Friction: An Overview

P. Emile Rossouw

Binding of the bracket on the guiding archwire (bracket-archwire interface) occurs through a series of tipping and uprighting movements (Figs 1-3); it signifies orthodontic tooth movement, moreover, it creates friction.[1]

The Phenomenon Known as Friction

Friction is a clinical challenge, particularly with sliding mechanics, and must be dealt with efficiently to provide optimal orthodontic results (Fig 4). An understanding of the terminology used in the context of friction is imperative, as this insight enables the orthodontist appropriate utilization of orthodontic biomechanical principles, as well as how it pertains to the orthodontic appliances. The second article of this journal in general deals with these concepts of friction. It will become clear why friction could delay treatment, moreover, it could be advantageous in providing anchorage in respect to other planned tooth movements. However, the anchorage generated by the friction phenomenon could also cause unwanted tooth movements. Resistance during tooth movement may be a result of physical or biological parameters.

The orthodontic literature notes numerous variables that affect the levels of friction at the bracket-archwire interface. In addition, experimental protocol and design often affect the outcome of *in vitro* frictional studies. The nature of friction in orthodontics is multi-factorial, derived from both a multitude of mechanical or biological factors.[2] Numerous variables have been assessed using a variety of model systems with nearly equally varying results. Variables affecting frictional resistance in orthodontic sliding mechanics include the following:

1. Physical/mechanical factors such as:
   i) Archwire properties: a) material, b) cross-sectional shape/size, c) surface texture, d) stiffness.
   ii) Bracket to archwire ligation: a) ligature wires, b) elastomerics, c) method of ligation.
   iii) Bracket properties: a) material, b) surface treatment, c) manufacturing process, d) slot width and depth, e) bracket design, f) bracket prescription (first-order/in-out; second-order/toe-in; third-order/torque).
   iv) orthodontic appliances: a) interbracket distance, b) level of bracket slots between teeth, c) forces applied for retraction.
2. Biological factors such as:
   a) saliva, b) plaque, c) acquired pellicle, d) corrosion, e) food particles.

In articles 3 and 4 of this issue, the relationships of the various mechanical factors will be explored and illustrated. Articles 5, 6, and 7 will, in addition to mechanical, also deal with some of the biological influences on the friction between bracket and archwire.

What is Friction in Orthodontics?

Friction is a force that retards or resists the relative motion of two objects in contact. The direction of friction is tangential to the common boundary of the two surfaces in contact.[3] As two surfaces in contact slide against each other, two components of total force arise: the frictional force component (F) and the normal force component (N) perpendicular to the contacting surfaces and to the frictional force component.[4] Frictional force is directly proportional to the normal force, such that $F = \mu N$, where μ = coefficient of friction.[5] The static frictional force is the smallest force needed to start the motion of solid surfaces that were previously at rest with each other, whereas the kinetic frictional force is the force that resists the sliding motion of one

From the Department of Orthodontics, Baylor College of Dentistry, Dallas, TX.

Address correspondence to Dr. P. Emile Rossouw, BSc, BChD, BChD (Hons), MChD, PhD, FRCD(C), Professor and Clinic Director, Department of Orthodontics, Baylor College of Dentistry, 3302 Gaston Avenue, Dallas, TX 75246.

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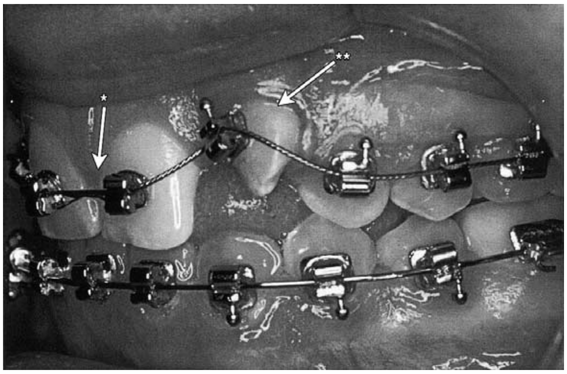

Figure 1. A patient with congenitally absent maxillary lateral incisors; the treatment objective is to utilize the maxillary canine in the lateral incisor position. Friction is needed to rotate and upright this mal-positioned canine. Note the figure 8 ligation of the central incisors to prevent inappropriate movement, an example of creating advantageous friction. Bracket design differences, as well as method of ligation, influence the amount of friction.

