In vitro evaluation of different methods of ligation on friction in sliding mechanics

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Aim: The aim of this study was to evaluate the effect of different methods of ligation in tie configurations on friction in dry and wet conditions. Methods: Four methods of ligations were used: regular round tie, figure eight, twist, and diagonal. Materials used were Alastik (3M Unitek), Power O module (ORMCO), O-ring ligatures (JES), stainless steel ligatures (TP Orthodontics), 0.019 × 0.025–inch straight-length stainless steel archwires and stainless steel MBT 0.022-inch slot brackets (3M Unitek). Results: Figure eight ligation had the highest friction, followed by round, twist, and diagonal ligation, in the descending order. Comparisons were statistically significant with a 100-g load. Dry group samples had higher friction than the wet group. These comparisons were statistically significant with a 50-g load. Conclusions: The study concluded that figure eight ligation had the highest friction, and diagonal ligation produced the least friction. Among the dry and wet groups, lubrication showed significant reduction in friction. ORTHODONTICS (CHIC) 2013;14:e102–e109. doi: 10.11607/ortho.905

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When comparing operator skill in contemporary treatment mechanics with the preadjusted edgewise appliance to other earlier fixed appliances, it is noticed that the need for wire bending has been substantially reduced. Space closure using friction mechanics relies exclusively on sliding mechanics, which itself will reduce the burden of formation of complicated loop configurations for retraction. Whenever sliding occurs, frictional resistance is encountered, which is an unavoidable variable, and clinically this translates to a loss of applied force.

Because the efficiency of fixed appliance therapy depends on the fraction of force delivered with respect to the force applied, high frictional forces due to the interaction between the bracket and the guiding archwire affect treatment outcomes and duration in a negative manner. By controlling frictional resistance at the bracket-archwire-ligature interfaces, lower levels of force can be applied during orthodontic treatment to obtain an optimal biologic response for effective tooth movement.

Friction can be defined as the force that acts at the surface between two objects when one object slides relative to the other.¹² A number of factors are said to influence frictional resistance. These variables may be either mechanical or biologic. Mechanical variables include bracket material,³–⁵ bracket width,⁶,⁷
Controversy

slot size, angulation, wire material, wire size, wire cross section, ligature material, and force of ligation. Biologic variables implicated are saliva, plaque, acquired pellicle, and corrosion. With an aim of reducing friction, self-ligating brackets have been introduced, and they have been shown to reduce friction to a certain extent.

The type of ligation employed to secure the archwire to the brackets can account for a part of frictional resistance occurring during sliding mechanics. One of the problems encountered with elastomeric modules is that they can act as a potential host for microbial accumulation. Current scientific thinking suggests that materials used in the oral environment should be poor bio-hosts. Coating elastomeric ligatures with a hydrophobic polymeric substance has been suggested as a method for eliminating friction at the archwire-bracket interface and in repelling salivary adherents. New Alastik (3M Unitek), Power O module (ORMCO), and O-ring ligatures (JES) have been marketed for potential reduction in friction and treatment time. They also are intended to provide good retention, tensile strength, and better elastic properties. If this is indeed true, then canine retraction and other tooth movements could be facilitated with greater ease, at lower force levels, and without taxing the anchorage.

In securing the archwire to the brackets during sliding, the amount of frictional resistance depends not only on the different types of ligatures used, but also on different ligation techniques employed. Different methods of bracket-archwire ligation (ie, tie configurations) produce different levels of friction in the bracket-archwire interface. Different methods of ligation (ie, tie configurations) can be used, such as:

1. Regular round tie pattern
2. Figure eight pattern
3. Twist ligation method
4. Diagonal ligation pattern

Dry and wet conditions also affect the level of friction in the bracket-archwire interface. Using these modules as well as the conventional stainless steel ligature, it was decided to compare the effect of different ligation methods on frictional resistance occurring during sliding mechanics.

METHODS

This study was conducted in the Department of Orthodontics, Government Dental College, Trivandrum, Kerala, India. The in vitro tests were conducted at the Regional Research Laboratory, Pappanamcode, Trivandrum, Kerala, India. The basic study design is to evaluate the effect of ligation on friction using the aforementioned four different ligation methods (Figs 1 and 2) and to evaluate the friction in both dry and wet conditions using four different ligature materials: Alastik, Power O module, O-ring, and conventional stainless steel (TP Orthodontics).
Frictional characteristics
The evaluation of friction between the brackets and the archwire was carried out as per the test protocol described by Tidy. It consisted of a simulated half-arch fixed appliance with archwire ligated in position. Four standard stainless steel MBT brackets (3M Unitek) having a 0.022 × 0.028-inch slot with central incisor 17-degree torque and 4-degree angulation, lateral incisor 10-degree torque and 8-degree angulation, and first and second premolar –7-degree torque and 0-degree angulation were bonded onto a rigid Perspex sheet (Plexiglas) at 8-mm intervals (Fig 3). Canine brackets with –7-degree torque and 8-degree angulation were used for sliding along the archwire. A space of 16 mm was left at the center for sliding the canine bracket to simulate canine retraction. The movable canine bracket was soldered with a 12-mm power arm, from which weights of 50 and 100 g were hung to represent the single equivalent force acting at the center of resistance of the tooth.

