ORIGINAL RESEARCH

Comparison of Friction among Low-friction Ligation, Conventional Ligation and Self-ligation with Conventional-Stainless Steel and Esthetic Brackets: An *in vitro* Study

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ABSTRACT

Friction between the archwire and brackets is one of the major determinant of tooth movement in preadjusted edgewise appliance. The aim of the present study was to evaluate the differences in the frictional forces among low-friction ligation modules, conventional ligation and self-ligation systems with stainless brackets and ceramic brackets. Stainless steel (SS), Damon self-ligating and ceramic brackets of 0.022" × 0.028" slots 5 to 5 to represent the upper right to the upper left second bicuspid were used. Archwires used were 0.016" NiTi-straight length 18 cm long and 0.019" × 0.025" SS-straight length 18 cm long, and slide low-friction ligatures and alastik modules were used. The testing apparatus consisted of a friction-testing device, Instron universal testing instrument, load cell, signal amplifier and computer. The mean and standard deviation (SD) were calculated. The mean values were compared by one-way ANOVA. Multiple range tests by Tukey-Kramer honest significant difference (HSD) procedures were employed to identify the significant groups if p-value in one-way ANOVA is significant by using statistical software. The results showed that conventional ligation exhibited higher fiction than low-friction and self-ligation with all the archwire-bracket combinations. Damon self-ligating system exhibited less friction than low-friction ligation with lower archwires and higher friction with higher archwires.

Keywords: Friction, Self-ligating brackets, Ceramic brackets, Stainless steel, Slide ligatures.

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INTRODUCTION

The success of tooth movement during orthodontic treatment with preadjusted appliances depends to a large extent on the ability of orthodontic archwire to slide through brackets and tubes. The major disadvantage with the use of sliding mechanics is the friction that is generated between the bracket and the archwire during orthodontic movement.

Friction is defined as 'the force tangential to the common boundary of two bodies in contact that resists the motion of one relative to the other. The amount of friction is proportional to the force with which the two surfaces are pressed together and dependent on the nature of the surfaces in contact, such as composition of the material, surface roughness, etc.[1]

The friction encountered during tooth movement can be divided into static friction and kinetic friction. Static friction is defined as the force required to initiate tooth movement, whereas kinetic friction is the force that resists motion.

Static friction is considered to have a greater importance because it needs to be overcome each time the tooth moves a little. A number of studies have identified the principal factors that may influence orthodontic frictional resistance are:[1] relative bracket-wire clearances, archwire size, archwire cross-section (round *vs* rectangular wires), torque at the bracket-wire interface, surface conditions of the archwires and bracket slot, bracket and archwire materials, bracket slot width, bracket type (conventional *vs* self-ligating brackets), type and force of archwire ligation.

The dissipation of the orthodontic force as resistance to sliding may vary between 12 and 60% or it may lead to a stop in tooth movement hand, an excessive increase in orthodontic forces to overcome frictional resistance during retraction of the anterior teeth may produce increased posterior anchorage loss.[2] Frictional resistance must be kept to a minimum during sliding mechanics so that orthodontic tooth movement can be generated through light optimal forces. Schumacher et al[3] found that friction was determined mostly by the type and force of ligation. On the other ligation with stainless steel (SS) ties can lead to higher forces as a range of ligating forces may be used by different operators and ligation forces cannot be precisely controlled. Also, incidents of injury to gingival tissues and to the operator have been reported.

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Although loose SS ligatures produce less friction compared with elastomeric modules, and elastomeric ligatures are subject to permanent deformation with time and they also deteriorate in moist environment as a result of slow hydrolysis,[3] the convenience and speed of application of elastomeric rings are likely to ensure their continued popularity among clinicians.

To overcome the disadvantages of the conventional ligation techniques, self-ligating (SL) brackets were introduced. Although the first self-ligating bracket was the Russell lock, there has been renewed interest in the development of self-ligating brackets by orthodontists since the mid 1970s. This is a ligatureless bracket system with a mechanical device built into the bracket to close off the bracket slot.[4]

Damon 2 is an improvement of the original Damon SL brackets which are brackets with a passive vertical slide action, spring clip.[5] The modification in the recent version include placement of the slide within the tie wings, metal injection molding and reduced size, and hence reduction in frictional force.

Ceramic brackets were developed in the 1980s to improve esthetics during orthodontic treatment. In clinical use, however, they have problems including brittleness leading to bracket or tie-wing failure, iatrogenic enamel damage during debonding, enamel wear of opposing teeth, and high-frictional resistance to sliding mechanics.[6]

Recently, new low-friction ligatures (Slide©, Leone, Firenze, Italy) have been introduced, similar to elastic ligatures, but with an anterior part that is more rigid and similar to the mechanical device of self-ligating brackets.

According to the manufacturer, Slide© is constructed from a special polyurethane mix approved for medical use. It can be applied in the same way as classical elastic ligatures and, once on the bracket, it self-ligates on the slot forming a 'tube-like' structure, allowing the archwire to slide freely and to produce its effects more readily on the dentoalveolar component. The manufacturer claims that it is useful when low-friction is desired, while conventional ligatures can be used when more friction is required. This study investigated the frictional properties of these ligatures.

