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Frictional Resistance in Orthodontics-A Review

Hiba A.Kamel , Shaym Sh. Taha
Department of Orthodontics, College of Dentistry, University of Baghdad, Baghdad,10011, Iraq
*Correspondence Auther: heba.Ali1203a@codental.uobaghdad.edu.iq
https://orcid.org/0009-0004-5466-6294
dr_shaymaa77@yahoo.com

Abstract:

During orthodontic treatment, sliding mechanics are frequently used. This mechanic has some drawbacks, one of which is the friction that is formed at the bracket/archwire interference, which may reduce the amount of desirable orthodontic movement achieved. Friction is the resistance to motion that occurs when one object travels tangentially against another.Friction is classified into two types: static and kinetic. In order for one object to slide over another, the force provided must be greater than the frictional resistance created.Frictional resistance between archwire and brackets is caused by a variety of physical and biological reasons.

Keywords: Friction ; Binding ; Notching ; Bracket properties ; Archwire material

INTRODUCTION:

Friction is the force that limits movement when an object moves tangentially against another object (Shah et al., 2019). When two surfaces slide alongside one another, two kinds of forces appear frictional (FF) forces that are tangential to the surfaces in contact and normal force (FN) forces that are that are parallel to the surfaces in contact (Prashant, Nandan and Gopalakrishnan, 2015). As illustrated by the equation F=KN, where k is the coefficient of friction, which is a constant and highly related to the surface characteristics of each material, FF is directly proportional to N and depends on the coefficient of friction of both the contacting surfaces (Rossouw, 2003; Nanda and Ghosh, 1997).

In orthodontics, static and kinetic friction are both taken into account. The amount of resistance used to start motion between two surfaces is known as static friction. The force of resistance used to prevent motion from spreading between two objects is known as kinetic friction. Practically, the kinetic friction does not apply to orthodontic tooth movement because the teeth don't move continuously along the archwire (Burrow, 2009).

There are two different forms of space closure mechanics in orthodontics, the first type is called "segmentedArch Mechanics"(SAM) in which the tooth or group of teeth move due to the moment-to-force ratio generated during the activation of loops. The reason why SAM is also known as "frictionless mechanics" is that the brackets and tubes do not move along the archwire (Shroff et al.,1995). In the case of anterior teeth crowding, high canine, and midline discrepancy separated capsid retraction (frictionless technique). The T loop is the preferred spring due to its characteristics. The other is sliding mechanics (SM), in which brackets and tubes are moved along an archwire while creating considerable amounts of friction (Nahidh , Yassir and McIntyre ,2023).

Resistance to sliding

Most frequently, the term "friction resistance" is used to describe the force keeping the teeth from slipping. The phrase "resistance to sliding" (RS) is more precise, referring to the three phenomena known as classic friction (FR), binding (BI), and notching (NO). FR+BI+NO is the usual format for writing RS (Figure1). Classical friction occurs when there is space between the surfaces of the brackets and the archwire. This happens when there is no angulation and the archwire is in a passive configuration inside the bracket's slot. Binding happens in the active wire configuration when the wire starts to bind against the bracket corners and the clearance between it and the bracket slot disappears. The critical angle (c) is the angle at which the FR disappears and the binding takes control of the situation. Notching occurs when a severe binding incidence causes a permanent wire deformation at the bracket-wire contact, causing the sliding action to stop (Kusy and Whitley,1997). Different RS combinations are felt by the teeth during the sliding motion. The tooth does not move continuously. The crown tipping that starts the cycles of tooth movement also causes the binding of the brackets and archwires. The tooth can then move and the bracket binding can be released as the periodontium that surrounds it reacts to start the root uprighting in the direction of the provided force (Burrow, 2009; Omana, Moore and Bagby ,1992).

