Saudi Journal of Oral and Dental Research (SJODR) **ISSN 2518-1300 (Print)**
Scholars Middle East Publishers **ISSN 2518-1297 (Online)**
Dubai, United Arab Emirates
Website: http://scholarsmepub.com/

Friction: An Indispensable Aspect of Biomechanics in Orthodontics- A Review

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Review Article

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Article History
Received: 03.10.2018
Accepted: 13.10.2018
Published: 30.10.2018

DOI:
10.21276/sjodr.2018.3.10.7

Abstract: Friction is the vital aspect of Orthodontics which requires attention during all the phases of treatment, especially during the phase of space closure. In Orthodontics, space closure can be achieved by the sliding mechanics and/or the segmented arch mechanics. Though sliding mechanics is the most commonly used space closure mechanics, it has the disadvantage of generating the friction at the bracket-archwire interface which indirectly affects the desired tooth movement. Due to the universal acceptance of this type of mechanics, the role of friction in orthodontics has become the topic of interest. Thus, this article enlightens the role of friction in orthodontic tooth movement, with an approach to its clinical implication, the importance of frictional resistance, and the recent advances in orthodontics to reduce the friction.
Keywords: Friction, Mechanics, Bracket properties, Archwire materials, Saliva.

INTRODUCTION

In today's world, aesthetics and appearance play a vital role in every individual's life. Orthodontic treatment involves improving a patient's appearance by smile correction with the application of controlled force. This is done using various archwires and orthodontic brackets. With the use of archwires and brackets come the frictional forces which are generated during their interaction. If excess and unaccounted for, these frictional forces may have detrimental effects on the treatment plan.

Among various researchers Robert Kusy has done an extensive research in the field of orthodontic friction and observed that, the knowledge about friction and orthodontic materials complements with each other [1]. Thus it is important to learn about these forces, how they affect the treatment and measures to control it.

What is friction in Orthodontics?

Friction is referred to as a force which resists or retards the relative motion of two objects which are in close contact with each other [2]. As two surfaces in contact slide against each other, two components of force arise, the frictional force component (FF) and the normal force component (N). FF is directly proportional to N and depends on the coefficient of friction of both the contacting surfaces such that F=kN, where k = coefficient of friction which is a constant and is closely related to the surface characteristics of each material [3, 4].

There are two types of friction considered in orthodontics: Static and Kinetic. Static friction is the force of resistance to initiate the motion between the two surfaces. Kinetic friction is the force of resistance to prevent the propagation of the motion between the two surfaces (Fig-1). Practically, the kinetic friction is inapplicable for orthodontic tooth movement since the continuous movement of the teeth along the archwire does not occur [2].

Abbreviations

Segmented arch mechanics = SAM, Sliding mechanics = SM, Stainless-Steel = SS, Nickel-Titanium alloy = Ni-Ti, Titanium Molybdenum alloy = TMA, Cobalt-Chromium alloy = Co-Cr, Classical Friction = FR, Resistance to Sliding = RS, Frictional force component = FF, Normal force component = N, Notching = NO, Binding = BI.

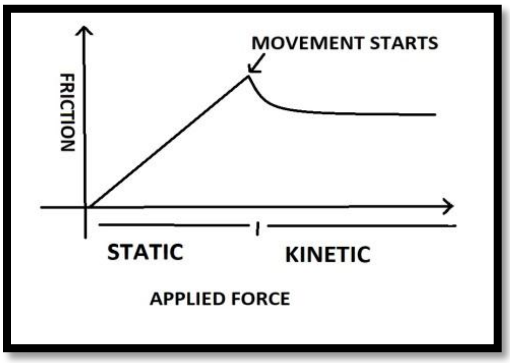


Fig-1: Static friction opposes initial motion, and kinetic friction opposes the continuation of motion of the objects

In orthodontic tooth movement, friction (static or kinetic) results from the interaction between the orthodontic archwire and the sides of an orthodontic bracket or the ligature. Although it is present throughout the treatment, it is predominantly present during the alignment and space closure phases [4, 5].