AIMS AND OBJECTIVES

The aim of the study was to investigate the frictional characteristics of slide low-friction ligatures in various conditions.

The objectives of the present study are to compare the frictional forces generated by slide low-friction ligatures with that of self-ligation and conventional ligation, and to find out whether slide low-friction ligatures are able to provide a similar reduction in friction with ceramic brackets as with SS brackets.

MATERIALS AND METHODS

This *in vitro* research study investigated the effects of various ligation methods and bracket materials on friction. Three types of brackets (Stainless steel, ceramic, and self-ligating) and two types archwires (0.016" nickel-titanium, 0.019" × 0.025" stainless steel) were used in combination with three different ligation methods (Conventional, low-friction modules and self-ligation) to evaluate the amount of resistance to sliding present. Friction is the load necessary to pull the archwire through the brackets when the archwire was secured to the brackets with different ligation methods. A total of 100 testing procedures were performed in this investigation, 50 times with only the terminal brackets ligated and other 50 times with all the brackets ligated.

Materials

Brackets selected for this study were of 0.022" × 0.028" slots to represent the upper right to the upper left second bicuspid (15, 14, 13, 12, 11, 21, 22, 23, 24 and 25).

The brackets used were (Fig. 1):

(1) Damon 2 self-ligating bracket (Ormco, Glendora, Calif), (2) InVu ceramic bracket—standard roth prescription (TP orthodontics), (3) Gemini SS—standard roth prescription (3M Unitek, Monrovia, USA).

The elastomeric modules used were (Figs 2 and 3): (1) Slide low-friction ligatures (Leone orthodontics, Firenze, Italy), (2) Alastik modules (3M Unitek, Monrovia, USA).

The archwires used in this study were (Fig. 4): (1) 0.016" NiTi-straight length 18 cm long (American braces, USA) (2) 0.019" × 0.025" SS-straight length 18 cm long (American braces, USA).

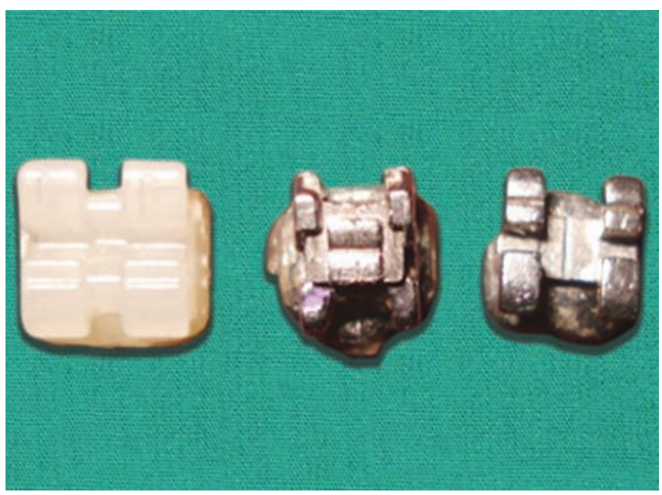


Fig. 1: Brackets used in the study (InVu, Damon, Gemini)

Fig. 2: Modules used in the study

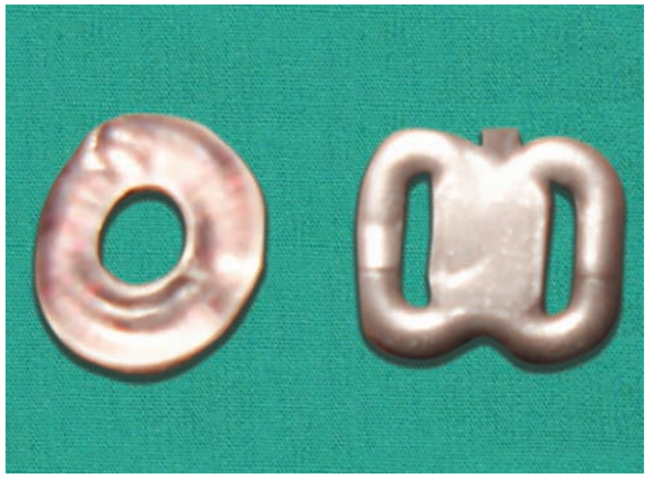


Fig. 3: Modules used in the study (Alastic, Slide)

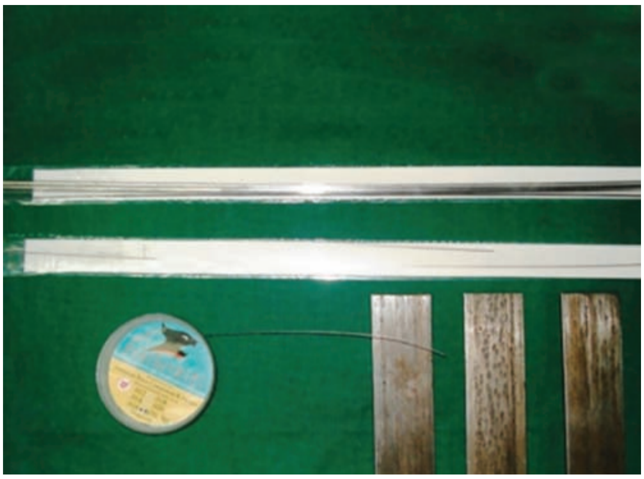


Fig. 4: Test models and wires used in the study

Fig. 5: Instron testing machine

Fig. 6: Computer used in the study

The brackets and archwires were tested in the following order:

- Gemini SS brackets
- InVu ceramic brackets
- Damon 2 SL brackets

Order of archwires studied:

- 0.016" nickel-titanium
- 0.019" × 0.025" stainless steel.

