 x 0.025-in TMA archwire.

Gupta (2013), reported that when considering tooth movement along a 0.019" × 0.025" in stainless steel archwire, Super slick module produce less friction when compared to regular module, module tied in ‘figure of 8’ pattern and tight SS ligation produced more friction when compared to loose SS ligation and slide module. Slide modules produce least friction when compared to other available methods of ligation. Modules tied in a ‘figure of 8’ pattern generate highest friction. Slide modules produce least friction followed by loose SS ligation, slick modules, regular modules, tight SS ligation and highest friction was produced by regular modules tied in a 'figure of 8' pattern. Width of bracket had no influence on friction produced.

The word friction refers to the resistance to motion encountered when one solid body slides or tends to slide over another solid body. It may be described as force acting parallel to the direction of motion and opposing the motion. One of the most important factors which strongly determine the orthodontic tooth movement is friction between archwire and bracket. Friction is an important factor in all forms of sliding mechanics, such as space closure, canine retraction into an extraction site, and in levelling and alignment where the wire must slide through the brackets and tubes. Friction may exist in two forms as follows, first static friction, which is the component of frictional force that has to be overcome to initiate motion. Second dynamic friction, which is the component of frictional force that has to be overcome to maintain motion. The static frictional force usually is somewhat higher than the dynamic frictional force. The nature of friction in orthodontics is multifactorial, derived from both a multitude of mechanical and biological factors. Magnitude of friction depends on the amount of normal force pushing the two surfaces together which is decided
by the method of ligation, the surface roughness and the nature of materials from which the surfaces are made.

One of the most important factors which strongly determine the orthodontic tooth movement is friction between archwire and bracket interface. Fixed appliances used for orthodontic tooth movement are always associated with generation of friction between the bracket-wire interfaces. It has been proven in previous studies that the material properties of the bracket, wire, ligature and the amount of force by which the archwire is pressed against the bracket play an important role in the amount of friction generated. Tooth movement can occur only when tooth moving forces adequately overcome the friction at the bracket-wire interface. For these reasons there is a continuous search for methods to reduce friction while tooth movement is taking place. When ligating the archwire to the bracket; friction produced by different methods varies because of different material properties and differences in the amount of force pushing the archwire against the slot surface. The first law of friction states that the frictional force produced is directly proportional to the amount of 'normal' force which is the force produced by the ligation in the case of tooth movement.

When planning for orthodontic tooth movement clinician should select the proper combination of bracket and ligation method to reduce the friction and increase the efficiency of the appliance. Newly introduced slide modules produced least friction when compared to other available methods of ligation. Super slick module introduced by TP Orthodontics produce less friction when compared to regular module, regular module tied in 'figure of 8' pattern and tight SS ligation but more friction when compared to loose SS ligation and slide module. Modules tied in a 'figure of 8' pattern generated highest friction because of increased amount of normal force pushing the archwire against the bracket slot. 'Figure of 8' modules can be used in the final phase of treatment when full engagement of archwire in the bracket slot is necessary for proper tip and torque expression. Static frictional force was observed to be more than dynamic friction. It can be concluded that use of either single width or twin bracket will not make much of a difference in friction produced at the archwire-bracket interface, while performing sliding mechanics.

According to Paola, et al. (2008), frictional forces close to 0 g were recorded in all tests with self-ligating bracket and in all tests with unconventional elastomeric ligatures on conventional bracket with both wire types. Resistance to sliding increased significantly (87–177 g) (P<.05) when conventional elastomeric ligature on conventional bracket was used with both wires. Unconventional elastomeric ligatures may represent a valid alternative to passive self-ligating bracket for low-friction biomechanics. When sliding biomechanics are used with fixed appliances, the main force that contrasts tooth movement is the frictional force developed by the interaction of the bracket slot and the orthodontic wire. As the efficiency of fixed appliance therapy depends on the fraction of force delivered with respect to the force applied, high frictional forces resulting from the interaction between the bracket and the guiding archwire affect treatment outcomes and duration in a negative way. During orthodontic treatment with fixed appliances, frictional forces should be kept to a minimum so that lower levels of force can be applied to obtain an optimal biological response for effective tooth movement. Several factors can influence frictional resistance directly or indirectly. Among these factors, features of archwire and bracket (in terms of size and material) have been investigated extensively in relation to friction production, methods and properties of archwire ligation, which have an important role in generating friction, have received limited attention in literature. Most investigations have concluded that elastomeric modules significantly increase resistance to sliding compared with stainless steel ligatures, especially when the latter are tied loosely.