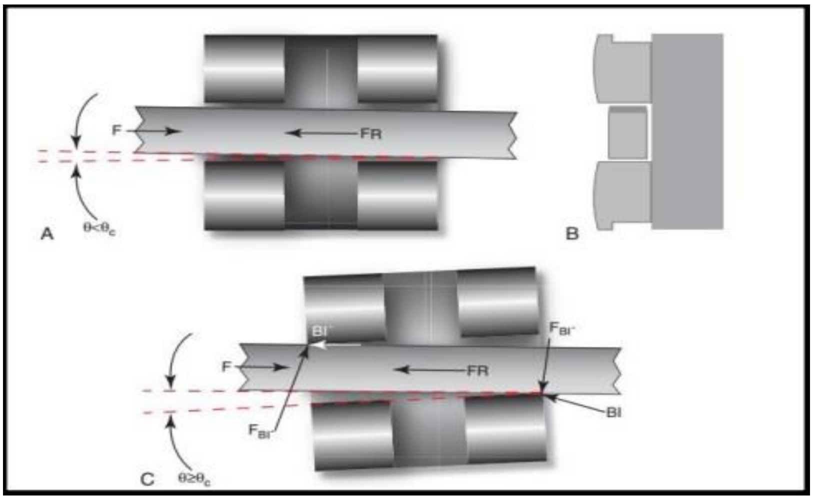

Figure1: A and B- The force (F) that moves the bracket along the archwire at the beginning will be resisted by friction (FR), C- The tooth begins to tip till the wire contacts the bracket's corner, at that point the elastic binding (BI) will add to the resistance to sliding (Proffit et al., 2019).

In orthodontic mechanics, variables influence frictional resistance (Savoldi et al.,2018; AlSubie and Talic, 2016).

Frictional forces in orthodontics are multi-factorial in nature, resulting from mechanical and biological causes.

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A.Physical/Mechanical factors:

1. Archwire properties:

Archwire materials:

Different types of materials are used for the fabrication of archwires. Stainless steel archwires have a high modulus of elasticity (high stiffness), high strength, reduced cost, good formability, less bracket-wire friction, and good welding and soldering properties (Krishnan and Kumar, 2004; Burstone and Choy, 2015)**.** Other common alloys have been developed in the last decades because they have good properties such as Elgiloy, NiTi, and TMA arch wires (Kusy and Whitley, 1999). These types of archwires have varying degrees of friction since they are made from different materials. Stainless steel archwires produce less amount of friction with stainless steel brackets, while Elgiloy and NiTi wires have higher friction than stainless steel but in comparable proportions, while TMA has the highest friction (Kusy and Whitley, 1999; Jian-Hong et al., 2011).

Coated wires:

The aesthetic component of orthodontic appliances has been considered to be important for patients seeking orthodontic treatment, hence numerous attempts have been made to construct various aesthetic archwires and aesthetic brackets (Kim et al.,2014). To coat stainless steel or nickel titanium wires, manufacturers frequently utilize numerous types of coating materials, including Teflon, Epoxy, polymer, and rhodium materials (Ryu et al.,2015) (Figure 2). Rhodium enhances aesthetics when used as a coating material for standard orthodontic arch wires because of its silvery-white glossy look and friction-reducing properties (Katic et al.,2015), and shows non-significan color change after immersion in the biofresh mouthwash (Al-joubori et al.,2023).The mechanical and frictional characteristics of arch wires may be impacted by the presence of a coating layer (Washington, 2014; Choi et al.,2015). As a result, manufacturers frequently attempt to cover wires with materials that have excellent aesthetic and frictional properties (Elayyan, 2010). Previous research found that measured wire dimensions frequently differed from those stated by the manufacturer, and that frictional forces were significantly influenced by wire size and coating thickness, with frictional forces being higher in labially coated wires due to increased wire size and coating thickness and lower in fully coated wires due to reduced total dimensions and thin coating thickness (Abbas and Alhuwaizi, 2018).

Figure 2: Comparison between coated and uncoated archwires (Orthotechnology product catalogue, 2021).

Wire size and shape (Cross-section)

In the sliding mechanism, the cross-sectional area of the archwire is important according to previous reports (Matarese et al.,2008; Lombardo et al., 2013). In various investigations, an increase in wire size has been linked to an increase in bracket-wire friction. The elasticity of nickel-titanium, however, means that increasing the size of the wire does not always increase frictional resistance (Mendes and Rossouw.,2003; Kojima and Fukui, 2005). In general, rectangular wire produces more friction than round wire When there are no bracket/wire angulations, friction is mostly determined by the area of contact between the bracket and wire, but at greater bracket angulations, friction is primarily determined by the location of wire contact with bracket edge. The bracket slot may "bite" into the wire at one point when utilizing round wires, producing an indentationHowever, with rectangular wire, the force is distributed over a large area resulting in less pressure and, therefore, less resistance to movement (Nanda, 1997). Archwires size and geometry (going from round to square or rectangular) increases so does the frictional. Smaller round archwires have less friction because of their greater flexibility. However, greater friction due to notching of the archwire can occur if excessive force is used (Sadique, 2004; Husain and Kumar, 2011).

