

## Effects of Different Ligature Materials on Friction in Sliding Mechanics

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### Abstract:

**Background:** During orthodontic tooth movement friction occurs at the bracket wire interface. Out of the total force applied to the tooth movement, some of it is dissipated as friction, and the remainder is transferred to the supporting structures of the tooth to mediate tooth movement. However many factors affect friction, and method of arch wire ligation being an important contributing factor. Hence, this study was carried out to evaluate the effects of different ligature materials on friction in sliding mechanics and to compare the effect of environment (dry and wet) on friction produced in sliding mechanics.

**Materials and Methods:** The evaluation of friction between the bracket and the archwire consisted of a simulated half arch fixed appliance with archwire ligated in a vertical position. Four 0.022" maxillary stainless steel premolar brackets having a - 0° torque and 0° angulation were aligned with a 0.019" × 0.025" stainless steel arch wire onto a rigid Plexiglass sheet. The movable test bracket was fitted with a 10 mm long, 0.045" thick stainless steel power arm on the bonding surface. Testing was performed on a Hounsfield material testing machine. A total of 100 g weight was suspended from the power arm and the load needed to move the bracket over the distance of not <4 mm across the central span was recorded separately. Fifteen representative readings were taken with one reading per test sample.

**Results:** The results showed that the mean frictional force of different groups in dry and wet state was statistically significantly different. The mean frictional force in a dry state was statistically significantly higher than wet state in elastomeric group.

**Conclusion:** The type of ligation material and environment significantly affected the degree of friction generated during sliding mechanics. Teflon coated stainless steel ligatures produced the least friction among the materials tested in both dry and wet conditions

and there was no significant effect on friction in this group caused due to lubrication.

**Key Words:** Friction, ligature, sliding mechanics

### Introduction

Orthodontics involves tooth movement. Two types of mechanics are involved in orthodontic tooth movement; they are segmental or sectional mechanics also called as frictionless mechanics and the friction mechanics or sliding mechanics. One of the main differentiating factors between the two types of mechanics pertains to friction.<sup>1</sup> In clinical practice, friction occurs at the bracket wire interface. Whatever force is applied for the tooth movement, some of it is dissipated as friction, and the remainder is transferred to the supporting structures of the tooth to mediate tooth movement. Hence, it is necessary that the applied force is of sufficient magnitude to overcome friction and at the same time lie within the optimum range of force necessary for tooth movement.<sup>1,2</sup> Friction can be defined as the force that acts on the surface between two objects when one object slides relative to the other. It may be divided into static friction, which is the force required to initiate the tooth movement and kinetic friction the force that resists motion.<sup>1</sup>

A number of factors have been implicated in influencing friction which include kinematics of the surfaces in contact (the direction and magnitude of the relative motion between the surfaces in contact), externally applied loads and/or displacements (including orthodontic ligation), environmental conditions such as temperature and lubricants, surface topography, and material properties.<sup>3</sup> The method of archwire ligation is an important factor contributing to the frictional forces generated. Loosely tied stainless steel ligatures are generally thought to produce less friction than the elastomeric ligatures. Newer elastomeric ligatures like silicone coated and polymer coated elastomeric ligatures are claimed to be low friction ligature material by the manufacturers.

The aim of this study is to investigate the effect of ligation material and environment (dry and artificial saliva) on friction in sliding mechanics.

### Materials and Methods

- Brackets: 0.022" slot standard edgewise stainless steel (maxillary right premolar) brackets - with 0° torques and 0° angulations were used (Libral traders)
- Archwire: Straight lengths of 0.019" × 0.025" stainless steel

wire (3M Unitek), each 7 cm long, was selected because it is the recommended size for sliding mechanics with 0.022" slot size brackets

c. Ligation materials:

- 0.010" stainless steel ligature wire (G & H wire Company)
- 0.010" Teflon coated stainless steel ligatures (G & H wire Company)
- 0.12" elastomeric ligature ties (American Orthodontics).

d. Artificial saliva: Wet mouth salivary substitute (ICPA Pharmaceuticals)

e. Armamentarium: Pin and ligature cutter, ligature tucker, straight probe, twizer, alcohol and cotton

f. Jig: A custom made apparatus was constructed to hold the 0.019" × 0.025" wire parallel to the vertical framework of the universal strength testing machine (Figure 1)

g. Machine: A universal strength testing machine (Instron 5564, Italy) was used to carry out the test (Figure 2).