There are two types of space closure mechanics in orthodontics, the first type is the "Segmented Arch Mechanics" (SAM) in which the tooth or group of teeth move due to the moment to force ratio generated during the activation of the loops. SAM is also called "frictionless mechanics" because; the brackets and the tubes do not actually slide along the archwire [6]. The other is the Sliding Mechanics (SM), involves the actual sliding of the brackets and the tubes along the archwire which generates a considerable friction [7].

The disadvantages of SAM are that it is technique sensitive, requires a proper understanding of the biomechanics, increased patient discomfort and chair-side time. Conversely, the advantages of SM are its simplicity in the use of pre-formed archwires, less chair time and discomfort to the patient. As a result of which SM is most commonly used for orthodontic treatment [7]. However, SM generates a great amount of friction at the bracket-wire interface [2]. Thus, with SM due consideration of friction is important to start the motion.

Resistance to Sliding

Although friction and resistance to sliding (RS) appear to be similar they are separate. Kusy and Whitley divided the resistance to sliding (RS) into 3 components [8]:

Classical Friction (FR)

It occurs due to the contact of the archwire with the bracket surfaces. The inherent properties of the archwire and the bracket materials such as the hardness or smoothness can affect classical friction in the following 3 ways:

Plowing

It occurs when harder material removes a part of the softer material causing a permanent deformation.

Roughness

It is an interlocking due to the engagement of the asperities which then undergo plastic deformation, after which the movement starts (Fig-2).

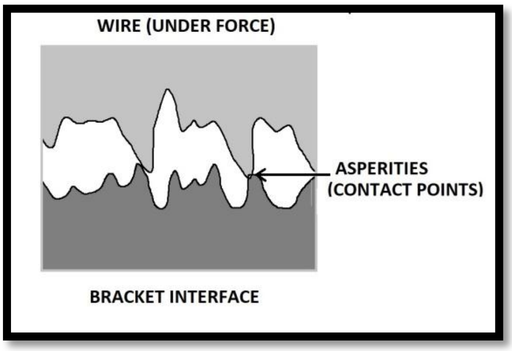


Fig-2: Asperities are the microscopic peak irregularities found on the surfaces of the objects

Shearing

It occurs if the asperities are high and if their yield strength is more, they have to break before the movement starts and the resistance felt at that time is known as shearing.

Binding (BI)

It is the resistance created when the tooth tips or the wire flexes, the wire contacts the corners of the bracket and binding occurs.

Notching (NO)

It is the resistance created due to the permanent deformation of the wire which occurs at the wire-bracket corner interface. Tooth movement stops when a notched wire catches the bracket corner and continues only when the notch is released.

Thus, RS = FR + BI + NO.

The contributions of friction, binding and notching to resistance to sliding can be best understood by considering the following 4 stages in the active phase of orthodontic tooth movement (Table-1).

Table-1: Illustrates the 4 stages in the active phase of orthodontic tooth movement

