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Review Article

Governing the Friction in Fixed Orthodontic Appliance

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Abstract

Friction is defined as the force that resists a movement when objects move tangentially against each another. Various forces arise, when two surfaces which are in contact slide against one another. An orthodontist has various difficulties related to friction specially with sliding mechanics and has to deals with it successfully to provide effective tooth movement. During Orthodontic treatment, sliding mechanics is used widely. Friction generated at the bracket/archwire interface is one of the disadvantages of this mechanics, which reduces the quality of desired orthodontic movement acquired. Both clinicians and scientists have an interest in the role of friction in Orthodontics, due to its application. As per clinical studies, the resistance to bodily tooth movement by sliding has far too less to do with friction. It is mainly a binding-and-release situation that is similar to conventional and self-ligating brackets.

Keywords: Fixed Orthodontic Treatment, Orthodontic Appliances, Friction

1. Context

Friction is the resistance to movement of an object moving in relation to another. Friction is one of the parts of tribology, which is "a study of friction, wear, lubrication and design of bearings". Friction is not a fundamental force, as it is a result of electromagnetic attraction between charged particles in two touching surfaces. All surfaces are irregular to a certain extent, therefore, the physical interpretation of friction is performed based on the true contact area (1). These can be determined by asperities, which are defined as "unevenness of surface, roughness, ruggedness", the forces with which the surfaces are forced together. Regarding benefits of low friction in orthodontic tooth movement, companies producing orthodontic appliances are trying to market their self-ligating brackets. In clinical orthodontic practice, friction has been given importance. When a tooth is retracted along a continuous arch-wire or in space consolidation, low friction plays an important role; whilst in closing loop mechanics, anchorage, and two-couple systems (torqueing arch), high friction in required.

The 2 types of friction are: static and kinetic. Friction opposing the applied forces is called Static Friction. The movement starts when the magnitude required to stop the motion between two surfaces is overcome. Kinetic friction then resists the relative movement of the surfaces when they are in motion. Static friction between surfaces is always higher than Kinetic friction.

In orthodontic tooth movement, the interaction of an archwire with edges of an orthodontic bracket or ligature wire results in friction. Friction is a rather small part of the resistance to motion of bracket when it slides along an archwire. According to Kusy and Whitley (2), resistance to sliding (RS) can be divided into 3 components: (1) friction, static or kinetic (FR), happens when there is contact of the wire with bracket surfaces; (2) binding (BI), happens when there is tipping movement of tooth which leads to contact between the wire and the corners of the bracket (in order to move a tooth, when a force is applied to a bracket, the tooth tips in the direction of the force until the wire contacts the corners of the bracket and binding occurs), or when the wire flexes; and (3) notching (NO), at the wire-bracket corner interface, the wire component permanently deforms. It usually happens in clinical conditions. When a notched wire catches on the bracket corner, the tooth movement stops and resumes only when the notch is corrected (2).

2. Variables Affecting Frictional Resistance During Tooth Movement

2.1. Archwires

Kusy and Whitley (2) explained the effects of varying wire sizes on friction. They described the critical contact angle between the wire and bracket slot. Whenever there is increase in the diameter of wire, there is decrease in the free space in the bracket slot which subsequently decreases the amount of tipping needed to attain critical contact angle. They claim that there is a greater friction in bigger diameter wires as the critical contact angle is achieved even with tip in the bracket. In addition to the friction caused by critical contact angle, the larger wires are stiffer which increase the probability of notching of the wires. Studies even suggest that in certain circumstances, compared to round wires, greater friction is produces by the rectangular wires (2).

2.2. Brackets

Stainless steel (SS) is the most popular and widely used material in orthodontics. Kapila et al. (3) studied the friction between edgewise SS brackets and orthodontic wires made of four different alloys (SS, Co-Cr, NiTi, and B-Ti). The mean frictional force made by conventional cast SS brackets varied between 40 and 336 g. Vaughan et al. evaluated the frictional forces of sintered SS brackets against conventional ones. They concluded that the kinetic friction generated by sintered SS brackets is 45% of the frictional force generated by conventional SS brackets.