Since the 1980s, self-ligating brackets have become increasingly popular. These types of brackets are characterized by the presence of a fourth mobile wall that converts the slot into a tube. Self-ligating brackets are claimed to reduce friction levels in a considerable way because they simply allow the wire to move freely into the bracket slot. Several studies have demonstrated a significant decrease in friction by using these types of brackets with a reduction in the time necessary for single tooth movements.

Recently, an innovative unconventional elastomeric ligature (Slide, Leone Orthodontic Products, Sesto Fiorentino, and Firenze, Italy) has been introduced into the market. Once applied on conventional brackets this ligature is completely passive,

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like the labial cover of passive self-ligating brackets; thus, it guarantees the same freedom of sliding to the wire. Previous in vitro studies have shown that this unconventional elastomeric ligature is able to reduce frictional forces with respect to conventional elastomeric ligatures both during leveling and aligning and during sliding mechanics. No statistically significant difference was found between the frictional forces produced by self-ligating brackets and by unconventional elastomeric ligatures on conventional brackets when used with
0.14 NiTi wire and with 0.019x0.025 SS wire. All of these values were close to 0 g (mean values ranging from 0.1 g to 1.2 g).

Conventional elastomeric ligature on conventional brackets coupled with both types of wires generated significantly greater static and kinetic frictional forces with respect both to self-ligating brackets and to unconventional elastomeric ligatures on conventional brackets (mean values ranging from 86.7 g to 177.4 g). Self-ligating brackets and unconventional elastomeric ligatures on conventional brackets are able to produce significantly lower frictional forces compared with conventional elastomeric ligature on conventional brackets when coupled with .014NiTi wire and with 0.019x0.025 SS wire.

Leone system has developed elastomeric ligature. It is believed to give favorable friction properties compared to some of the ligatures mentioned and advertised as slide low friction ligatures. Slide ligatures can be used in cases where considerable levelling and alignment are required, as well as in patients who need sagittal or transverse expansion. The advantages of the system are especially evident in the early stages of orthodontic treatment, when the archwire can slide freely inside the tunnel between the bracket slot and the ligature. The objective of this research was to compare slide low friction ligatures and stainless steel ligature wires.

Ethical Considerations

No human or animal was harmed in this study. All the study materials were collected from licensed dental material companies and suppliers.

CHAPTER III MATERIALS AND METHODS

This chapter presents the research methods and procedures that the researcher applied during the duration of the study. This chapter includes a discussion of the research design, samples and sampling technique, research instruments, data gathering procedures, and statistical tools used in the study.

Research Design

This study used descriptive quasi experimental method because it assessed and compared the frictional force of slide low friction elastomeric ligatures and stainless steel ligature wires. Universal Test Machine (Instron machine) was used to compare the frictional force in slide low friction elastomeric ligatures and stainless steel ligature wires.

Sample and Sampling Technique

This study used purposive sampling technique to determine the frictional force of slide low friction elastomeric ligatures and compare it with stainless steel ligature wires 0.010” in size. One hundred twenty ligatures were used as samples. Thirty ligatures from slide low friction elastomeric ligatures were ligated with the vertically positioned brackets for group A. Thirty ligatures from stainless steel ligature wires 0.010” in size were ligated with the vertically positioned brackets for group B. Thirty ligatures from stainless steel ligature wires 0.010” in size were ligated with the high canine brackets for group C. Thirty ligatures from stainless steel ligature wires 0.010” in size were ligated with the high canine brackets for group for group D.