The specimens were tested in two conditions: Dry state, wet state. Each bracket and archwire were used for maximum of 15 readings and after 15 readings a new bracket and archwire was used. Each ligature was used only once.

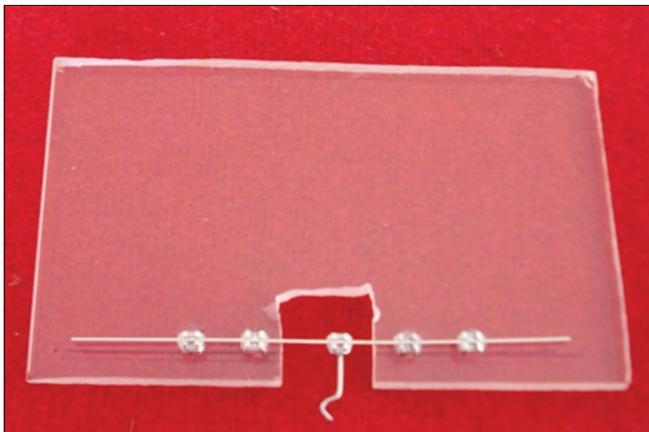


Figure 1: Testing jig with test sample.

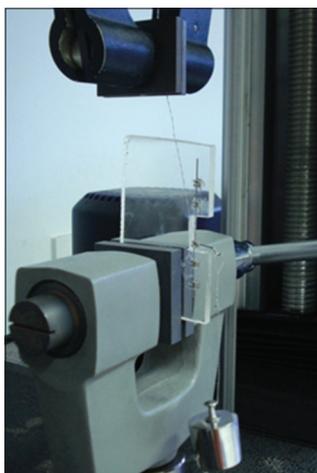


Figure 2: Testing of sample on Hounsfield universal testing machine

### Experimental groups

The whole sample size was divided into three groups. The three groups were further subdivided into two subgroups - A and B. Subgroup A represented the test in a dry state and subgroup B represented the test in a wet state. 15 readings were taken per subgroup.

### Test groups

Group	Specimen (combination used)
1A	Brackets with stainless steel ligatures in dry state
1B	Brackets with stainless steel ligatures in wet state
2A	Brackets with Teflon coated stainless steel ligatures in dry state
2B	Brackets with Teflon coated stainless steel ligatures in wet state
3A	Brackets with elastomeric ligature in dry state
3B	Brackets with elastomeric ligature in wet state
Total sample size is 90	

### Method

The evaluation of friction between the bracket and the archwire consisted of a simulated half arch fixed appliance with archwire ligated in a vertical position. Four 0.022" maxillary stainless steel premolar brackets having a - 0° torque and 0° angulation were aligned with a 0.019" × 0.025" stainless steel arch wire and bonded with a cynoacrylate resin Fevikvik (Pidilite) onto a rigid Plexiglass sheet at 8 mm intervals. This length is the recommended interbracket distance. A span of 16 mm was left at the center for sliding the test bracket to simulate tooth movement. The test samples were ligated to the four brackets fixed to the jig with elastomeric ties. The specimens for the dry group were ligated 1 h prior to testing. Specimens tested in the wet field were soaked in artificial saliva for 1 h prior to testing. This helps in minimizing differences in elastic tension between the groups.

The movable test bracket was fitted with a 10 mm long, 0.045" thick stainless steel power arm on the bonding surface with the help of light-cure composite material. From this power arm, a weight of 100 g was attached to represent the single equivalent force acting at the center of resistance of the tooth root. The length of the power arm was chosen to represent the distance from the slot to center of resistance of a typical premolar tooth.

Each test sample was prepared by cleaning the bracket and archwire with an alcohol wipe before the modules or ligatures were tied. For preparing the test samples for Group 1 and 2, the stainless steel ligatures were initially fully tightened with a ligature tying plier and then unwound by three turns. Loose ligation was checked by rocking the ligature to confirm that there was a little play between the ligature and the archwire. The end of the ligature was then tucked in over the archwire on the right corner with a tucker. For preparing the test samples for Group 3, the passive elastomeric ties were placed under one tie-wing, and subsequent ligation was completed with the help of a straight probe.