The gemini SS bracket was selected and the InVu ceramic bracket for its alleged high friction. The Damon 2 self-ligating bracket was chosen due to its proposed reduced friction over conventional brackets and their differing mechanisms of archwire engagement. The wires were chosen due to their frequent use in aligning and space closure stages.

The testing apparatus consisted of a friction-testing device, Instron universal testing instrument (model no 4501, Instron corp), load cell, signal amplifier, and computer (Figs 5 and 6). The upper member of the Instron machine engaged one end of the vertically oriented archwire, which was inserted in the bracket slots, and it pulled the archwire upward while the lower member of the machine held the metal bar in place. The load cell registered the force levels needed to move the wire along the 10 aligned brackets, and the values were transmitted to a computer. Each bracket archwire combination was tested 5 times with terminal brackets ligated and 5 times with all brackets ligated, which yielded friction and the displacement. The data was analyzed to determine which ligation methods and brackets yielded the least resistance to sliding.

The testing model used in this study was as described by Tecco et al.[7] The testing model was composed of an iron metal bar, approximately 10 cm long, 3.5 cm wide, and 1 cm thick (Figs 7 and 8). On one of the larger surfaces of the metal bar, 10 brackets (to represent the upper right second premolar to the upper left second premolar) were bonded using cyanoacrylate adhesive (Fevi Kwik, Pidilite Industries, Mumbai). For alignment of the brackets, a 0.021" × 0.028" SS archwire was inserted in the slots of the brackets, without ligation, before bonding. The brackets were kept at 8.5 mm apart. This distance is the average inter-bracket distance. All brackets were oriented in the direction that it would have in the oral cavity. The brackets were bonded from the border to the middle of the metal plate. After bonding of the brackets on the metal bar, the SS archwire was carefully removed.

However, as minor malalignments of the brackets or nonlinearity of the wire could not be controlled, to estimate the extent to which the friction could be attributed to malalignment rather than ligation, a confirmatory check was performed by measuring the friction for each bracket-archwire combination with only the terminal brackets ligated, each bracket-archwire combination tested 5 times (Fig. 9).

The model was made 3 times, using each of the three types of brackets, Damon SL II (Ormco), Gemini (Gemini series, 3M Unitek) and InVu Ceramic (TP orthodontics) brackets (Fig. 1).

Each model was inspected for general appropriateness before it was selected for frictional evaluations. The testing model was held in position by the pneumatic grip of the lower member of the machine.

Conventional SS and ceramic brackets were first ligated with conventional elastomeric modules (Alastik modules, 3M Unitek) with a hemostat and the tests were carried out (Fig. 10). No prestretching of the modules was done.[8] One minute was allotted for ligation of elastic modules, followed by a 3 minutes waiting period to allow a reproducible amount of stress relaxation to occur. Then the brackets were ligated with slide low-friction ligatures (Leone orthodontics) and tested which was followed by using Damon SL brackets.

Two types of archwires, 0.016" NiTi (American braces) (Fig. 11) and 0.019" × 0.025" SS wire (American braces) were

Fig. 7: Models with brackets aligned

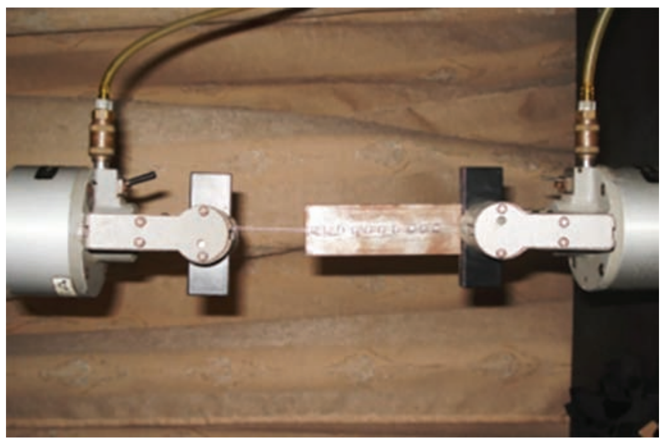


Fig. 8: Pneumatic grips, mounting plate, test brackets, arch wires and load cell

Fig. 9: Armamentarium used in the study

Fig. 10: Alastic modules on Gemini brackets with 0.016" NiTi

Fig. 11: Damon self-ligation brackets with 0.016" NiTi

selected as representative of the wires used in aligning and space closure stages of orthodontic treatment. Ten sample groups were made by using the following bracket-archwire combination:

1. Stainless steel brackets with conventional module and 0.016" NiTi.
2. Stainless steel brackets with conventional module and 0.019" × 0.025" SS.
3. Stainless steel brackets with low-friction module and 0.016" NiTi.
4. Stainless steel brackets with low-friction module and 0.019" × 0.025" SS.
5. Ceramic brackets with conventional module and 0.016" NiTi.
6. Ceramic brackets with conventional module and 0.019" × 0.025" SS.
7. Ceramic brackets with low-friction module and 0.016" NiTi.
8. Ceramic brackets with low-friction module and 0.019" × 0.025" SS.
9. Self-ligating brackets with 0.016" NiTi.
10. Self-ligating brackets with 0.019" × 0.025" SS.