Surface texture

One of the main factors that have an effect on the frictional force is the surface roughness of orthodontic appliance; therefore, it has an effect on the performance of these appliances. However, the friction produced by archwires is not always a reflection of their surface roughness (AlSubie and Talic, 2016; Choi et al., 2015).

2.Bracket properties

Bracket material

Metal brackets

Material for the brackets When compared to other brackets, stainless steel brackets have the lowest coefficient of friction(figure3) (Proffit et al., 2019). Cobalt chromium brackets generate significantly more frictional resistance than titanium brackets when using titanium-molybdenum and stainless steel archwires, and more friction than stainless steel brackets with stainless steel archwires (Nair , Padmanabhan and Janardhanam, 2012). Even when using the same archwire material, titanium brackets produce more friction than SS ones, which was explained by the material's surface roughness and coefficient of friction (Husain and Kumar, 2011).

Figure 3: Stainless steel brackets (Ortho Technology Product Catalog, 2018).

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Aesthetic brackets

Because there is a greater desire for aesthetics in dentistry, orthodontic companies have been working to develop brackets made of new materials that are more aesthetically pleasing than SS. Ceramic brackets are typically constructed of aluminum oxide. These brackets are classified into two types: monocrystalline alumina brackets (sapphire) and polycrystalline alumina brackets(ceramic)(Figure4). Sapphire brackets are generally milled directly from one sapphire crystal using diamond tools. To ensure that the particles are fused, the polycrystalline alumina tends to bind thermally (Kusy, 1988; Elekdag-Türk and Yilmaz,2018). The color stability of the esthetic materials used is regarded as the most important aspect of successful esthetic treatment. When using sapphire orthodontic brackets, The patient's cooperation and habits need to be taken into account. Additionally, patients should be instructed to consume limit-staining beverages (Hassan and Ghaib,2020). Polycrystalline ceramics have a rough surface and create high resistance to sliding than monocrystalline ceramic and stainless steel, which are comparable (Russell , 2005).

Figure 4: A: Polycrystalline ceramic brackets. B: Monocrystalline ceramic brackets (Ortho Technology Product Catalog, 2018).

Self-ligating brackets

Active and passive self-ligating brackets are the two primary categories of Self-ligating brackets (Figure 5) (Zreaqat and Hassan, 2011). Active self-ligating brackets have a flexible segment that holds the archwire in place and can store and then release energy through elastic deformation (Yanget al., 2017). Passive self-ligating brackets have a rigid, moving part to carry the archwire inside the bracket slot, resulting in the formation of a hollow tube in the bracket during closure. Damon Q self-ligating brackets, an example of passive self-ligating brackets, were found in previous studies to smooth out the insertion of the archwire and reduce frictional forces, which is advantageous when sliding movements are used(Pacheco, Jansen and Oliveira, 2012; Kulshrestha, Tandon and Chandra, 2015). Passive SLBs have less static and kinetic friction force than active SLBs or traditional brackets (Huang et al., 2012) .Interactive types of self-ligation techniques (pactive)have both passive and active characteristics; the Pactive brackets produced significantly higher friction than the passive bracket (Damon) and this can be attributed to their flexible clip versus the sliding clip design of Damon brackets; as with the smaller round archwire, the clip acts passively, yet with the larger rectangular wire, the clip of the Pactive system encounters deflections yielding higher friction (Kanbar, Obaid and Ibrahim., 2002).

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Figure 5:Different designs of self ligating brackets (Proffit et al., 2019).

Bracket width

The force of friction is greater with wider brackets than with narrower brackets because the area of surface contact between the archwire and the wider brackets is greater. Moreover, wider brackets generate more friction because of the use of elastomeric ligature that requires more stretching to be secured, therefore, applying large force (Pacheco, Jansen and Oliveira, 2012; Hain, Dhopatkar and Rock, 2003).

slot size

The slot sizes for the orthodontic brackets are 0.018 inches and 0.022 inch. Using a 0.022-inch slot bracket is preferable to using a 0.018-inch slot bracket when sliding teeth because it allows using a heavier gauge archwire that gives more strength during sliding with excellent clearance. Proffit et al. suggested that to reduce friction during sliding mechanics, at least 2 mils of clearance must be present between the archwire and the bracket slot, and the more clearance is better (Proffit et al., 2019).