Testing was performed on a Hounsfield material testing machine with a crosshead speed of 5 mm/min with a full scale load set at 50 N. The movable premolar bracket was suspended from the load cell of the machine using the upper cross head with a length of 0.010” stainless steel wire, while the jig was mounted with the lower crosshead and was held rigidly. The upper crosshead connected with the suspended test bracket moved upward at a speed of 5 mm/min. A trial run was performed at the start of each test with no load on the power arm to remove the slack from the suspended wire. Then a 100 g weight was suspended from the power arm and the load needed to move the bracket over the distance of not <4 mm across the central span was recorded separately. 15 representative readings were taken with one reading per test sample. The load cell reading represented the clinical force of retraction that would be applied to the tooth, a part of which will be critical friction while the rest would be the translation force on the tooth.

**Results**

The data obtained on testing the frictional resistance to sliding at the end of this *in-vitro* study was calculated and tabulated. The frictional resistance was recorded in kilograms and converted to grams. The mean, standard deviation (SD), standard error, and the range of frictional force (maximum and minimum) for each group in a dry state were calculated.

Graphs 1 and 2 depict the mean frictional force obtained for various groups in dry and wet state respectively, in graphical form.

One-way ANOVA test was applied to test whether there is a significant difference in frictional force in a dry state among three groups. It was observed that mean frictional force of different groups in a dry state is statistically significantly different ( $P < 0.001$ ) same is shown in Table 1.

Table 2 shows the result of Tukey’s *post-hoc* test in a dry state, which was used for pair-wise comparison for each group. It was observed that, the mean frictional force of stainless steel group was statistically significantly higher than the mean frictional force of Teflon coated group in a dry state ( $P = 0.002$ ). The mean frictional force of stainless steel group was statistically significantly lesser than mean frictional force of elastomeric group in a dry state. ( $P < 0.001$ ).The mean frictional force of Teflon coated group was statistically significantly lesser than mean frictional force of elastomeric group in a dry state ( $P < 0.001$ ).

One-way ANOVA test was applied to test whether there is a significant difference in frictional force in the wet state among three groups. It was observed that mean frictional force of different groups in the wet state is statistically significantly different ( $P < 0.001$ ) same is shown in Table 3.

**Table 1: One-way ANOVA in dry state.**

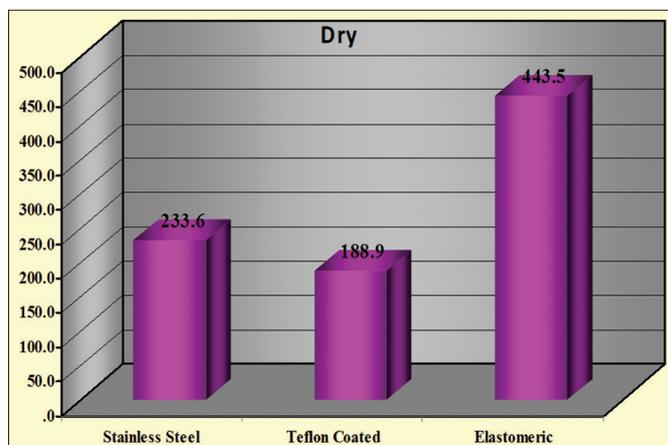
Dry	Sum of squares	df	Mean square	F	P value	Significance
Between groups	554331.2	2	277165.6	259.6	<0.001	Significant
Within groups	44837.1	42	1067.5			
Total	599168.3	44				

**Table 2: Tukey’s post-hoc test in dry state.**

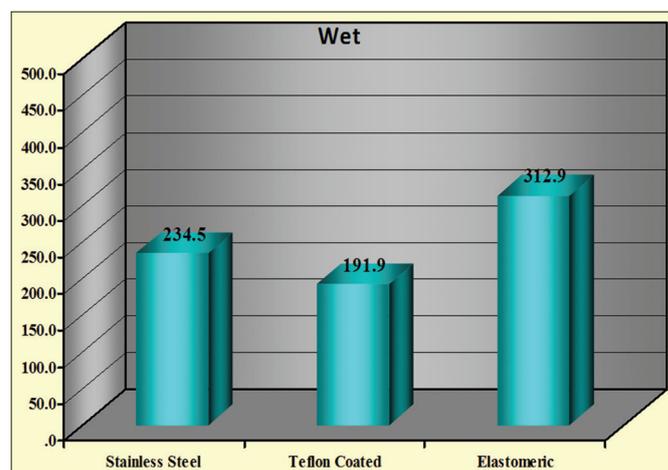
Dry	Mean difference	Standard error	P value
Stainless steel			
Teflon coated	44.7	11.9	0.002
Stainless steel			
Elastomeric	-209.9	11.9	<0.001
Teflon coated			
Elastomeric	-254.6	11.9	<0.002