Inclusion Criteria:

- Standard edgewise bracket 0.022 slot
- Metal flat plates
- Slide low friction elastic ligature
- 0.010” Stainless steel ligature wires
- 0.014” Straight superelastic nickel-titanium wire

Exclusion Criteria:

- Detached brackets
- Distorted plates
- Corrugated wires
- Cracked acrylic blocks

Research Instruments

In this study, different research instruments were used to determine the frictional force between slide low friction elastomeric ligatures and stainless steel ligature wires 0.010”. The helpful materials used for testing frictional force in this study were: forty metal plates to hold the brackets during the testing, three brackets of the lateral, canine, first premolar, respectively adhered to each plate using cyanoacrylate as a bonding agent. All brackets used were 0.022 x 0.028- in slot stainless steel twin standard edgewise brackets with 0.014” straight wire superelastic nickel-titanium straight wire were used. The ligating methods slide low friction elastomeric ligatures and stainless steel ligature wires 0.010”.Universal Test Machine INSTRON was used to measure the frictional force between slide low friction ligatures and stainless steel ligature wires. There are other instruments and materials used in this study such as millimetric ruler, matthau pliers, bracket holder, ligature director, adhesive material, dental loupes magnifying glass. The friction values were analyzed with statistical software using t-test.

Data Gathering Procedures

According to the specification of universal testing machine (Instron), forty rectangular metal plates 5 cm long by 2.5 cm wide and 0.2 cm thick were fabricated. The custom metal plate's fixtures allowed a straight wire to be ligated to all three brackets and to be passively centered in all of the bracket slots by creating a line on the metal plate as the same width of the bracket to prevent generation of any undesirable friction for group A and B. Three brackets of the lateral, canine, first premolar of 0.022 x 0.028 slots respectively were adhered to each plate using cyanoacrylate as a bonding agent. For the group C and D metal plates, three brackets of the lateral, canine, first premolar of 0.022 x 0.028 slots respectively were adhered to each plate using (cyanoacrylate) as bonding agent following the high canine model which the bracket of the canine was high by 2 mm from the adjacent brackets. Forty acrylic blocks were made (1.5 cm long by 0.5 cm width and 0.5 cm thickness) and the 0.014" superelastic nickel-titanium straight wires were embedded within the acrylic blocks. Each of these wires was settled passively within the bracket slots of the metal plates. The acrylic blocks was held by the Instron on the other side. Twenty 0.014" superelastic nickel- titanium straight wires were used for Groups A and B; the bracket was in vertical position.

Twenty 0.014" superelastic nickel-titanium straight wire were used for group C and D; the bracket was in high canine position. The stationary metal plate for each group was fixed to the lower part of Universal Test Machine (Instron). While the upper part of Instron machine held the acrylic block.

The friction values obtained between the wire and ligature set were measured using Instron at the speed of 6 mm/minute gandinia et.al (2008). A test run was done each time to ensure that the new 0.014" superelastic nickel- titanium straight wire was bonded passively in line with the others. This was important because the frictional force that was reported includes not only the friction from the ligature but also any friction from the wire binding on the bracket if it were not bonded passively.

Statistical Tools

1) Standard deviation: In statistics, the standard deviation (SD), represented by the Greek letter sigma σ or the Latin letter s, is a measure that isused to quantify the amount of variation or dispersion of a set ofdata values. A low standard deviation indicates that the data points tend to be close to the mean the expected value of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

$$s = \sqrt{\frac{\sum(x - \overline{x})^2}{N - 1}}$$

The formula for standard deviation is shown below:

Where:

s = standard deviation x = Values given

x¯ x¯ = Mean

n = Total number of valuesMean value :

The mean is found by adding up all of the given data and dividing by the number of data entries. It is also known as the average.

Mean = Sum of all data values Number of data values

2) The friction values were analyzed using the t-test.

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\frac{S_1{}^2}{N_1} + \frac{S_2{}^2}{N_2}}}$$

Where:

x1¯ x1¯ = Mean of first set of values x2¯ x2¯ = Mean of second set of values

S1 = Standard deviation of first set of values

S2 = Standard deviation of second set of values n1 = Total number of values in first set

n2 = Total number of values in second set.