Both wires were tested with conventional, ceramic and self-ligating brackets (Fig. 1). The drawing force value was evaluated 5 times for each archwire. A total of 100 testing procedures were performed in this investigation, 50 times with only the terminal brackets ligated and other 50 times with all the brackets ligated. The tests were run in the dry state at an ambient temperature of 34°C.

The universal testing machine (Instron corp, model no. 4501) used was set with a ±1 kN tension load cell, calibrated from 0 to 1000 gm. The archwires were gripped by the pneumatic grips of the upper member of the machine while the metal rod was held in position by the lower member of the machine. It allowed sliding of the wire along the 10 brackets and recording of the frictional forces (Fig. 7). A randomized sequence for each type of archwire was performed. Prior to each trial, the test bracket and archwire were wiped with 95% alcohol to remove any residue and then air-dried.

The archwires were moved through all 10 brackets with a crosshead speed of 0.5 mm/min. Once archwire movement began, each run lasted for approximately 5 minutes (2.5 mm). The load cell, ±1 kN located on top of the Instron machine recorded the friction at the bracket-archwire interface. Load values were calculated in Newtons (N) and converted to Grams. After each test, the testing machine was stopped, the bracket-archwire assembly removed, and a new assembly placed. This was done for five nonrepeated evaluations for each bracket-archwire combination. The load cell registered the force levels needed to move the wire along the 10 aligned brackets, and the values were transmitted to a computer.

STATISTICAL ANALYSIS

The frictional resistance was measured as the maximum force recorded during the movement of the archwire through the brackets. All the data was collected by the computer connected to the Instron machine. Each archwire-bracket combination was tested 5 times with the terminal brackets ligated and 5 times with all the brackets ligated. A total of 100 trials were performed. Load was measured in Newtons and converted to Grams. The data was transferred to Microsoft Excel 2000, where appropriate titles for archwires, brackets and trial number were placed. Data from every trial was graphed using Microsoft Excel 2000.

To find out the extent to which friction could be attributed to the minor malalignments or nonlinearity of the wire that occurred while bonding the brackets on the metal rod , the data obtained for all brackets ligated was compared with the data obtained for the terminal brackets ligated using Student's t-test.

The data was further analyzed to compare the resistance to sliding for two size archwires in relation to

a. The method of ligation.
b. Bracket material.
c. Archwire size and material.

The data were grouped under 0.016" NiTi and 0.019" × 0.025" SS wires. The mean and (SD) were calculated. The mean values were compared by one-way ANOVA. Multiple range tests by Tukey-Kramer honest significant difference (HSD) procedures were employed to identify the significant groups if p-value in one-way ANOVA is significant by using statistical software (Statistical Package for the Social Sciences (SPSS) for Windows. In the present study, p-value of <0.05 was considered as the level of significance.

RESULTS

The resistance to sliding of three different types of ligation was tested in this study. The force needed to pull the archwire through the brackets was measured in universal testing machine and the values were plotted using Microsoft Excel 2000. On the graph, the force increases to a peak after which it falls down and continues at a lower level (Graph 1). This peak denotes the static friction, the smallest force needed to initiate tooth movement. Therefore, selecting the highest force value recorded will be the amount of static friction present.

When the data for all 10 brackets ligated were compared against only the terminal brackets ligated, it was found to be statistically significantly higher (p-value < 0.001) than when terminal brackets alone were ligated for all bracket-archwire combinations except for one combination. Damon SL II engaged with 0.016" NiTi archwire showed no significant difference (Table 1).

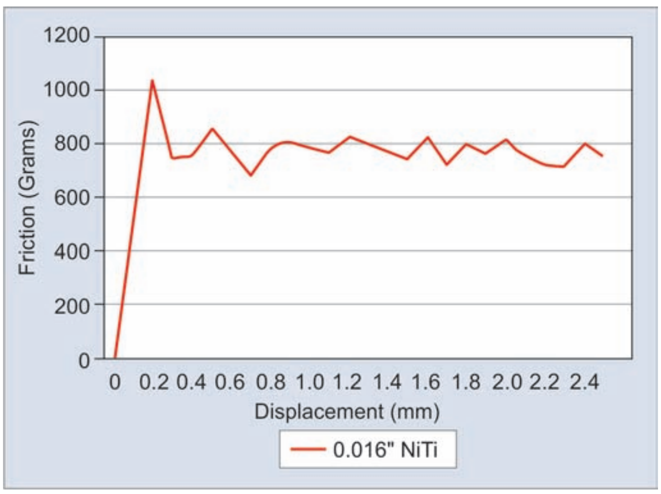
The frictional forces (F), observed when terminal brackets were ligated, all the brackets had been ligated, for each bracket-archwire combination are reported in Table 1 as the mean and SD, and their significant differences are shown.