**Table 3: One-way ANOVA in wet state.**

Wet	Sum of squares	df	Mean square	F	P value	Significance
Between groups	113011.6	2	56505.8	55.3	<0.001	Significant
Within groups	42931.6	42	1022.2			
Total	155943.2	44				



**Graph 1:** Comparison of frictional force in various groups in dry state.



**Graph 2:** Comparison of frictional force in various groups in wet state.

Table 4 shows the results of Tukey's *post-hoc* test in the wet state, which was used for pair-wise comparison for each group. It was observed that, the mean frictional force of stainless steel group is statistically significantly higher than the mean frictional force of Teflon coated group in the wet state ( $P = 0.002$ ). The mean frictional force of stainless steel group is statistically significantly lesser than mean frictional force of elastomeric group in the wet state ( $P < 0.001$ ). The mean frictional force of Teflon coated group is statistically significantly lesser than mean frictional force of elastomeric group in the wet state ( $P < 0.001$ ).

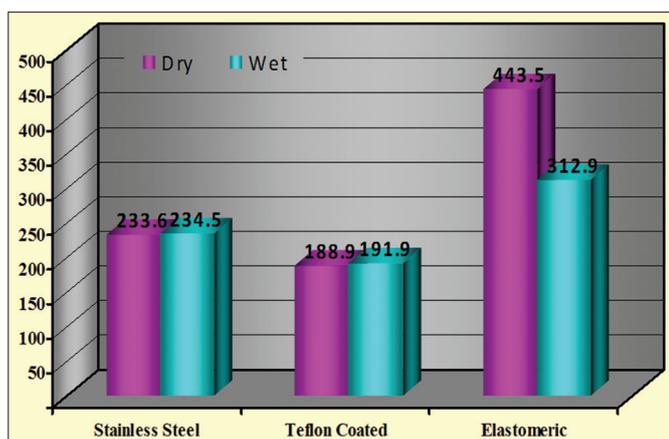
Graph 3 shows the graphical representation of mean fractional forces from all three groups in both states (dry and wet).

In Table 5, results of paired *t*-test are shown, which is used to compare mean frictional force in dry and wet state among different groups. It was observed that, the mean frictional force of stainless steel was not statistically significantly different among dry and wet state ( $P = 0.941$ ). The mean frictional force in the wet state was not statistically significantly different from the dry state in Teflon coated group ( $P = 0.590$ ). The mean

Wet	Mean difference	Standard error	P value
Stainless steel			
Teflon coated	42.6	11.7	0.002
Stainless steel			
Elastomeric	-78.4	11.7	<0.001
Teflon coated			
Elastomeric	-121.0	11.7	<0.001

Group	Dry		Wet		<i>t</i> -test	
	Mean	SD	Mean	SD	P value	Significance
Stainless steel	233.6	29.0	234.5	42.7	0.941	Not significant
Teflon coated	188.9	21.8	191.9	23.2	0.590	Not significant
Elastomeric	443.5	43.4	312.9	26.5	<0.001	Significant

SD: Standard deviation



**Graph 3:** Comparison of frictional force in various groups in dry and wet state.

frictional force in dry state was statistically significantly higher than wet state in elastomeric group ( $P < 0.001$ ).

## Discussion

Friction is a force that retards or resists the relative motion of two objects in contact. Fixed appliances used in orthodontic therapy are always associated with the generation of friction between the bracket arch wire interface and the ligation wire interface. It has been proven in previous studies that the material properties of the bracket, wire, and the ligation material play a significant role in the generation of friction. The tooth movement can occur only when applied forces adequately overcome the friction generated.

Various mechanical and biological factors affect frictional properties these factors include archwire properties, i.e. arch wire material and dimensions, bracket to arch wire ligation i.e. type of ligation material, and bracket properties, i.e. the bracket slot dimension, the biological properties include saliva and masticatory forces.<sup>2</sup>

Sliding mechanics is the term usually applied in orthodontics to the controlled movement of teeth along the arch wire. It is hypothesized that, when a slotted bracket is sliding along an arch wire friction impedes movement of the tooth to which the bracket is attached and reduces the force available for tooth movement.<sup>3</sup>

Ligatures commonly used in orthodontics are either heat treated stainless-steel or elastomeric rings.<sup>4</sup> Elastomeric products have been in use in orthodontics since 1960's as ligatures, continuous chains, etc. Technologically, this is one area that has undergone various studies to prove their existence in the field of orthodontics. These studies have increased the acceptance of these materials in clinical orthodontics.<sup>5</sup>

Elastomeric ligatures are widely used for engaging the arch wire in the bracket slot due to their ease of application, esthetic appearance, and potential for fluoride release. The force exerted by the elastomeric ligatures is usually in excess than what is required to secure the arch wire in the bracket slot. This excess binding force impedes movement of the bracket along the arch wire by increasing friction, thereby increasing the treatment duration.