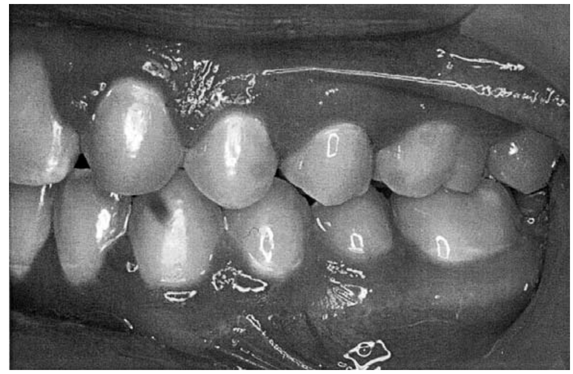

Figure 3. The maxillary canine is in position as a replacement for the lateral incisor and ready for esthetic recontouring where needed. These goals were attained by utilizing both friction and/or no friction as part of the clinical treatment mechanotherapy.

solid object over another at a constant speed.[6] As the tooth moves in the direction of the applied force, kinetic friction occurs between the bracket and archwire.[7] Movement of the crown mostly precedes displacement of the root because a tipping moment is placed on the crown of the tooth. The moment that led to the tipping is determined by the combination of the location of the force application relative to the center of resistance and the amount of resistance to tooth movement.[8] This tipping leads to increased friction from binding between the archwire and bracket restricting movement of the entire tooth. Engagement of the archwire with the bracket creates a counter-moment that will bring the root of the tooth in the direction the crown has moved.[3] The coupled sequence of successive crown tipping then root uprighting will continue along the same plane of space as the direction of the applied motive force. This allows approximation of translation of the tooth during sliding mechanics. The static and kinetic

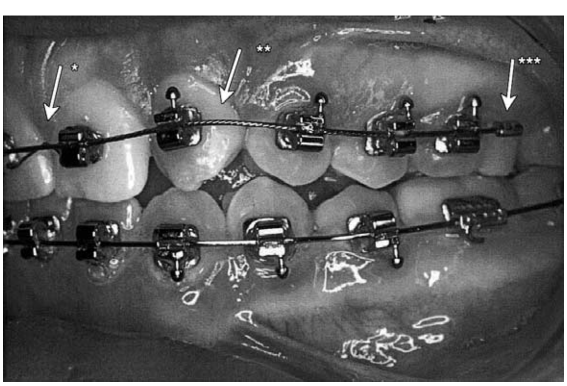

Figure 2. A continuation of treatment also necessitates uprighting of the canine in pursuit of an ideal root-crown relationship. The frictionless posterior wire-bracket interface allows the archwire to gently slide posteriorly and protrude distally from the maxillary molar buccal tube.

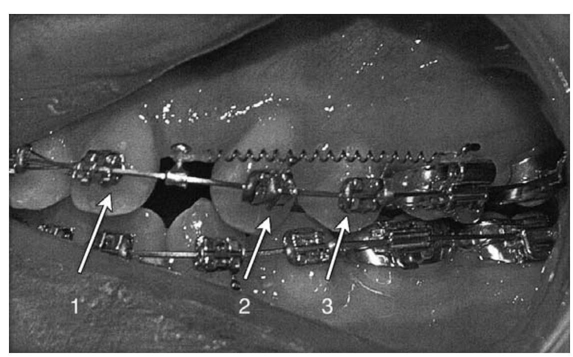

Figure 4. The maxillary anterior segment is being retracted utilizing Class I sliding mechanics. Note the following aspects of the treatment mechanics that have a detrimental impact on friction: 1) Anterior segment ligated together to form a unit for en masse retraction: anchorage considerations important to ensure maintenance of the Class I relationship; 2) Canine with an elastic tie as well as steel tie over the rectangular archwire: an increase in friction, sliding resistance, and subsequent impact on anchorage; 3) Elastic tie over rectangular wire: increase in friction with impact on anchorage.

frictional forces should be minimized to obtain optimal tooth movement.[9]

The noted information will be adequately illustrated throughout all the articles of the Journal and thus provide insight into the complexity of friction mechanics and, more importantly, assist the clinician in the choice of the correct combination of archwires and brackets.

Loss of Applied Force

Orthodontic tooth movement is dependent on the ability of the clinician to use controlled mechanical forces to stimulate biologic responses within the periodontium.[10] Investigators have indicated that applying the proper magnitude of force during orthodontic treatment will result in optimal tissue response and rapid tooth movement.[11,12] In a critical review of some of the hypotheses relating orthodontic force and tooth movement,[13] it has been concluded that the rate of tooth movement increases proportionally with increases in applied force up to a point, after which additional force produces no appreciable increase in tooth movement.

