Friction and resistance to sliding in orthodontics: A critical review

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Despite the emphasis it now receives in the marketing of self-ligating brackets, friction is not the major component of resistance to sliding in clinical treatment. Laboratory studies show that binding of the wire against the corners of the bracket, which occurs soon after tooth movement begins, is much more important than previously thought, and that notching of the archwire, which temporarily stops movement, can occur. Clinical studies support the view that resistance to bodily tooth movement by sliding has little to do with friction and, instead, is largely a binding-and-release phenomenon that is about the same with conventional and self-ligating brackets. The limited clinical trial data available now do not support the contention that treatment time is reduced (presumably because of lower friction) with self-ligating brackets. (Am J Orthod Dentofacial Orthop 2009;135:442-7)

Friction in clinical orthodontics now is receiving much attention because orthodontic companies have decided that low friction is good and are using that concept to market their self-ligating brackets. Sometimes low friction can be important, as in retracting a tooth along a continuous archwire or in consolidating space; sometimes high friction is needed, as in closing-loop mechanics, anchorage, and 2-couple systems (torquing arch). Often friction is not an issue, as in a 1-couple system (intrusion or extrusion arch) or for repositioning an impacted tooth with a cantilever. This article evaluates friction in the context of resistance to sliding of brackets along an archwire or an archwire through brackets, when friction is just 1 component of the total resistance.

Friction is the resistive force between surfaces that opposes motion. Friction is part of the study of tribology, which is a “class of problems involving friction, lubrication and wear.” It is not a fundamental force, because it is derived from electromagnetic forces between atoms. All surfaces are more or less irregular, and the physical explanation of friction is in terms of the true area of contact, which is determined by asperities (Fig 1), and the force with which the surfaces are forced together. There are 2 types of friction: static and kinetic. Static friction opposes any applied force. Its magnitude is exactly what it must be to prevent motion between 2 surfaces, up to the point at which it is overcome and movement starts. Kinetic friction, which usually is less than static friction, then opposes the direction of motion of the object (Fig 2).

For all practical purposes, kinetic friction is irrelevant in orthodontic tooth movement because continuous motion along an archwire rarely if ever occurs. In sliding mechanics, we are dealing with a quasi-static thermodynamic process, which means that the process happens slowly and goes through a sequence of states that are close to equilibrium. Forces and resistance to sliding change as the tooth moves down the wire, tips, has a biologic response, uprights as bone remodels around the root, and then tips again.

In orthodontic tooth movement, friction (static or kinetic) results from the interaction of an archwire with the sides of an orthodontic bracket or a ligature. Friction is only a part, and usually a small part, of the resistance to movement as a bracket slides along an archwire. Kusy and Whitley divided resistance to sliding (RS) into 3 components: (1) friction, static or kinetic (FR), due to contact of the wire with bracket surfaces; (2) binding (BI), created when the tooth tips or the wire flexes so that there is contact between the wire and the corners of the bracket (when a force is applied to a bracket to move a tooth, the tooth tips in the direction of the force until the wire contacts the corners of the bracket, and binding occurs); and (3) notching (NO), when permanent deformation of the wire occurs at the wire-bracket corner interface. This often occurs under clinical conditions (Fig 3). Tooth movement stops when a notched wire catches on the bracket corner and resumes only when the notch is released.

Interactions occur as 1 object influences another. In orthodontics, tooth/bracket movement has major
interactions that involve the teeth, periodontal ligaments, alveolar bone, and forces of mastication. For a bracket attached to a tooth to move relative to a wire in the bracket slot, the tooth must move. The tooth’s resistance to being moved contributes to resistance to sliding, particularly when bodily movement rather than tipping is desired; this is why binding and notching occur in clinical treatment to an extent that might not be included in laboratory simulations with just brackets and wire.

A series of studies in the late Robert Kusy’s laboratory established the basis for binding and notching as the primary components of resistance to sliding. Articolo and Kusy studied resistance to sliding as a function of 5 angulations of .021 × .025-in steel, nickel-titanium, and beta-titanium alloy wire to conventionally ligated edgewise brackets (0°, 3°, 7°, 11°, and 13°), using various combinations of archwires and brackets (Table). They noted that the binding influence became greater as the wire-bracket angulation increased. With a 7° angulation, the binding made up 80% of the resistance to sliding; when the angle was increased to 13°, binding produced 99% of the resistance to sliding, and friction was not an influence.

Thorstenson and Kusy compared a series of self-ligating brackets with conventionally ligated brackets.

Fig 1. When surfaces slide against each other, such as an orthodontic wire against a bracket, contact occurs only at the asperities, which are the microscopic peaks found on even smooth surfaces (data from Proffit).

Fig 2. As a force is applied to an object, static friction occurs until the force is great enough to overcome the initial resistance to movement of the object; then kinetic friction opposes continuation of the movement. Kinetic friction force is less than static friction.

Fig 3. Notching of an archwire occurs when \( \theta_c > \theta_z \); \( \theta_c \) is the critical contact angle after which binding occurs (BI). \( \theta_z \) is the angle that is the demarcation between elastic and plastic deformation where BI stops and physical notching (NO) begins. NO is physical deformation when the wire, bracket, or both permanently change shape.