Three types of ligation methods were compared with two types of bracket materials and two sizes of wires. One-way ANOVA was used to compare the three factors (ligation methods, bracket materials and wires) and significance was measured using Tukey's post hoc.

Method of Ligation

With 0.016" NiTi wire-stainless steel bracket combination, it was found that conventional ligation exerted considerable amount of friction than slide and self-ligation (p < 0.001), (Table 2). The difference between slide ligation and self-ligation was not statistically significant. Damon SL II exerted almost nil force on the archwire (Fig. 12).

With 0.019" × 0.025" stainless steel wire, conventional ligation exerted higher force than other two types of ligation. However an interesting finding was that with 0.019" × 0.025" wire, slide ligature exerted less friction than Damon self-ligating bracket. With the Tukey-HSD test, significant differences were found between conventional ligation with other two methods, and insignificant difference between the two (Table 2).



Graph 1: Sample graph of raw data with label

Fig. 12: Slide ligatures on Gemini brackets with 0.016" NiTi

Table 1: Frictional forces with terminal brackets ligated and all brackets ligated

			Friction (Grams)				
			Only terminal brackets ligated		All 10 brackets ligated		Significance
Archwire	Bracket	Ligation method	Mean	SD	Mean	SD	(p-value)
0.016" NiTi	Stainless steel	Conventional	310.000	10.863	1043.4	85.427	<0.001**
		Slide	11.500	1.164	12.881	3.123	0.046*
	Ceramic	Conventional	320.000	8.860	1206.8	76.280	<0.001**
		Slide	14.200	1.451	15.897	4.772	0.017*
		Damon	10.620	1.331	10.948	1.037	0.0675 (NS)
0.019" × 0.025" SS	Stainless steel	Conventional	410.400	8.562	1390.8	142.779	<0.001**
		Slide	18.260	1.146	32.98	2.844	0.028**
	Ceramic	Conventional	474.500	15.296	1634.8	184.937	<0.001**
		Slide	20.500	3.441	44.840	5.767	<0.001**
		Damon	15.160	2.131	50.24	2.145	0.002**

*denotes significant at 5% level (NS) denote insignificant; **denotes significant 1% level

Table 2: Frictional forces with three different ligation methods

Archwire	Bracket	Ligation	Friction (Grams) Mean	SD	Significance (p-value)
0.016" NiTi	Stainless steel	Conventional	10.43.40[b]	85.42	<0.01**
		Slide	12.88[a]	3.12	
		Damon	10.94[a]	1.037	
0.019" × 0.025"	Stainless steel	Conventional	1390.80[b]	142.77	<0.001**
		Slide	32.98[a]	5.767	
Stainless steel		Damon	50.24[a]	2.145	

**Indicates statistically significant at 0.01%; Different alphabets between groups indicate significance at 5% level

Archwire Size and Ligation

For the two types of archwires used in this study, it was found that with both 0.016" NiTi and 0.019" × 0.025" SS, conventional ligation exerted more amount of force than Slide and self-ligation. As the archwire size increased, the frictional value also increased for all the ligation methods (Graphs 2 and 3).

BRACKET MATERIAL

The frictional resistance values obtained when ceramic brackets were compared with SS for different ligation methods are given in Table 3. It was found that ceramic brackets when ligated with conventional elastomeric modules had higher friction compared to SS brackets. Their friction increased as the wire size was increased to 0.019" × 0.025" (Graphs 2 and 3). With Slide ligatures also the trend remained the same. However, with Slide ligatures, ceramic brackets exhibited lower friction than with conventional ligation with both wires.

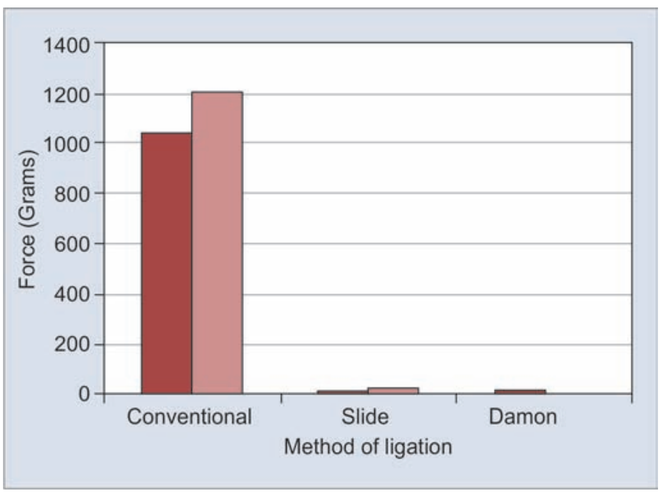
SLIDE *vs* DAMON

The frictional resistance of Slide and Damon were compared and the values are given in Table 4. When Slide ligature was compared with Damon self-ligation, for 0.016" NiTi, Damon exhibited lower friction than Slide ligation (Graph 4). But with 0.019" × 0.025" SS wire, the pattern was reversed (Graph 5). Slide ligatures exhibited less amount of friction than Damon self-ligation (Graph 6).