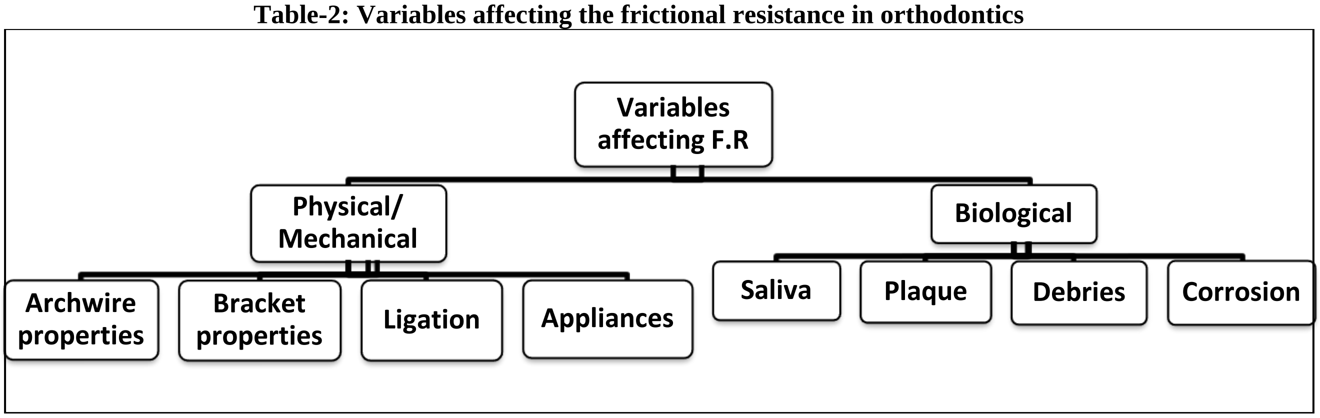
Stage1	• Archwire is in contact with base of bracket. • RS=FR
Stage 2	• As the tooth tips, contact of wire with corners of bracket begins • RS=FR+BI
Stage 3	• As the contact angle increases • RS=BI
Stage 4	• As the contact angle becomes steep, notching occurs, other forces become insignificant • RS=NO

In a clinical situation, tooth movement stops from NO, until elastic deformation of the wire occurs as bone remodelling and bone bending during mastication displaces the teeth, and the notch is released from contact with the bracket [2].

Variables affecting the frictional resistance in orthodontic mechanics [4, 9, 10-12]

Friction in orthodontics is multi-factorial in nature and derived from both mechanical and biological factors (Table-2).

Table-2: Variables affecting the frictional resistance in orthodontics



Archwire properties

Archwire materials

The four most commonly used archwire alloy in contemporary orthodontics are Stainless steel (SS), Cobalt-chromium alloy (Co-Cr), Nickel-Titanium alloy (Ni-Ti) and Titanium Molybdenum alloy (TMA). For efficient SM in general and specifically during space closure, the working archwire should have a low coefficient of friction.

Kusy *et al.*, investigated the correlation between the surface roughness and frictional characteristics between various archwire alloys and observed that the SS wire appears to have the least surface roughness and frictional coefficient amongst others [13]. They also observed that among Co-Cr, Ni-Ti and TMA, Ni-Ti has the greatest surface roughness but the coefficient of friction was greater for TMA than for Ni-Ti because of higher titanium content, as a result, they concluded that the surface roughness cannot be used as an indicator to determine the frictional resistance [13].

Two independent studies concluded that ion-implantation on the surface of archwire reduces only the surface roughness but does not affect the frictional resistance [14, 15].

Among the aesthetic archwires, Teflon-coated archwires produce lower friction than the corresponding uncoated archwires [16, 17]. Recently, it has been observed that hard chrome carbide-plated wires generate lower friction than that of the uncoated wires [18]. It was found in a recent study that passing the metal archwire to the Polyether ether ketone tube reduces the friction and colour difference was almost identical to that of coated wires [19].

Archwire dimension and cross-section

Kusy *et al*., observed that as the dimension of the wire increases friction increases because the critical contact angle is met with less amount of tip [8]. Drescher *et al.*, and Nikolai *et al.*, observed that the occluso-gingival dimension of the wire was the most critical factor affecting the friction [20, 21]. Two independent studies concluded that 16x22 and 19x25 archwire should be used respectively in 0.018-inch and 0.022-inch slots for space closure with SM [21, 22].

Bracket properties

Bracket materials

(Metal brackets)

Stainless-steel (SS) brackets are most commonly used in orthodontics. Kapila *et al*., observed that SS bracket with all the archwire combinations showed the lowest amount of friction as compared to the other bracket materials [23]. There are two types of SS brackets, cast and sintered. Vaughan et al. studied the relative kinetic friction between sintered SS brackets and various orthodontic archwires found that sintered SS brackets produced approximately 40% to 45% less friction than that of the conventional SS brackets [24].