CHAPTER IV

PRESENTATION, ANALYSIS, AND INTERPRETATION OF DATA

This chapter presents, analyzes, and interprets the data collected in the study based on the research questions enumerated in Chapter I.

Two types of ligation methods were used in this study. One type of material used was slide low friction elastomeric ligatures and the others were 0.010” stainless steel ligature wires. There were thirty brackets with 0.014” superelastic nickel-titanium ligated with slide low friction elastomeric ligatures in straight bracket position (group A) and thirty brackets with 0.010” stainless steel ligature wires (group B). Another set of thirty brackets with a 2 mm high canine bracket position as compared with the first two groups with 0.014” superelastic nickel-titanium ligated with slide low friction elastomeric ligatures (group C) and thirty brackets with 0.010” stainless steel ligature wires (group D) were utilized. They were adhered to rectangular metal plates and pulling forces were applied and measured by Instron Universal Testing Machine. This was measured with a certificate of calibration in October 2018

Independent t-test revealed that there was a statistically significant difference in the frictional force between groups A and B.

Also, independent t-test revealed that there was no statistically significant difference in the frictional force between groups C and D.

Problem No. 1: What is the frictional force of slide low friction ligatures in vertical positioned brackets?

A total of ten (10) out of forty (40) selected plates were chosen for group A (slide low friction elastomeric ligatures) and were tested to determine the effect of frictional forces of slide low friction elastomeric ligatures. The unit of force that was used is in Newton. The results obtained in this study are shown in Table 1

Table 1: Frictional Forces of Slide Low Friction Elastomeric Ligatures of Vertical Bracket High

Slide low friction elastomeric ligatures	Frictional Force (Newton)
A1	0.09935
A2	0.1378
A3	0.33902
A4	0.50615
A5	1.54936
A6	1.58774
A7	0.38097
A8	0.70353
A9	0.0863
A10	0.17014

The minimum frictional force of slide low friction elastomeric ligatures was 0.08 N while the maximum frictional force was 1.58 N. The mean of frictional force was 0.55 N and the standard deviation was 0.56 as shown in Table 2.

Table 2: The Mean Value and Standard Deviation of Slide Low Friction ElastomericProblem No. 2: What is the frictional force of stainless steel ligatures wires in vertical positioned brackets?

Variable	N	Mean	Std. Deviation
Group A	10	.55604	.568247

A total of ten (10) plates out of forty (40) were chosen for group B (stainless steel ligature wires) and were tested to determine the effect of frictional forces of stainless steel ligature wires. The unit of force that was used is in Newton. The results obtained in this study are shown in Table 3.

Table 3: Frictional forces of stainless steel ligature wires of vertical bracket high

stainless steel ligature wires	Frictional Force (Newton)
B1	0.21324
B2	1.6059
B3	1.15597
B4	0.74448
B5	0.94111
B6	1.13918
B7	0.88433
B8	3.07688
B9	0.9331
B10	1.22765

The minimum frictional force of stainless steel ligature wires was 0.21 N while the maximum frictional force was 3.07 N. The mean of frictional force was 1.19 N and the standard deviation was 0.75 as shown in Table 4.

Table 4: The Mean Value and Standard Deviation of Stainless Steel Ligature Wires

Variable	N	Mean	Std. Deviation
Group B	10	1.19218	.753682

Table 5: The Difference in the Frictional Force between Slide Low Friction Elastomeric Ligatures and Stainless Steel Ligature and t-test Results

group A vs. group B	t-value	df	p-value
	-2.131	18	0.047

Ho: There is no significant difference in the frictional force between group A and group B.

Decision rule: reject Ho if p-value is less than 0.05 level of significance, otherwise do not reject Ho.

The results of the independent t-test as shown in Table 5 revealed that there is a statistical significant difference in the frictional force between group A and group B with a p-value of 0.047 which is less than 0.05 level of significance.

Problem No. 3: Is there a significant difference in the frictional force between slide low friction ligatures and stainless steel ligature wires in high bracket position?