The objective of this study was to investigate the effects of ligation method and environment (in dry and wet state) on friction in sliding mechanics.

The basic study design was to compare three ligation materials - stainless steel, elastomeric ligatures, and Teflon coated stainless steel ligature - in a custom made jig with 0.019" × 0.025" stainless steel arch wire in 0.022" slot bracket combination in dry and wet conditions.

Samples were divided into three groups, which were again subdivided into two sub-groups which were in the dry and wet conditions.

Effects of artificial saliva on sample were evaluated by putting the test samples in artificial saliva for at least 1 h prior to testing. Samples in dry state were also ligated 1 h prior to testing to avoid any difference in elastic tension of the ligature materials.

The effect on friction of the two main variables i.e. type of ligation material and environment (dry and wet) were analyzed with ANOVA test, Tukey's *post-hoc* test and paired *t*-test.

The results indicated that each variable had a very high significant effect on friction generated at the interface. This is in conformation with studies conducted by Hain *et al.*,<sup>6,7</sup> Kusy *et al.*,<sup>8,9</sup> Tselepis *et al.*,<sup>10</sup> Stannard *et al.*,<sup>11</sup> and Bednar *et al.*<sup>12</sup> All these studies have also found a significant contribution of these two factors to the variance in there data.

In dry environment, the lowest mean frictional resistance was found to be for Teflon coated stainless steel group with a mean value of 188.9 g and SD of 21.8, followed by stainless steel group with mean value of 233.6 g (SD-29), followed by the elastomeric ligatures with mean value of 443.5 g (SD-43.4).

In wet environment (artificial saliva), the lowest mean frictional resistance was found to be for Teflon coated stainless steel group ( $191.9 \pm 23.2$  g), followed by stainless steel ( $234.5 \pm 42.7$  g) and elastomeric ligatures ( $312.9 \pm 26.5$  g).

Since the interaction between ligation material and environment was also found to be highly significant, the three material groups were tested for each environment (dry and wet) separately with one-way ANOVA tests (Tables 1 and 3). The three material groups were found to be significantly different for each environment also suggesting a high difference in mean performance (frictional force).

Consequently, pair-wise comparison between various material groups was done using Tukey's *post-hoc* test. In the dry environment, pair-wise comparison for each group shows that the mean frictional force of stainless steel group is statistically significantly higher than the mean frictional force of Teflon coated group in a dry state. The mean frictional force of stainless steel group is statistically significantly lesser than mean frictional force of elastomeric group in a dry state. The mean frictional force of Teflon coated group is statistically significantly lesser than mean frictional force of elastomeric group in dry state (Table 2).

In wet environment, pair-wise comparison for each group shows that the mean frictional force of stainless steel group is statistically significantly higher than the mean frictional force

of Teflon coated group in the wet state. The mean frictional force of stainless steel group is statistically significantly lesser than mean frictional force of elastomeric group in the wet state. The mean frictional force of Teflon coated group is statistically significantly lesser than mean frictional force of elastomeric group in the wet state (Table 4).

The mean frictional force between each group in separate environment was compared and it was seen that the mean frictional force of stainless steel was not significantly different among dry and wet state, the mean frictional force in wet state was not significantly different from dry state in Teflon coated group, while the mean frictional force in dry state was significantly higher than wet state in elastomeric group.

The variety of experimental methods used in the literature makes it difficult to compare the results of different studies of this type. Loftus and Artum,<sup>13</sup> have commented on the high variability of friction measurement methods. The amount of freedom of movement of the bracket relative to the archwire appears to affect results greatly. Differences in the finish of the same material (e.g. surface smoothness of wire from different manufactures) also make it difficult to compare findings and to isolate individual contributing factors. In addition, variation in time elapsed between ligation and testing, could affect the recorded values as a result of differing amounts of stress relaxation of the elastic modules.<sup>12</sup>

Stainless steel ligature produces a mean frictional force of 233.6 g in the dry environment and 234.5 g in the artificial saliva. The result of dry group was comparable to those of Vaughan *et al.*,<sup>2</sup> who found a similar range of mean frictional force.