All tests were conducted in both dry and wet conditions with an Instron 5500R universal testing machine (Instron) (Fig 4). The movable bracket was suspended from the load cell of the testing machine while the Perspex sheet was mounted on the crosshead below. The full-scale load was set at 10 N with a crosshead speed of 10 mm/minute.

At the start of each test, a trial run was performed with no load on the power arm to check whether there was any binding between the archwire and bracket. Then 50- and 100-g weights were sequentially suspended from the power arm, and the load needed to move the bracket across the central span in the apparatus was recorded separately. Ten representative readings were taken for each method of ligation using four types of ligature materials, and each method of ligation was tested in dry and wet conditions. Saliva was used for wet group testing. All samples in the wet groups were soaked in human saliva for 1 hour before testing. The dry groups were also tied 1 hour before testing to minimize differences in elastic tension between the samples. The stainless steel ligatures were initially fully tightened and then unwound by three turns.
Loose ligation was checked by rocking the ligature to confirm that there was a little play between both spans of the ligature and archwire. The load cell reading represents the clinical force of retraction that would be applied to the canine, part of which would be critical friction, while the rest would be the translation force on the tooth. The difference between the load cell reading and load on the power arm represents frictional resistance. The coefficient of friction of the archwire–bracket interface can be calculated by the formula:

\[ P = \frac{2Fh\mu}{W} \]

where \( P \) = frictional resistance, \( F \) = equivalent force acting at a distance, \( W \) = bracket slot width, and \( h = 12 \text{ mm} \), and \( \mu \) = coefficient of friction between the bracket and the archwire.

**Statistical analysis**

Data were entered in a personal computer and analyzed using computer software (SPSS version 10, IBM). Data are expressed as mean and standard deviation. One-way analysis of variance (ANOVA) was performed as a parametric test to compare the different variables. Duncan multiple range (DMR) test was also executed along with one-way ANOVA as post hoc analysis to elucidate treatment-wise multiple comparisons. For all statistical evaluations, a two-tailed \( P \) value of < .05 was considered significant (Tables 1 and 2).

Statistical analysis to evaluate the significance of the difference between the mean coefficients of kinetic friction (\( \mu_{k_f} \)) of different ligation methods in each sample at both loads and in both dry and wet conditions were done. The analysis was carried out by applying the ANOVA analysis (see Tables 1 and 2).

**RESULTS**

In comparing the mean coefficients of kinetic friction (\( \mu_{k_f} \)) between round, figure eight, diagonal, and twist ligation methods in dry and wet conditions at a 100-g load using four different ligature samples, it was found that figure eight ligation had the highest friction, followed by round and twist ligation, while the least friction was observed in diagonal ligation (Fig 5). The statistical analyses revealed that great majority of these comparisons were statistically significant (see Table 1).

When comparing the mean coefficients of kinetic friction (\( \mu_{k_f} \)) between round, figure eight, diagonal, and twist ligation methods in dry and wet conditions at a 50-g load using four different ligature samples, it was found that figure eight ligation had the highest friction, followed by round ligation, twist, and diagonal ligation, in descending order of friction (Fig 6). The statistical analyses revealed that the great majority of these comparisons were not statistically significant (see Table 2).

**Comparison between dry and wet groups**

When comparing the mean coefficients of kinetic friction (\( \mu_{k_f} \)) between dry and wet conditions at a 100-g load using four different ligature materials, it was found that dry group samples had higher friction than wet group samples. The statistical analyses revealed that the great majority of these comparisons were statistically not significant (see Table 1).

In comparing the mean coefficients of kinetic friction (\( \mu_{k_f} \)) between dry and wet conditions at a 50-g load using four different ligature materials, it was found that dry group samples had higher friction than wet group samples. The statistical analyses revealed that a majority of these comparisons were statistically significant (see Table 2).
Orthodontics as a science has undergone a sea change in the last century. There has been a paradigm shift in orthodontic philosophy and mechanotherapy. These innovations have been and are catalyzed by pioneering research in the field of orthodontic material science. Advancement in technology improved the clinician’s output and patient comfort, which led to the eventual reduction in treatment time while providing quality orthodontic care.