A total of twenty (20) plates out of forty (40) were chosen and divided into ten plates for group C (slide low friction elastomeric ligatures) high bracket position and ten plates for group D (stainless steel ligature wires) high bracket position. They were tested to identify the effect of frictional forces between slide low friction elastomeric ligatures and stainless steel ligature wires in cases of high bracket position. The unit of force that was used is in Newton. The results obtained in this study are shown in Tables 6 and 7.

Table 6: Frictional Forces of Slide Low Friction Elastomeric Ligatures with High Bracket Position

slide low friction elastomeric ligatures high bracket position	Frictional Force (N)

C1	2.82673
C2	1.30029
C3	0.91238
C4	1.91881
C5	0.93443
C6	3.96254
C7	1.30417
C8	2.19973
C9	1.44526
C10	5.45823

Table 7: Frictional Forces of Stainless Steel Ligature Wires with High Bracket Position

stainless steel ligature wires high bracket position	Frictional Force (Newton)
D1	2.13425
D2	1.77653
D3	5.6397
D4	1.53731
D5	1.0738
D6	2.70936
D7	2.73513
D8	3.01586
D9	1.7157
D10	3.64739

The minimum frictional force of slide low friction elastomeric ligatures high bracket position was 0.91 N while the maximum frictional force was 5.45 N. The mean of frictional force was 2.22 and the standard deviation was 1.47.

The minimum frictional force of stainless steel ligature wires high bracket position was 1.07 N and the maximum frictional force was 5.63 N. The mean of frictional force was 2.59 and the standard deviation was 1.31 as shown in Table 8.

Table 8: The Mean Value and Standard Deviation of Slide Low Friction Elastomeric Ligatures High Bracket Position and Stainless Steel Ligature Wires High Bracket Position

Variable	N	Mean	Std. Deviation
Group C	10	2.22626	1.476814
Group D	10	2.59850	1.319745

Twenty (20) metal plate samples of slide low friction elastomericligatures and stainless steel ligature were chosen and were used in this study. The mean value, standard deviation and t-test were used to determine the significant difference in the frictional force between the two types of ligatures.The t-test results revealed that there was no significant difference in the frictional force between slide low friction elastomeric ligatures and stainless steel ligature in case of high bracket position while there is significant difference in frictional force in the vertical bracket position as shown in Table 9.

Table 9: Difference in the Frictional Force between Slide Low Friction Elastomeric Ligatures and Stainless Steel Ligature in Case of High Bracket Position and t-test Results

group C vs.group D	T value	Df	p-value
	-0.594	18	0.560

Ho: There is no significant difference in the frictional force between group C and group D.

Decision rule: reject Ho if p-value is less than 0.05 level of significance, otherwise do not reject Ho.

The results of the independent t-test as shown in Table 9 revealed that there is no statistically significant difference in the frictional force between group C and group D with a p-value of 0.560 which is greater than 0.05 level of significance.

It is difficult to accurately determine the many variables affecting the frictional resistance in orthodontic sliding mechanics in a clinical situation. This is further complicated by the fact that there are such a variety of orthodontic appliances, as well as a vast variability in the biological parameters of patients. It has been suggested that clinically these forces because of frictional resistance may be overestimated and are less than what is measured in steady state laboratory experiments Kusy RP (2000).

Gandini et.al (2008), stated that an innovative slide low friction elastic ligature, manufactured with a special polyurethane mix by injection molding (Slide), was introduced. Once the ligature is applied on the bracket it simulates the labial cover of a passive selfligating bracket, thus transforming the slot into a tube that allows the archwire to slide freely. The results of the present study confirm previous findings by Baccetti (2006) who reported significantly lower levels of friction for with slide low friction elastic ligature compared with conventional elastomeric ligature during sliding mechanics with 0.014" NiTi wire.

Franchi et.al (2009) found no clinically meaningful difference in terms of the magnitude of forces generated by the various ligatures systems with the same wire and the same level of tooth misalignment, all low-friction systems behaved similarly, and they consistently produced forces for orthodontic movement.