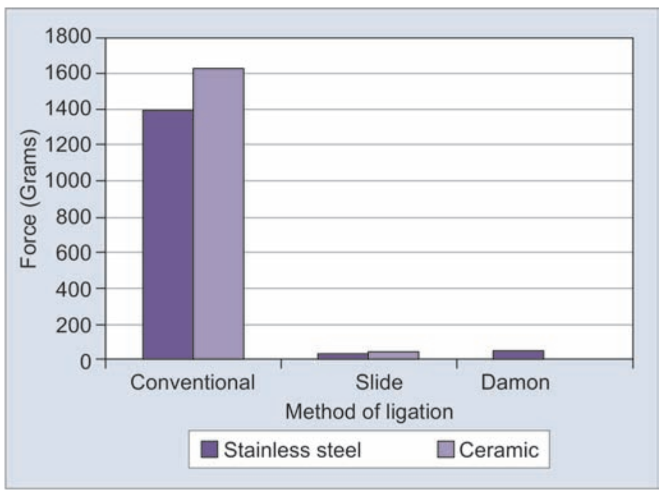
DISCUSSION

Sliding mechanics is commonly used in orthodontics in achieving closure of extraction spaces, distalization of teeth, eruption of high cuspids, correction of rotations, and leveling and aligning of teeth. It involves a relative displacement of wire through bracket slots. Frictional forces developed between the bracket and archwire opposes such movements 62. The consequent decrease in force available for tooth movement results in inhibition of tooth movement 52, requirement for larger retraction forces and anchorage taxation.

This higher frictional resistance requires an increase in the magnitude of orthodontic forces needed to overcome the friction, yet have enough residual force for optimal tooth movement. Therefore, orthodontists are always seeking techniques to minimize or even eliminate friction. In addition, as a result of appliance inefficiency and friction, it is difficult to determine and control the magnitude of force that is being received by the individual tooth.



Graph 2: The frictional values of three ligation methods with SS and ceramic brackets and 0.016" NiTi



Graph 3: The frictional values of three ligation methods with SS and ceramic brackets and 0.019" × 0.025" SS

Table 3: Frictional forces with three different bracket materials

Archwire	*Ligation*	*Bracket*	*Friction (Grams)* Mean	*SD*	*Significance (p-value)*
0.016" NiTi	Conventional	Stainless steel	1043.4	85.42	0.013*
		Ceramic	1206.8	76.28	
	Slide	Stainless steel	12.88	3.12	0.011*
		Ceramic	15.89	4.77	
0.019" × 0.025" Stainless steel	Conventional	Stainless steel	1390.8	142.77	0.048*
		Ceramic	1634.8	184.94	
	Slide	Stainless steel	32.98	2.84	<0.001**
		Ceramic	44.84	5.76	

*Indicates statistically significant at 5%; **indicates statistically significant at 0.01%

Table 4: Frictional forces with Slide and Damon self-ligation methods

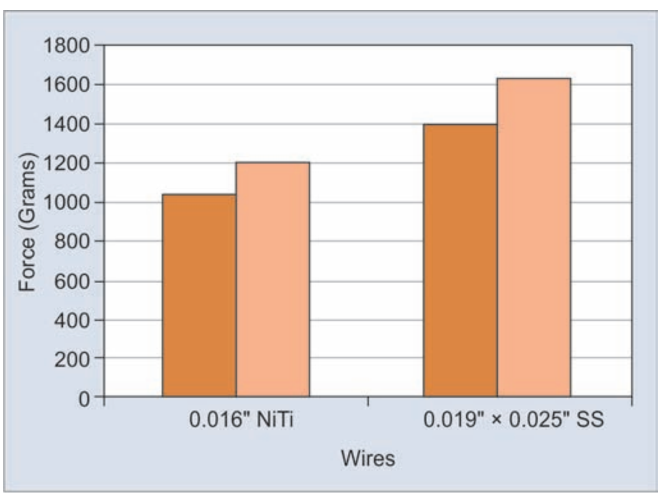
Archwire	*Ligation*	*Friction (Grams)* Mean	*SD*
0.016" NiTi	Slide	12.88	3.123
	Damon	10.95	1.037
0.019" × 0.025" Stainless steel	Slide	32.98	2.884
	Damon	50.24	2.145

Tidy[9] explained that slot size had no effect on frictional force and that a reduction in wire size and subsequent reduction in wire stiffness, permits greater tipping, and hence an increase in binding. Andreasen and Quevedo[10] concluded that slot size will not affect friction, whereas Frank and Nikolai[11] also concluded that bracket width did had an effect on friction, and it increased with wider brackets. Larger frictional forces with wider brackets may be attributed to the higher forces of ligation that result from the greater stretching of elastic ligatures on wider brackets. However, Drescher et al[12] concluded that as bracket width increased, friction decreased due to the reduction in tipping, and hence binding, by the wider bracket. No definite relationship has been found between archwire and bracket surface roughness and friction. The effects of roughness depend not only on the degree of surface roughness but also on the geometry of roughness, orientation of roughness features and relative hardness of the two contacting surfaces.