As increase for aesthetics in dentistry is in high demand, suppliers are trying to develop brackets which are considerably more aesthetic than Stainless Steel one. To meet these aesthetic demands, Ceramic, polycrystalline alumina, single crystal alumina, and polycarbonate brackets are produced. Furthermore, titanium brackets are being produced which claim to have more biocompatible properties than Stainless Steel which can better withstand oral environment. Kusy and Whitley (2) also studied the frictional properties of Stainless Steel and titanium brackets. They concluded that. The optical roughness of titanium brackets is more than that of stainless steel Brackets. However, titanium brackets have a more favorable coefficient of friction compared to their stainless steel counterparts. There is almost twice more friction generated by Ceramic brackets when compared to the stainless steel ones. Some manufacturers have incorporated a stainless steel slot into the ceramic bracket in order to overcome the increased friction of ceramic brackets (3).

2.3. Ligation

Combe et al. (4) evaluated the frictional forces generated in the four following ligation forms: conventional elastomeric modules or ligature wires used in a "figure of 8" configuration, ties made from stainless steel, and ligatures coated in Teflon. The highest amount of friction was produced when "figure of 8" modules were used. Hain et al. observed quite similar observations i.e., the highest friction were produced when the regular module was tied in a "figure of 8" pattern. The reason stems from a three point contact made between module and arch wires as well as increase in normal forces because of increased stretching of module, which subsequently firmly pushes the archwire against the bracket slot. The lowest mean frictional forces are observed with Teflon-coated ligatures. Little difference was observed between conventional module and stainless steel ligature in terms of frictional force (4).

3. Role of Friction in eliciting Biological Response

The correlation between presence of saliva and its effect on friction was observed by Baker et al. (5) They inferred that human saliva decreases frictional force by 15% - 19%. In another study by Kusy and Whitley (2), they concluded that depending on the archwire-bracket combination, saliva could act as either a lubricant or an adhesive. They also showed that for decreasing the friction, human saliva and water are better than artificial saliva. Occlusal force is the critical variable when it comes to orthodontic friction. During orthodontic treatment, the appliances attached to the teeth repeatedly move in relation to one another as the teeth contact thousands of times a day during chewing, speaking, and swallowing. Braun et al. added various systems and attachments to the bracket or wire to observe their frictional effects.

4. Role of Friction in Conventional Brackets Versus Self-Ligating Brackets

The interaction of an archwire with edges of an orthodontic bracket or ligature wire, results in friction. Friction is a rather small part of the resistance to motion of bracket when it slides along an archwire. According to Kusy and Whitley (2), resistance to sliding (RS) can be divided into 3 components: (1) friction, static or kinetic (FR), happens when there is contact of the wire with bracket surfaces; (2) binding (BI), happens when there is tipping movement of tooth which leads to contact between the wire and the corners of the bracket (in order to move a tooth, when a force is applied to a bracket, the tooth tips in the direction of the force until the wire contacts the corners of the bracket and binding occurs), or when the wire flexes; and (3) notching (NO), at the wire-bracket corner interface, the wire component permanently deforms. It usually happens in clinical conditions. When a notched wire catches on the bracket corner, the tooth movement stops and resumes only when the notch is corrected.

The contributions of friction, binding, and notching together in resistance against sliding can be understood best by considering the 3 stages in the active phase of tooth movement.

1) The initial stage is of sliding occurs when tipping of tooth happens and wire contacts with the corners of the bracket. The resistance to sliding is because of both friction and binding:

RS = FR + BI.

2) The second stage is where there is increase in contact angle between the bracket and the wire. The major source of resistance is binding and friction is inconsequential:

RS = BI.

3) The last stage consists of the contact angle being steep, wire becomes notched and both friction and binding become negligible:

RS = NO.