CHAPTER V

SUMMARY OF FINDINGS, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

This chapter presents the summary of findings, the conclusion obtained from the data collected, analyzed, and interpreted, and the recommendations based on the results of the study.

Summary of Findings

The results of the present study revealed that there was a statistically significant difference in the frictional force between group A and group B with a p-value of 0.047 which is less than 0.05 level of significance. On the other hand, there was no statistically significant difference in the frictional force between group C and group D with a p-value of 0.56 which is greater than 0.05 level of significance.

Conclusion

The frictional force in orthodontics is multifactorial. It is directly influenced by the types of ligatures used and it affects the efficiency of orthodontic tooth movement. The presence of friction is unfavorable in many clinical situations.

The physical or mechanical variables that influence friction formation are more frequently researched than the biological variables. They should be carefully taken into consideration during the different stages of the orthodontic treatment to increase efficiency in different clinical situations.

The slide low friction elastic generated significantly less friction at the straight bracket position than the 0.010” ligature stainless steel. The findings also showed that there was no significant difference combined with slide low friction ligature systems and ligature stainless steel 0.010” in size during the high canine position.

Implications

This describes how the results of this study could help and provide answers to the questions of the students and future researchers as well as their implications in the practice of orthodontics.

For Orthodontists

The results of this study would be an extraordinary help to orthodontist for them to get an opportunity to determine which type of ligatures causes less friction effect.

For Manila Central University

This study could be used as a research and reference material that students, future researchers, and analysts may utilize in their future endeavours.

For MCU-MSD Orthodontic Students

This study would be beneficial to students enrolled in the MSD program as they may choose the type of ligatures with less friction force that can decrease the treatment time needed.

Recommendations

In view of the findings and conclusions, the researcher came up with the following recommendations:

1. Faculty members may encourage their students to use different types of ligation method that can relate to the situational case of an orthodontic problem.
2. Clinicians may choose the most suitable ligation method and materials to reduce the friction and increase the efficiency of the appliance when planning for orthodontic tooth movement.
3. Future researchers may incorporate randomized clinical controlled trials to compare low friction ligatures with conventional ligatures with in terms of treatment time and efficiency.

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"الفرق في مقاومة الإحتكاك بين سلك الربط والأربطة المرنة"

(دراسة في المختبر)

إعداد الباحثين:

د.احمد خساره　　د.معن داودي.　　د.ارلين ليزلي دونيسا

خلاصة البحث:

المقدمة: كان الغرض من هذه الدراسة المخبرية هو مقارنة قوى مقاومة الاحتكاك الناتجة عن الأربطة المرنة المنزلقة منخفضة الاحتكاك وأسلاك الربط المصنوعة من الفولاذ المقاوم للصدأ أثناء مرحلة التسوية والمحاذاة.

الطرق: تتكون الصفائح المعدنية للاختبار من ثلاث حاصرات من الفولاذ المقاوم للصدأ بحجم 0.022 بوصة معدة مسبقًا للقواطع والناب والضواحك الأولى. كانت المقارنة الأولى هي موضع الحاصرات بشكل عمودي على الصفائح المعدنية . والثاني هو حاصرة الناب الذي تم لصقه كناب مرتفع بمعدل 2 مم. تم تسجيل القوى المولدة بواسطة الأسلاك (0.014 بوصة من النيكل والتيتانيوم فائقة المرونة) مع نوعين من ادوات الربط في موضع الحاصرات المختلف.

النتائج والاستنتاجات: أظهرت نتائج الدراسة الحالية وجود فروق ذات دلالة إحصائية في قوة الاحتكاك بين المجموعة (أ) والمجموعة (ب) بقيمة 0.047 p وهي أقل من 0.05 مستوى دلالة، في حين لم يكن هناك فرق ذو دلالة إحصائية. الفرق في قوة الاحتكاك بين المجموعة C والمجموعة D بقيمة p تبلغ 0.56 وهي أكبر من 0.05 مستوى الدلالة.

الكلمات المفتاحية: الدعم. قوى الاحتكاك, حركة السن تقويميا, المقاومة.