To overcome the nickel allergy, titanium brackets have been introduced. It was observed that the titanium brackets are not only comparable to SS brackets in terms of frictional resistance but also are more biocompatible [25, 26].

(Aesthetic brackets)

With the increase in aesthetic demands of the patients, ceramic, plastic, polycrystalline alumina, single crystal alumina and polycarbonate brackets have been introduced. Polycrystalline ceramic brackets have been shown to produce more friction than the metal brackets [27, 28]. To overcome their high frictional resistance, ceramic brackets with metal slots have been shown to produce significantly lower frictional forces [29, 30]. It was found in a study that silica-inserted ceramic bracket showed minimal frictional resistance among all the ceramic brackets, and was comparable to the SS bracket [31].

Kusy *et al*., found no significant difference between the polycrystalline ceramic bracket and zirconia bracket in their frictional characteristics [32]. Nanda *et al*., observed that the plastic brackets showed lower values of friction than polycrystalline ceramic brackets but greater than that of the metal brackets [33].

Self-ligating brackets

Self-ligating brackets have been introduced in orthodontics claiming that it reduces the friction as compared to the conventional ligating brackets [34]. However, Thorstenson *et al.*, concluded that binding is independent of the ligation method [35]. Most of the studies concluded that the self-ligating brackets do not have any added advantage over conventional ligating bracket systems in terms of frictional resistance [36-38].

Lingual brackets

Although similar to labial brackets, lingual brackets feature several differences in terms of clinical features and labial bio-mechanics cannot be applied to lingual brackets. It was observed in a study that the conventional lower lingual bracket produce less friction as compared with that of the self-ligating brackets [39].

Bracket Width, Inter-bracket distance and Slot Size

Apart from archwire and bracket materials the factors like bracket width, inter-bracket span and slot size also play an important role in friction. It was observed in a study that a wider bracket reduces the force needed to generate the moment and the contact angle which is essential for space closure by sliding mechanics [40]. The maximum practical width of the bracket is about half the mesio-distal width of a tooth [5].

Slot Size

The orthodontic brackets are available in 0.018-inch and 0.022-inch slots. Kusy *et al.*, found no difference between 0.018-inch and 0.022-inch slots in the passive configuration. However, when binding occurs the frictional force differs, and that would change according to the dimensions of the wire, slot size and the bracket width [41]. Tidy *et al.*, reported that the size of the slot does not produce any difference in the amount of friction [42]. Thus contradicting the results.

Ligation

Steel or elastic ligatures may contribute differently to the frictional resistance depending on the manner of usage. Khambay *et al.*, observed that SS ligatures produced the lowest mean frictional force, whereas elastic modules produced significantly higher mean frictional force [43].

Recently, Teflon coated, super slick ties and low force ligation systems has been introduced to reduce the friction and overcome the disadvantages of elastomeric ligature ties [4, 44, 45]. Teflon coated SS ligatures have been shown to produce the least amount of friction as compared to the SS and elastomeric ligature ties [46].

Also, low-friction elastomeric ligatures showed lower friction compared to the conventional elastomeric ligatures [47]. Leander et al. observed that the coated low friction ligatures-Super Slick Ties produces lower levels of friction (11%) for all archwire materials when compared to conventional uncoated ligatures [48].

Biological factors

The major biological factor influencing the friction seems to be the saliva, which might act as a lubricant or adhesive and plays an important role in friction reduction. This factor may be important while treating the patients with xerostomia or the patients taking medications which reduce the salivary production. Kusy *et al.*, found in their study that saliva produced the lowest amount of friction for a given archwire-bracket combination (Fig-3) [41, 49].

In a pilot study, the effect of dynamic oral environment on the frictional resistance was studied. It was observed that oral functions such as chewing, swallowing, speaking etc. result in periodic, repetitive, minute relative motion at the bracket-archwire interface several thousand times each day thereby reducing the friction [50].