Kusy and Whitley (2) established that the resistance to sliding has components like binding and notching. Articolo and Kusy (6) used various combinations of 0.21×0.25-inch steel, nickel-titanium, and beta-titanium archwires and conventionally ligated edgewise brackets and showed resistance to sliding as a function of 5 angulations of wire-bracket (0°, 3°, 7°, 11°, and 13°). They observed that when there is increase in wire-bracket angulation, the binding influence becomes higher. They showed that 80% of the resistance occurs by binding when sliding happened with 7° angle, while binding produced 99% of the resistance to sliding when the angle was increased to 13°, and friction did not play an important role (6-8).

A series of self-ligating brackets was compared against conventional ligated brackets by Thorstenson and Kusy in a similar yet extensive way. In a steady state laboratory, i.e., the process that does not change in time broadly, the models were studied under both dry and wet (saliva) conditions for assessment of friction and binding on resistance to sliding. There was an increase in wire-bracket angulation as the binding increased in both conventional and self-ligating brackets. The following Figure 1 shows the resistance to sliding with only friction as the bracket is held steady (no angulation). The self-ligating brackets have decreased resistance to sliding compared to that of a conventional bracket tied with a wire or an elastomeric ligature. In addition, the brackets with a passive clip have lower resistance to that of an active one (9-11).

However, clinically this condition almost never occurs. Bracket tips in relation to the wire as the force is applied, so, the bracket is held steady when it moves along the archwire (which cannot be done under clinical conditions). When the bracket corners contact the wire, binding occurs which leads to resistance to sliding.

It was inferred that "binding does not appear to be affected by the ligation method"; i.e., there is similar binding observed with both conventional and self-ligating brackets (Figure 2).

Clinical advantages of reduced resistance to sliding include decrease in time needed for alignment and space closure. This phenomenon has been investigated by several clinical studies. In a clinical trial carried out with 54 subjects who underwent non extraction treatment, Pandis et al. (12), observed the time needed to correct mandibular crowding with conventional brackets compared to Damon2 self-ligating brackets. They found that no difference was noted in duration of treatment when self-ligating Damon2 was compared to conventional edgewise brackets for correction of mandibular crowding. Miles et al., in a similar study, inferred that the Damon2 bracket "was no more effective at reducing irregularity when compared to the conventional twin bracket with elastomeric ligation". Miles (13) reported similar results while comparing SmartClip to conventional brackets in a limited clinical trial (12).

Rinchuse and Miles (14) in a review study of self-ligating brackets, compared treatment duration when using self-ligating versus twin brackets. No significant difference in treatment time was shown by past studies. The rate of en-masse space closure accomplished by conventional brackets and tied by steel ligature versus self-ligating brackets was compared by Miles and not much difference was observed (13-16). The following points were concluded by clinical studies:

1) Resistance to sliding is mainly because of binding and notching, which can be temporarily relieved by oral function and the laboratory findings support this.

2) With the use of self-ligating brackets, there is no evidence to support the theory that it reduces the treatment duration.

Results from several studies demonstrate a series of results in the friction produced by self-ligating brackets and conventionally tied brackets.

1) Highest levels of friction are produced by conventional brackets which can be used for all bracket/archwire combinations. Self-ligating brackets generated comparatively lower level of friction when compared to electrometrically tied conventional brackets.

2) With increase in archwire dimensions, the friction also increases in conventional brackets. When ligatures are used instead of elastomeric modules, friction is also significantly increased.

3) There is an increase in friction when self-ligating brackets are used with 0.017 inch wires and higher dimension wires because the spring clip contacts with archwire in the slot. There was negligible friction at lower archwire dimensions used with Damon self-ligating brackets. It was even lower with 0.019×0.025 inch rectangular archwire.

4) It was confirmed that when the archwire size increases, the frictional resistance rises.