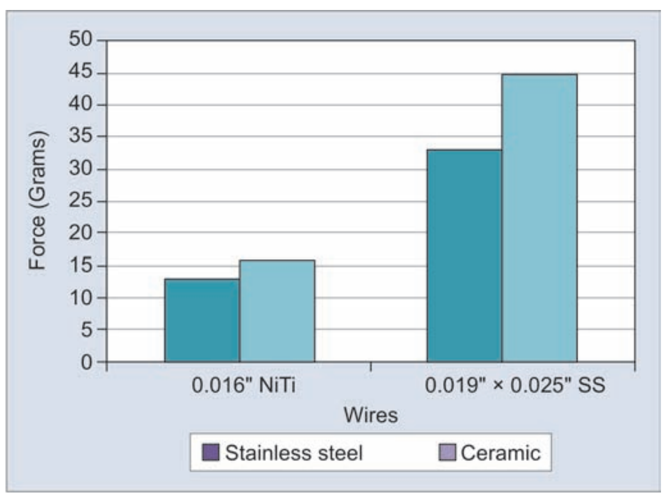
Schumacher et al[3] stated that friction was determined mostly by the nature of ligation and not by the dimensions of the different archwires. Elastomeric and SS ligation methods of engaging the wire in the bracket slot provide varying ligation force levels and affect frictional values. Steel ligatures were found to induce less friction than elastic ligature.

Andreasen and Quevedo,[10] however, concluded that steel ligatures can be very clinician sensitive and that as the force of ligation increased, the frictional resistance increased. Investigations have also shown that elastomeric modules produce a wide variation in force levels.

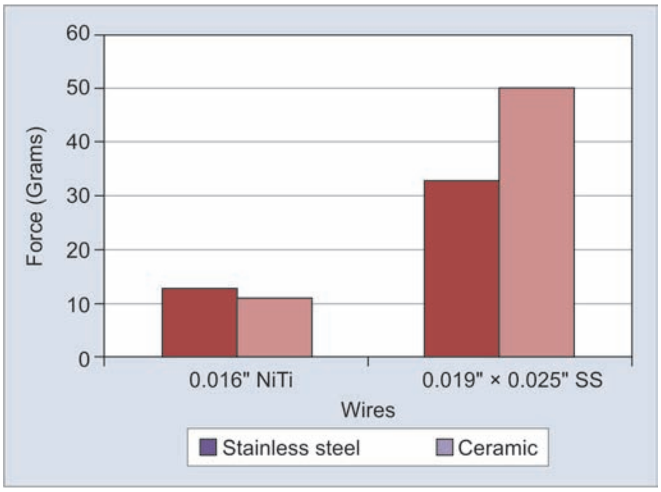
Elastomeric ligatures have been shown to increase friction by 50 to 175 gm. The placing of Figure 8 elastomeric ties was reported to increase friction by a factor of 70 to 220% compared to conventional elastomeric ties permanent deformation of elastomerics, related to time (stress relaxation), how fast they are stretched, and deformation as a result of hydrolysis due to water



Graph 4: The effect of increased wire dimension on friction with conventional ligation



Graph 5: The effect of increased wire dimension on friction with slide slow friction ligation



Graph 6: The effect of wire size when comparing Slide and Damon

and moist heat in the oral environment, were reported to change the degree of frictional resistance modules.[13]

Therefore, static friction decays over time with elastomeric ceramic brackets were developed to improve esthetics during orthodontic treatment. Those with a ceramic slot generated more friction than those with a SS slot and SS brackets increased roughness and porosity of the ceramic surface. This is most likely due to the pointed and a sharp bracket, slot edge thus, resulting in a higher coefficient of friction.[14]

Monocrystalline ceramic brackets have smoother surfaces than those of polycrystalline, but the observed amount of friction appears to be similar.[15]

The binding between the ligatures and the rough ceramic surface can also result in increased friction. Other investigators suggested that the major cause of the increased resistance of ceramic brackets is due to the difference in surface hardness between the ceramic material and SS, beta titanium or nickel titanium wires. Attempts to reduce friction associated with ceramic brackets, such as mechanical polishing of the slot surfaces, rounding the slot corners Kusy and Whitley[15] have met with variable success. Omana[16] advocated insertion of gold and stainless and silica slots, inclusion of bumps on the slot walls.

When a self-ligating bracket was allowed to tip until the edges of the slot contacted the archwire, no significant difference was observed between the resistance to sliding measured for self-ligating and conventional SL brackets.[15] Added to that, SL brackets are more expensive than ordinary brackets. It has also been proved that there is no difference in root resorption between Damon[2] SL and conventional edgewise brackets. Thorstenson and Kusy[17] pointed out that resistance to sliding occurs throughout orthodontic treatment.