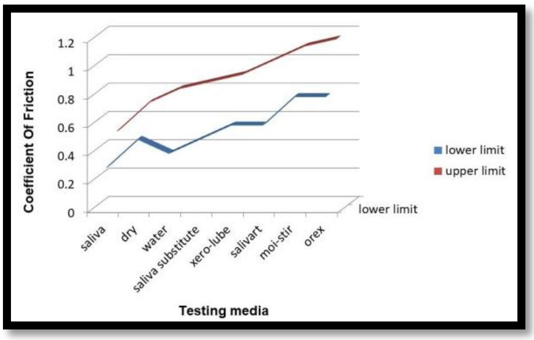


Fig-3: Illustrates the relationship between the fluid media's and coefficient of friction

Debris

The accumulation of debris on the surface of orthodontic appliances appears to have a significant influence on friction thereby affecting orthodontic treatment. There is a direct relation between the accumulated debris and the frictional force [51, 52]. Costa et al. observed that both the self-ligating and conventional brackets, when exposed to the oral environment, showed a clinically significant increase in the frictional force during the SM, however, debris accumulation was higher for the self-ligating bracket after clinical use [53].

Biodegradation of orthodontic materials

SS archwires showed a significant increase in debris deposition, surface roughness, and friction forces after 6 weeks of intra-oral use. So continuing the same archwire after alignment and levelling for space closure is not recommended [54]. Metal brackets undergo significant degradation with time thereby increasing the possibility of friction. However, at present, there are no studies to predict these changes on the treatment [55].

Elastomeric ties have been shown to produce the maximum force decay during the first 24 hours and then continuing at a lower rate during the 8 weeks period and also changes in colour with time [56]. However, their associated frictional forces might not be affected in the same manner [57].

Merits and Demerits of friction in orthodontics:

In a finite element test study done by Kojima Y *et al.*, reported that approximately 60% of the orthodontic force applied to a tooth is lost as a static friction [58]. Thus, the response of the biological tissues to mechanical stimulus takes place only when the force is great enough to overcome it. Ultimately, a higher amount of orthodontic force may be required to overcome higher friction level and this may compromise the orthodontic tooth movement as well as may complicate the anchorage control.

Despite the undesirable effects of the friction in some stages of the orthodontic tooth movement, there are some clinical situations in which the presence of friction is beneficial, such as, torquing of the teeth during finishing stage or anchorage conservation etc [6]. Nowadays, many companies are marketing newer materials claiming that they reduce the friction. These may be used to reduce the friction; however, so far, no research is done to back up these claims. Therefore the knowledge of friction, its impact on the orthodontic therapy, the variables that affect it and the ways to better control friction, is most important to the orthodontist.

Clinical implications

The success of orthodontic mechanotherapy depends on the careful management of friction. From the above discussion, it is clear that friction is an unavoidable phenomenon in orthodontics.

- Stainless-steel archwire-bracket combination and among the aesthetic archwires, Teflon coated archwire produces the least amount of friction thereby increasing the efficiency of orthodontic tooth movement.
- Self-ligating brackets do not provide any added advantage over the conventional ligating brackets in terms of friction control.
- Titanium brackets can be used in patients who are allergic to Nickel and offer comparable frictional resistance to that of stainless-steel bracket.
- Teflon coated ligatures and Super Slick ties generate less friction as compared to that of the stainless-steel ligation system. However, the cost factor should be kept in mind for patients with economic constrain.
- Biological factors such as the saliva, debris, plaque accumulation around the brackets increase the frictional resistance. Therefore, in patients with xerostomia saliva substitutes and maintenance of oral hygiene could help counteract it.

CONCLUSION

The knowledge of frictional forces and the appreciation of its role in treatment planning are critical for the orthodontists who employ sliding mechanics. The best archwire-bracket combination should be used so as to control the friction. The recent innovations to lower frictional forces seem to have good potential; however, the cost of these materials is significantly higher than the traditional ones and requires more research from their clinical perspective.

ACKNOWLEDGEMENT

All authors are thankful to Dr. Dhara Patel for helping in review preparation.

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