Franco *et al.*,<sup>14</sup> found Teflon coated ligatures to produce the least friction of all ligation methods. The present study also showed similar findings. The low friction arising from a ligature depends upon its coefficient of friction and forces it exerts on the bracket and archwire. Teflon has a low coefficient of friction, and therefore Teflon-coated ligatures invoke lower forces of friction than either elastomeric ligatures or uncoated steel ligatures.

In their studies Bednar *et al.*,<sup>12</sup> found stainless steel ligature to produce less frictional force when compare to elastomeric ligatures. This is also found to be true in the present study.

However, Frank *et al.*,<sup>15</sup> and Thorstenson,<sup>16</sup> found in their studies no significant difference in frictional force between stainless steel and elastomeric ligatures.

In the present study, stainless steel and Teflon coated ligatures when compared for frictional force in dry and wet environment was not showing any significant difference, whereas the

frictional force significantly decreases in wet environment as compare to dry in case of elastomeric ligatures.

Thorstenson,<sup>16</sup> in their study on frictional forces concluded that saliva does not have any significant role in the generation of friction.

However, studies performed by Hain *et al.*,<sup>6</sup> Tselepis *et al.*,<sup>10</sup> customs and central excise

Baker *et al.*,<sup>17</sup> revealed that frictional forces decrease in the presence of saliva, which is also seen in the present study in case of elastomeric ligature. The explanation given by them for these results is that saliva acts as a lubricant between two surfaces. Tselepis *et al.*,<sup>10</sup> explains these differing observations on the basis of different saliva solutions and techniques of applying the saliva to the bracket/archwire assembly.

Baty *et al.*,<sup>18</sup> has noted that when extended and exposed to an oral environment, elastomeric materials absorb water and saliva, permanently stain, and suffer a breakdown of internal bonds that leads to permanent deformation. They also experience a rapid loss of force due to stress relaxation, resulting in a gradual loss of effectiveness. This loss of force makes it difficult for orthodontists to determine the actual binding force transmitted.

Bortoly *et al.*,<sup>19</sup> stated elastomeric materials in general, exhibit force decay after stretched. In oral environment, these changes might be more significant because of moisture and saliva. Besides dimensional alterations, the exposure of elastomers to water leads to weakening of intermolecular forces and subsequently to matrix decomposition and chemical degradation of these materials. Clinically this reduction might be considered as an advantage in orthodontic procedures such as space closure and an overjet reduction with sliding mechanics, especially for the critical posterior anchorage.

Other studies performed by Stannard *et al.*,<sup>11</sup> Pratten *et al.*,<sup>20</sup> and Kusy *et al.*,<sup>8</sup> conclude that saliva increases the friction generated. Stannard *et al.* attributed this phenomenon to electrolytic polarity of the liquid like saliva, which results in increased atomic attraction among ionic materials as explained by the adhesion theory of friction.

Pratten *et al.*,<sup>20</sup> explained that at high loads, saliva might be forced out from the contacts between the archwire and the bracket, resulting in the increased frictional values.

Kusy *et al.*,<sup>8</sup> stated that in stainless steel bracket-archwire couple, the chromium oxide layer rendered the surface chemically passive and hence smooth, whereas saliva may act to chemically breakdown the surface and act as an adhesive because of surface tension effects thus leading to increased frictional values.

It is clear from the present study that the Teflon coated ligatures produce the least friction at the wire/ligature interface. This reduction could be of benefit clinically. However, when considering the total friction generated at the bracket/archwire interface in clinical situation factors other than ligation are also involved, including binding forces between archwire and bracket as teeth moved through a series of tipping and uprighting phases.<sup>21,22</sup>

### Conclusion

The objective of this study was to investigate the effect of ligation material and environment (dry and wet) on friction in sliding mechanics. The study was designed to compare three ligation materials - Stainless steel, elastomeric ligatures (Sili Ties), and Teflon coated stainless steel ligatures in a custom made jig using a 0.019" × 0.025" stainless steel arch wire in a 0.022" slot under dry and wet conditions. The following conclusions were drawn:

1. When arch wire and bracket angulation was kept constant the type of ligation material and the environment significantly affected the degree of friction generated during sliding mechanics
2. Teflon coated stainless steel ligatures produced the least friction amongst the materials tested in both dry and wet conditions, and there was no significant effect on friction in this group caused due to lubrication
3. Artificial saliva produced increased friction in elastomeric modules, but does not cause any significant difference in friction when stainless steel or Teflon coated stainless steel ligatures are used.

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