Elastomers have myriad applications in orthodontic mechanotherapy. This is one area that has grown exponentially in the last two decades. Elastomeric ligatures, threads, and other such applications are commonplace in orthodontics today. Elastomeric ligatures are a ubiquitous entity in today’s practice and facilitate the rapid positioning of the archwire in the slot, and in many cases help in achieving correction of tooth rotation.

Kusy\textsuperscript{13} has shown that an ideal ligature should have optimum stress-relaxing characteristics so that normal force due to ligation decays rapidly with time, thereby reducing the frictional force and consequently the frictional couple. Frictional forces measured in this study were comparable in magnitude with those of a previous study.\textsuperscript{5}
In the present study, keeping all other parameters constant, it was possible to evaluate the change in friction with different tie configurations and also dry and wet conditions. All tests were conducted in human saliva to replicate the clinical environment. Artificial saliva is said to be an inadequate substitute for human saliva in friction studies, as advocated by Downing and McCabe.\(^\text{14}\)

Elastomeric chains have a weak molecular attraction consisting of primary and secondary bonds. At rest, a random geometric pattern of folded linear molecular chains exists. On extension or distortion, these molecular chains unfold in an ordered linear fashion at the expense of the secondary bonds. Cross-links of primary bonds are maintained at a few locations along the molecular chains. The release of the extension will allow for a return to a passive configuration provided the distraction of the chains is not sufficient to cause rupture of these primary bonds. If the primary bonds are broken, the elastic limit has been exceeded, and permanent deformation occurs.\(^\text{15}\)

Many new elastomeric modules claiming low friction have entered the market. By using different tie configurations between archwire and bracket, it is possible to reduce the drag force while still allowing the ligature to maintain the archwire in the slot.
The result of this study showed that while comparing the mean coefficients of kinetic friction ($\mu_k$) between round, figure eight, diagonal, and twist ligation methods in dry and wet conditions at a 100-g load using four different ligature samples, figure eight ligation had the highest friction, followed by round and twist ligation, with the least friction observed in diagonal ligation (see Fig 5). The statistical analyses revealed that the great majority of these comparisons were statistically significant (see Table 1).

When comparing the mean coefficients of kinetic friction ($\mu_k$) between round, figure eight, diagonal, and twist ligation methods in dry and wet conditions at a 50-g load using four different ligature samples, it was found that figure eight ligation had the highest friction, followed by round and then twist ligation, with the least friction observed with diagonal ligation (see Fig 6). However, statistical analyses revealed that the great majority of these comparisons were not statistically significant (see Table 2).

Tying modules in a figure eight pattern is useful to ensure full archwire engagement. Therefore, this technique can be recommended when spaces are almost closed and sliding requirements are minimal.

Hain et al. evaluated the effect of ligation method on friction and found an increase in frictional value of figure eight ligation compared with a regular round ligation. The results revealed by the present study are in agreement with this conclusion.

When comparing the dry and lubricated groups, the majority of wet groups showed a reduction in friction. This was found to be highly significant with a 50-g load for all four groups. This is in keeping with the results obtained by Hain et al.

However, when the load increased to 100 g, there was no significant difference between dry and wet groups. This is probably because lubrication is not able to overcome the frictional resistance at higher loads.

Frank and Nikolai compared frictional resistance between elastomeric and steel ligations using 225 g force and found no differences between elastomeric chains and stainless steel ligatures. This is similar to the results of our study, which found that among the samples used, stainless steel ligature showed the least amount of friction in the majority (although not all) of the ligation methods.

The result of the present study indicates that the diagonal ligation produced the least friction. This would facilitate easier adjustment and sliding. The figure eight tie configuration generated maximum friction. Therefore, when rigid full engagement of the archwire with less sliding is desired, this may be preferred. Lubrication considerably decreased friction. In a clinical situation, factors other than ligation are also involved. The level of influence of the ligature is also said to diminish as bracket-archwire angulation increases. Further in-vivo studies are needed to select the ideal ligation technique depending on each clinical situation.

**CONCLUSIONS**

This in vitro study was intended to evaluate the variation in the level of frictional characteristics of different methods of ligation using four different ligation methods: regular round tie, figure eight, twist, and diagonal ligation patterns under dry and wet conditions. The results were statistically analyzed, and the following conclusions were drawn:
1. Figure eight ligation had the highest friction, and diagonal ligation produced the least friction.
2. Round ligation produced less friction than the figure eight configuration, and twist ligation produced more friction than diagonal ligation.
3. Among the dry and wet groups, lubrication showed statistically significant reduction in friction with the 50-g load.

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DEDICATION

Dedicated to our parents, guardians, teachers, and colleagues.

REFERENCES