Ligation

The ligation method has a significant impact on the frictional force generated at the bracket/archwire interface. Depending on how they are used, steel or elastic ligatures may attribute to frictional resistance in different ways. However, there was a controversy with the result of these studies. Part of these studies found that the loose stainless steel ligatures produce less friction in comparison with elastomeric ligatures (Hain, Dhopatkar, and Rock, 2003; Thorstenson and Kusy, 2003), while the other part found that there is no difference between them (Matarese et al.,2008).

Torque

The torque prescription that is built in the pre-adjusted brackets is considered a variable that affects the amount of frictional force generation; when the torque is high, the frictional force will be high because the amount of clearance between the bracket slot and the archwire is reduced (Moore, Harrington and Rock, 2004).

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Biological factors

1.Saliva

Saliva is regarded as a major biological factor related to friction, as it sometimes serves as a lubricant when the teeth slide (Pacheco, Jansen and Oliveira, 2012), hence, this reality must be considered in studies that assess the effectiveness of archwire/bracket combinations (Almeida et al., 2019). In the *in vitro* studies; sometimes, distilled water is utilized as a lubricant (Ribeiro etal.,2012), although it is a lubricant but its lubricating capacity is not as natural saliva (Leal et al.,2014). Therefore, to mimic the therapeutic effects of natural saliva, artificial saliva utilized in vitro investigations is a suitable replacement (Almeida et al., 2019).

2. Plaque and calculus

A significant amount of dental biofilm builds on an orthodontic appliance after only eight weeks of intraoral use. The collection of that debris is regarded as a key element that causes an increase in friction throughout the orthodontic treatment (Marques et al.,2010). The calcified integuments may make the surface rougher, which will result in increased resistance to sliding (Eliades and Bourauel, 2005).

3. Corrosion

In most cases of orthodontic treatment dental plaque accumulates around the orthodontic appliance on the teeth surfaces, the cause of this accumulation is that the appliance presence hinders oral hygiene maintenance. The outcome of this plaque accumulation for a long duration is an evolution in the anaerobic status, therefore, much favoring the corrosion of orthodontic appliances. The consequence of this corrosion is the increase in frictional force between the archwire and bracket as the corrosion maximizes the surface roughness of the archwire (Eliades, 2007; Pazziniet al.,2009).

4- Mastication

The masticatory force acts a role in friction generation that occurs during orthodontic treatment; as the teeth contact each other thousands of times in a day (speaking, chewing, or swallowing) the appliance and the teeth will move in relation to each other. Many studies tried to simulate the masticatory force: they applied various loads (20, 25,100, 150, 250, and 400g) with repetitive displacements of the archwire, and they discovered that the continuous repetitive vertical displacements of the archwire produce a decrease in sliding resistance of the archwire within the slot of the bracket and the percentage of reduction was 85% when the applying loads are between 100 and 250g, while there is a reduction in friction more than 50% with small loads (Iwasaki et al.,2003).

5. Topical fluoride

Topical fluoride contains fluoride ions that can damage the oxidized layer that forms on the surface of stainless steel and nickel titanium, causing corrosion and roughening of these alloys' surfaces. This can increase the force of friction when used in the presence of stainless steel brackets/archwires or nickel titanium archwires (Almeida et al.,2019).

CONCLUSION

- For orthodontists who use sliding mechanics, understanding frictional forces and how they affect treatment planning is essential. To reduce friction, the ideal archwire-bracket combination should be used.
- Friction is a complex phenomenon with multiple causes. It is affected by biological and physical factors. The literature contains thorough studies of physical components. These physical aspects are associated with the characteristics of the bracket and archwires as well as the ligation techniques.

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- When referring to the force preventing the teeth from sliding, the phrase "friction resistance" is most usually employed. But "resistance to sliding" (RS) is a better term because it may be subdivided into the three distinct phenomena of classic friction (FR), binding (BI), and notching (NO).

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