The experimental design used in this study consists of 10 brackets aligned on a metal rod. Previously single brackets or a quadrant brackets were used for frictional studies. Frictional resistance increases as the number of brackets included in the assembly increases. The static friction recorded for single brackets generally doubled when two premolar brackets were used, indicating a linear increase in frictional forces with number of brackets.[18]

Therefore, 10 brackets model provides a more realistic vision of friction than a model involving single bracket or a quadrant.

In the present study, when the data for all 10 brackets ligated were compared against only the terminal brackets ligated, it was found to be statistically significantly higher than when terminal brackets alone were ligated for all bracket-archwire combinations. This indicated that the higher values obtained when all 10 brackets were ligated were due to the forces of ligation. Only one bracket-archwire combination bracket, Damon self-ligating bracket 0.016" NiTi wire combination showed statistically insignificant difference in both conditions. The low-friction related to the Damon SL bracket reflects the lack of normal force in these brackets. This accounts for the negligible friction at zero degrees found in some studies.

Sims et al[19] found that SL brackets require less force to produce tooth movement apply less frictional contact to the archwire than brackets.

Three different ligation methods were compared with each other using ANOVA followed by Tukey-Kramer HSD analysis for comparison between the groups. Of the three types of ligation methods compared, with 0.016" NiTi, conventional ligation exhibited higher friction (<0.001) than other methods. Both low-friction ligation and self-ligation showed significantly lower levels of friction. The significant difference between conventional ligation and self-ligation are similar to those reported by Pizzoni et al[20] and Thomas et al.[21] The difference between Slide and Damon ligation systems were insignificant. When combined with 0.019" × 0.025" SS wire also conventional ligation exhibited higher friction. But with 0.019" × 0.025" SS wire Slide ligatures showed less friction than the Damon system. This shows that Damon system has less friction only when used with lower diameter wires.

This finding is in agreement with the findings of Simona Tecco et al[7] hypothesized that this could be associated with their elastic design; probably, when coupled with the larger archwires, their elastic properties decrease and they may lose the capability to create high friction between the archwire and slot. Two types of bracket materials were also tested in this study. Ceramic brackets generated more friction than the SS brackets with both SS and NiTi wires. This is most likely due to the increased roughness and porosity of the ceramic surface and a sharp bracket slot edge, thus, resulting in a higher coefficient of friction. This is in agreement with the study of Loftus et al[22] who showed that ceramic brackets generated higher friction than SS. When compared to conventional ligation, Slide ligatures were able to reduce the friction of ceramic brackets. The presence of low-friction ligatures enables ceramic brackets to release a significant amount of orthodontic force during sliding, very similarly to SS brackets. When slide was compared with Damon system, for small round NiTi wires, Damon showed lower frictional value, although it was not statistically significant. With larger SS wires, Damon showed higher friction than slide low-friction ligatures.

Frictional demands during orthodontic treatment vary with the stage of the treatment. It is highly desirable to have the minimum friction during the aligning and space closure stages of treatment and more amount of friction in later stages. Previous studies have proven that conventional ligation exerts very high amounts of normal force on the bracket-archwire couple leading to higher friction. The solution to reduce friction is the use of SL brackets which exert very minimal normal force. But they have associated problems as well, particularly higher cost when compared to conventional brackets and reduced control over tooth movements.[23]

Although the present study does not replicate the exact conditions of the oral cavity and second and third order moments, effect of saliva, functional forces of the stomatognathic muscles, and also the force degradation of elastomers are not taken into account, using a 10 brackets model gives a more credible record of friction than single or a quadrant bracket study.

Low-friction is suggested as an alternative between conventional ligation and self-ligation. Slide ligature is valuable option to Damon self-ligating bracket in that it provides comparable amount of friction as Damon when low-friction is required and gives the option of using conventional or steel ligatures when higher friction is required in the later parts of the treatment at a fraction of a cost of SL brackets. The concept of differential friction whereby applying low-friction modules on specific teeth that needs low-friction (such as highly placed canines, lingually blocked out incisor etc.) friction has been described recently.

The frictional needs of the specific cases are evaluated early in the treatment and conventional or low-friction modules can be applied depending on that. As it reduces the friction of ceramic brackets also, the use of low-friction ligatures allows the orthodontist to join the advantages of low-friction biomechanics to those in the use of esthetic ceramic brackets.

The study on low-friction ligation has opened new avenues for further research. The force degradation properties of these modules should be studied both *in vivo* and *in vitro*. The frictional properties should also be investigated in a model which can provide second and third order angulations and simulate the effect of mastication and in presence of saliva. It should also be tested against metal lined ceramic brackets and esthetic SL brackets.

SUMMARY AND CONCLUSION

This study compared the frictional resistance of slide low-friction ligation with conventional and self-ligation methods and with ceramic and SS brackets. The frictional resistance was measured in a universal testing machine by pulling a wire through 10 brackets aligned in a linear manner attached to a metal bar.

The following conclusions were made:

- Conventional ligation exhibited higher fiction than low-friction and self-ligation with all the archwire-bracket combinations.
- Damon self-ligating system exhibited less friction than low-friction ligation with lower archwires and higher friction with higher archwires.
- Slide low-friction ligatures were able to reduce the friction of ceramic brackets in a similar way to SS brackets.

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