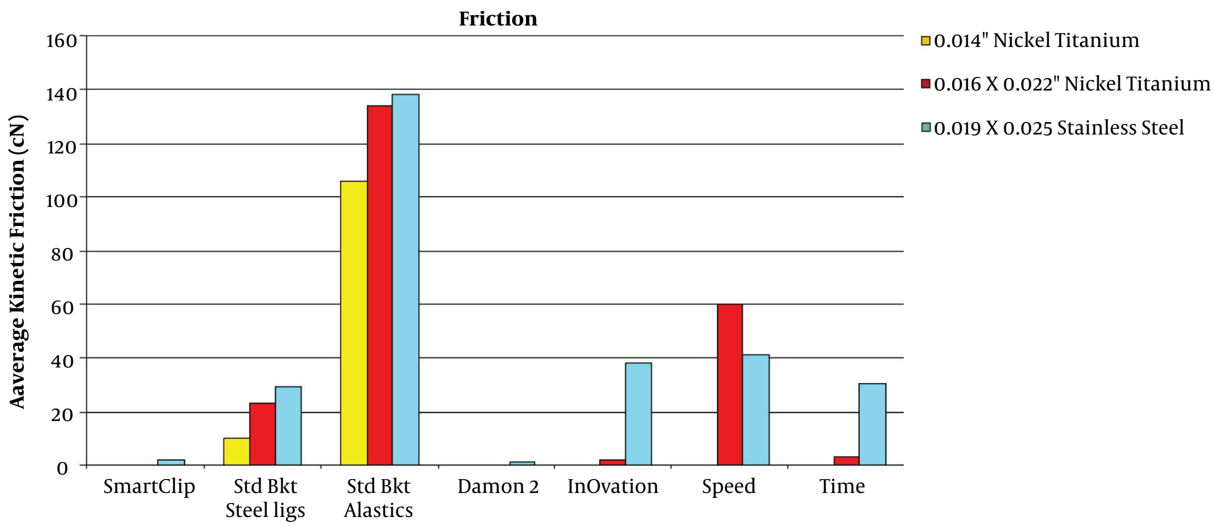

Figure 1. Friction of various types of brackets with 3 different archwires. For any self-ligating bracket, when a small nickel-titanium wire is inserted, there is a decreased friction. With larger wires, an active clip adds friction. Compared to steel ligatures, elastomeric rings have more friction (data from Thorstenson and Kusy (10).

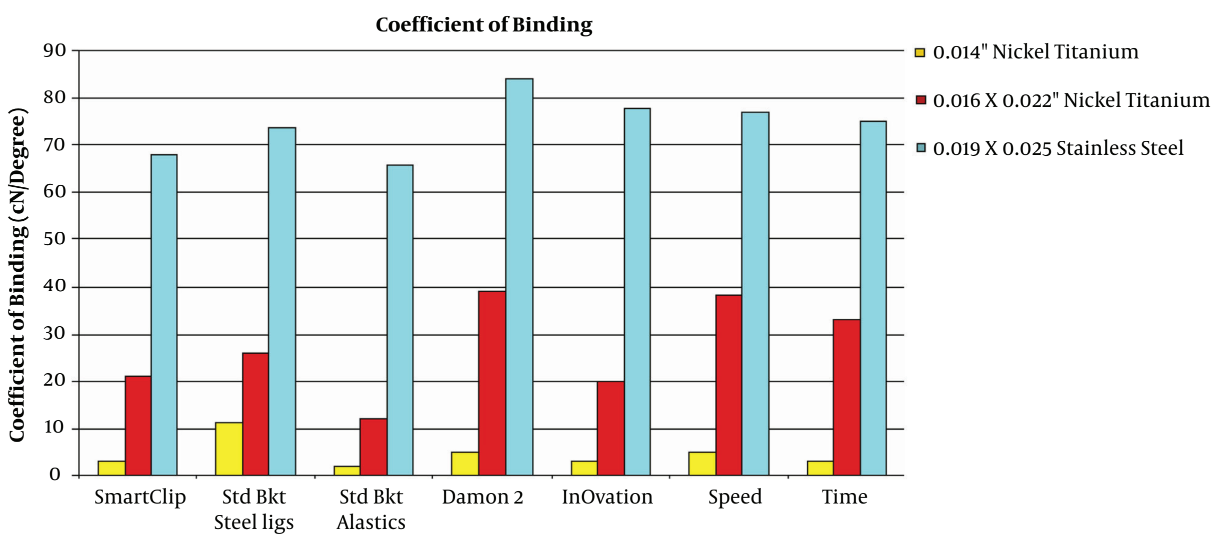

Figure 2. Coefficient of binding for the same brackets and wire sizes. For both conventional and types of self-ligating brackets, similar binding is observed, unlike friction. (Data from Thorstenson and Kusy).