With orthodontic mechanotherapy, a biologic tissue response with resultant tooth movement will occur only when the applied forces adequately overcome the friction at the bracket-wire interface.[5] This means that the mechanotherapy to move a tooth via a bracket relative to a wire results in friction localized at the bracket-wire interface that may prevent the attainment of an optimal force in the supporting tissues. Therefore, orthodontists need to have a quantitative assessment of the frictional forces encountered to achieve precise force levels to overcome friction and to obtain an optimal biologic response for efficient tooth movement.[14,15]

Problems of loss of applied force because of friction during sliding mechanics have been recognized for some time.[16,17] The portion of the applied force lost because of the resistance to sliding can range from 12% to 60%.[18] If frictional forces are high, the efficiency of the system is affected, and the treatment time may be extended or the outcome compromised because of little or no tooth movement and/or loss of anchorage.[3,5,19,20] In addition, the amount of frictional resistance will impact on the moment-to-force ratios of the teeth and, consequently, their centers of rotation.[21]

Controlling Friction

Friction is not likely to be eliminated from materials, thus the best remedy is to control friction by achieving two clinical objectives: maximizing both the efficiency and the reproducibility of the orthodontic appliances.[18] Efficiency refers to the fraction of force delivered with respect to the force applied, while reproducibility refers to the ability of the clinician to activate the orthodontic appliance so that it behaves in a predictable manner.[18] Therefore, the clinician should be aware of the characteristics of the orthodontic appliance that contribute to friction during sliding mechanics and the extent of the amount of force expected to be lost to friction.[22] This will help allow efficient reproducible results to be achieved. Articles 3 and 5 of this issue especially will provide a guide as to the importance of the correct combination of bracket-archwire interface.

Contemporary studies of friction in orthodontics have set forth to characterize the magnitude and the nature of the resistance to sliding encountered between brackets and arch wires. What is actually being measured by these studies may be a combination of true frictional resistance and binding at the archwire interface.[4] When the archwire and the bracket have clearance, classical friction exists as the only component to the resistance to sliding.[23] When clearance disappears and an interference fit occurs between the bracket and the arch wires, binding arises as a second component to the resistance to sliding superimposed on the classical friction.[23]

The hindrance to sliding mechanics with increasing archwire dimension and especially the combination in an active versus passive appliance are well portrayed in the various chapters presented in this issue of *Seminars in Orthodontics.*

Experimental Canine Retraction Model

An objective of this edition on friction of *Seminars in Orthodontics* is to provide information with respect to the various methods of testing of friction and, in addition, show how testing methodology has evolved from updated *in vitro* to *in vivo* testing apparatuses. Canine distalization using sliding mechanics is possibly one of the most frequently executed tooth movements. It is thus not uncommon to also find canine retraction in the latter mode as the choice for testing model *in vitro* experiments. During canine distalization with sliding mechanics, a significant amount of the applied force to move the tooth may be lost because of frictional resistance. Minimization of frictional resistance during canine retraction allows most of the applied force to be transferred to the teeth while optimizing orthodontic tooth movement and decreasing undesirable anchorage loss. Clinical success thus depends on analysis of the frictional resistance of brackets and arch wires, and a simulated canine retraction model is of paramount importance to optimize all involved parameters. An experimental canine retraction model utilizing a servomotor capable of tipping and uprighting brackets will be used in a quantifiable analysis of the frictional resistance for various brackets and arch wires combinations. This model of testing is by no means the only acceptable method of testing friction; three different *in vitro* methods are illustrated (Articles 3, 4, 5, and 6) as well as a unique *in vivo* method (Article 7). However, the aim of Article 4 is to illustrate the intricacies of the development of a testing apparatus.

In vitro studies of frictional resistance utilizing static straight-line traction (sliding mechanics) applied to the bracket-wire interface does not simulate the complexity of tooth movements. However, it is still a method often used, and it will also be demonstrated how this method of testing can be used to validate manufacturer's claims regarding low friction modalities in Article 3. Straight-line testing, with or without second-order friction, could at very low velocities of testing provide some indication of the so-called "stick-slip" phenomenon, however, a closer simulation of the clinical situation is possible when the actual bracket is tipped to and fro to simulate tipping and uprighting tooth movements. The varied combinations of tipping and uprighting as accomplished during movements such as canine distalization is portrayed in a subsequent article in this issue. Caution should be exercised in interpreting the results of *in vitro* frictional resistance studies since experimental conditions do not always accurately represent the clinical situation. An evaluation of lubricants (such as saliva) and the effect on friction plays an important part in the evaluation of friction modalities and will become clear following perusal of Article 6 of this Journal, alluding in particular to this concept.

Therefore, analysis of the parameters affecting the frictional resistance, as demonstrated throughout this journal, becomes more meaningful when canine distalization via sliding mechanics is simulated experimentally as close to the clinical circumstances as practically allowed, and then continued in the oral cavity as shown in Article 7.

Conclusion

Classically, the gold standard for sliding mechanics had been established as couples between stainless steel arch wires and brackets[24,25] Recent manufacturing techniques of new and innovative orthodontic materials have led to lower frictional resistance than the same products tested in the past.[23]

It is difficult to accurately determine the many variables affecting the frictional resistance in orthodontic sliding mechanics in a clinical situation.[25] This is further complicated by the fact that there are such a variety of orthodontic appliances, as well as a vast variability in the biological parameters of patients. It has been suggested that, clinically, these forces, because of frictional resistance, may be overestimated and are less than what is measured in steady state laboratory experiments.[26]

Reduction in the applied force because of friction during sliding mechanics has been recognized for some time.[16-18] More importantly, to prevent undesired tooth movement and to ensure optimal tooth movement, friction must be understood and controlled. The pertinent literature presented in this edition of *Seminars in Orthodontics* will serve to elucidate the general trends of frictional resistance encountered in orthodontics and what it means clinically.

References

1. Farrant SD. An evaluation of different methods of canine retraction. Br J Orthod 1976;4:5-15.
2. Nanda R, Ghosh J. Biomechanical considerations in sliding mechanics. In: Nanda R (ed). Biomechanics in Clinical Orthodontics. Philadelphia, PA, WB Saunders, 1997;pp 188-217.
3. Drescher D, Bourauel C, Schumacher HA. Frictional forces between bracket and arch wire. Am J Orthod Dentofac Orthop 1989;96:397-404.

4. Dickson JAS, Jones SP, Davies EH. A comparison of the frictional characteristics of five initial alignment wires and stainless steel brackets at three bracket to wire angulations: an in vitro study. Br J Orthod 1994;21:15-22.
5. Kapila S, Angolkar PD, Duncanson MG, et al. Evaluation of friction between edgewise stainless steel brackets and orthodontic wires of four alloys. Am J Orthod Dentofac Orthop 1990;98:100-109.
6. Omana HM, Moore RN, Bagby MD. Frictional properties of metal and ceramic brackets. J Clin Orthod 1992; 27:425-432.
7. Bednar JR, Gruendeman GW, Sandrik JL. A comparative study of frictional forces between orthodontic brackets and archwires. Am J Orthod Dentofac Orthop 1991;100: 513-522.
8. Yamaguchi K, Nanda RS, Morimoto N, et al. A study of force application, amount of retarding force, and bracket width in sliding mechanics. Am J Orthod Dentofac Orthop 1996;109:50-56.
9. Nikolai RJ. Bioengineering analysis of orthodontic mechanics. Philadelphia, PApp 53-56, Lea & Febiger, 1985.
10. DeFranco DJ, Spiller RE, von Fraunhofer JA. Frictional resistances using Teflon-coated ligatures with various bracket-archwire combinations. Angle Orthod 1995;65: 63-72.
11. Schwartz AM. Tissue changes incidental to orthodontic tooth movement. Int J Orthod 1932;18:331-352.
12. Storey E, Smith R. Force in orthodontics and its relation to tooth movement. Aust J Dent 1952;56:11-18.
13. Quinn TB, Yoshikawa DK. A reassessment of force magnitude in orthodontics. Am J Orthod 1985;88:252-260.
14. Angolkar PD, Kapila S, Duncanson MG, Nanda RS. Evaluation of friction between ceramic brackets and orthodontic wires of four alloys. Am J Orthod Dentofac Orthop 1990;98:499-506.
15. Ogata RH, Nanda RS, Duncanson MG, et al. Frictional resistances in stainless steel bracket-wire combinations with effects of vertical deflections. Am J Orthod Dentofac Orthop 1996;109:535-542.
16. Stoner MM. Force control in clinical practice. Am J Orthod 1960;46:163-168.
17. Paulson RC, Spiedel TM, Isaacson RJ. A laminographic study of cuspid retraction versus molar anchorage loss. Angle Orthod 1970;40:20-27.
18. Kusy RP, Whitley JQ. Friction between different wire-bracket configurations and materials. Seminars Orthod 1997;3:166-177.
19. Downing A, McCabe J, Gordon P. A study of frictional forces between orthodontic brackets and archwires. Br J Orthod 1994;21:349-357.
20. Edward GD, Davies EH, Jones SP. The ex vivo effect of ligation technique on the static frictional resistance of stainless steel brackets and archwires. Br J Orthod 1995; 22:145-153.
21. Braun S, Bluestein M, Moore K, et al. Friction in perspective. Am J Orthod Dentofac Orthop 1999;115:619-627.
22. Frank CA, Nikolai RJ. A comparative study of frictional resistances between orthodontic bracket and arch wire. Am J Orthod 1980;78:593-609.
23. Articolo LC, Kusy RP. Influence of angulation on the resistance to sliding in fixed appliances. Am J Orthod Dentofac Orthop 1999;115:39-51.
24. Kusy RP. Orthodontic biomechanics: vistas from the top of a new century. Am J Orthod Dentofac Orthop 2000a; 117:589-591.
25. Kusy RP. Ongoing innovations in biomechanics and materials for the new millennium. Angle Orthod 2000b;70: 366-376.
26. Ho KS, West VC. Friction resistance between edgewise brackets and archwires. Aust Orthod J 1991;12:95-99.