5. Inhibitors to Sliding Mechanics

1) Occlusal interference can hinder canine retraction. To prevent this proper aligning and levelling of the arches is needed to avoid the interference from occlusion.

2) Friction and binding between the surfaces of bracket and archwire entails greater demand on anchorage. For favourable angulation, light archwires are used to tip the canine. Afterwards, retraction is started with a heavy rectangular arch wire placed passively into bracket slots. Theoretically, power arms could be used to cause more bodily movement and less binding.

3) Poor canine control can be a problem: the problem is reduced by retracting the canine on heavier arch wires.

4) Cortical plate resistance Alveolar bone in extraction sites is narrowed.

5) Excessive forces cause tipping of lower molar and distal cusps to extrude.

6) Soft tissue formation in the extraction space pre-

vents space closure, or can reopen space after treatment.

7) Rotation of canines mesio-bucally, and molar mesiopalatally. Buccal traction causes this problem. Lingual cleats or buttons for palatal traction can prevent this rotation. Rotation wedges can prevent canine rotation, while molar rotation can be prevented by adding a mild toe-in into the archwire. TPA, Nance's palatal button, lower lingual arch, headgear or intermaxillary elastics are used for retraction by sliding mechanics in maximum anchorage cases. In order to decrease friction, Molar correction has to be accomplished before canine retraction. The treatment duration also increases.

8) First order or rotational resistance at the mesiobuccal and distolingual surfaces of the posterior bracket slots is generated by rotational forces applied on the buccal aspects of those teeth. Intermittent lingual elastic forces are applied to counteract this resistance- From cuspid to first molar for a month and then from cuspid to second molar, next month.

9) Second-order or tipping resistance at the mesio-occlusal and distogingival surfaces of the posterior bracket slots is due to excessive and over activated tieback forces. This result in tipping of the posterior teeth, inadequate rebound duration to upright these teeth and a resultant binding of the system.

10) Third-order or torsional resistance can happen at any of the four sites of the bracket slot, wherever the edge of the archwires gets in contact. During sliding mechanics, the lower posterior teeth are rolled in lingually, the upper posterior lingual cusps drops down due to excessive and over activated tieback, similar to tipping resistance.

6. Conclusions

In orthodontics, the resistance to sliding is multifactorial. The types of materials used and the type of orthodontic tooth movement directly influence this resistance to sliding. In clinical situations, the presence of friction is unfavourable. However, it might be very critical in other conditions.

In order to decrease friction in specific clinical situations, technological innovations such as design alterations and surface treatment which are used to develop new low friction materials, presents promising potentials. The cost of traditionally used materials is significantly less than these newly introduced ones, while the real cost to benefit remains scientifically questionable.

Reduced frictional resistance and reduced treatment duration are the reason that the manufacturers of self-ligating brackets refer to. They also have research data to support their contentions. In clinical treatment, friction is not the major component of resistance to sliding. Since this phenomenon receives emphasis in marketing of self-ligating brackets, the other components might have been underrated. The overestimation of practical significance of friction happens due to simplification of complex biomechanical interactions that happen in steady state laboratory testing. Clinical studies support the idea that resistance to sliding is slightly dependent on friction and largely on binding-and release phenomenon which is more or less same in conventional and self-ligating brackets. The speculation that treatment time is decreased (presumably because of lower friction) with self-ligating brackets, is not supported by the limited available clinical trials.

Footnotes

Authors' Contribution: Study concept and design, acquisition of data, and analysis and interpretation of data: Somit Das. Drafting of the manuscript, critical revision of the manuscript for important intellectual content, and statistical analysis: Kunal Pallan. Administrative, technical, and material support: Vishal Dhanjani. Study supervision: Nilesh Mote.

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