Table. Binding index (BIX) and binding percentage (%BI) for various materials at N = 200 g

<table>
<thead>
<tr>
<th>Archwire material</th>
<th>Stainless steel</th>
<th>Nickel-titanium</th>
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</thead>
<tbody>
<tr>
<td>Angulation (°)</td>
<td>RS BI BIX %BI</td>
<td>RS BI BIX %BI</td>
</tr>
<tr>
<td>Stainless steel</td>
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<td></td>
</tr>
<tr>
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<td>0.02 0.00 0 0 0 0</td>
<td>0.03 0.00 0 0 0</td>
</tr>
<tr>
<td>3</td>
<td>0.08 0.06 3 73 0 05 0.02 1 45</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.35 0.33 15 94 0.39 0.36 13 93</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.69 0.67 30 97 0.60 0.57 20 95</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>0.88 0.86 38 98 0.80 0.77 27 97</td>
<td></td>
</tr>
<tr>
<td>Ceramic (PCA)</td>
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<tr>
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<td>0.03 0.00 0 0 0 0</td>
<td>0.02 0.00 0 0 0</td>
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<tr>
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<tr>
<td>7</td>
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<tr>
<td>11</td>
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<tr>
<td>13</td>
<td>1.37 1.34 46 98 0.31 0.29 13 93</td>
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Data from Articolo and Kusy. RS, Resistance to sliding; BI, binding; PCS, polycrystalline aluminum.
in a similar but more extensive way, studying the effect of friction to binding on resistance to sliding in a steady-state laboratory model under both dry and wet (saliva) conditions. They reported that, with both conventional and self-ligating brackets, binding also increased as the wire-bracket angulation increased. Figure 4 shows the resistance to sliding with only friction because the bracket is held steady (no angulation). In that condition, resistance to sliding was lower for all the self-ligating brackets than for a conventional bracket tied in with a wire or an elastomeric ligature, and lower for brackets with a passive clip than an active one.

This condition never occurs clinically, however. Unless the bracket is held steady as it moves along the archwire (which cannot be done under clinical conditions), it tips relative to the wire when a force is applied to move it. As soon as the corners of the bracket contact the wire, binding occurs, and this contributes most of the resistance to sliding. Data for binding with the same series of brackets are shown in Figure 5. The conclusion was that “binding does not appear to be affected by the ligation method”; ie, binding is similar with conventional and self-ligating brackets.

The contributions of friction, binding, and notching to resistance to sliding can be understood best by considering the 3 stages in the active phase of moving teeth.

1. The first is the early stage of sliding as the tooth tips and contact of the wire with the corner of the bracket begins to occur; both friction and binding contribute to resistance to sliding: \( RS = FR + BI \).

2. In stage 2, the contact angle increases between the bracket and the wire, when binding is the major source of resistance and friction becomes inconsequential: \( RS = BI \).

3. In stage 3, if the contact angle becomes steep enough, notching of the wire occurs, and both friction and binding become negligible: \( RS = NO \).

In clinical treatment, tooth movement stops from notching, until elastic deformation of the wire occurs as bone remodeling and bone bending during mastication displace the teeth, and the notch is released from contact with the bracket. Further permanent deformation of the wire (another notch) is likely to occur from contact with the corner of the bracket after the first notch is released.

It is interesting and informative to read studies of sliding in the laboratory from the perspective of what components of resistance to sliding they measured. Two reports represent a much larger group of studies in which bracket angle relative to the wire was prevented so that binding and notching could not occur, and only friction was measured.

Sims et al\(^8\) said that they were measuring “resistance to sliding of rectangular wire through the ligated brackets” and reported that frictional resistance for the self-ligating Speed bracket and Activa was less than mini-twin brackets. This was true, however, only because their system kept the bracket slot aligned precisely parallel to the wire as a wire was pulled slowly through the bracket. In this type of experimental setup,
if the wires are undersized relative to the bracket slot in a self-ligating bracket, it is possible to position the wire-bracket combination so that there is no contact. This is much like studying the effect of a truck on a bridge if the truck is positioned over the bridge but not actually lowered down onto it; this does not contribute to an evaluation of the stability of the bridge.

More recently but similarly, Hain et al.9 recorded static frictional force, the force needed to start movement, with 3 premolar brackets: Victory twin (conventional ligated bracket), Speed (active clip self-ligation), and Damon2 (passive self-ligation). The brackets were set up so that they would self-align—ie, with no angulation of the bracket relative to the wire. The authors concluded that the Damon bracket produces ‘significantly less friction than the other ligation systems’ and that their results agreed with those of Thorstenson and Kusy5,6—but they did not. Thorstenson and Kusy changed the angulation and got totally different results.

Braun et al.10 studied resistance to sliding using different wire sizes, different ligation methods, and different angles (binding). They concluded that “frictional resistance was effectively reduced to zero each time minute relative movements occurred at the bracket/wire interfaces. Factors such as the degree of dental tipping, relative archwire/slot clearances, and method of tying did not have a measurable effect on frictional resistance in the simulated dynamic of the oral environment.” Why was the resistance briefly reduced to zero when movements occurred at the wire-bracket interface at the corners of the bracket? Because binding and notching were temporarily released.

O’Reilly et al.11 oscillated the bracket while measuring the resistance to sliding, producing the same temporary release of binding. Their conclusion was similar: “If one considers the clinical situation, where there is intermittent movement between the bracket and archwire, then clinically we may not be looking at true friction, but rather a binding and releasing phenomenon. In the present study, it was found that repeated displacement of a bracket, equivalent to as little as 0.16 mm of mesiodistal crown movement, could reduce the sliding resistance by as much as 85%.”

If meaningful results for resistance to sliding in orthodontics are to be obtained from laboratory studies, bracket-wire angulation and the 3 stages of interaction between bracket and wire must be part of the investigation. Clearly, a binding and releasing phenomenon, not frictional resistance, is the major determinant of how well bracketed teeth move along an archwire.

Two early clinical studies comparing resistance to moving teeth along an archwire provide supporting evidence of movement as binding and releasing. Hixon et al.12 observed that vibrating the teeth decreased resistance to sliding, and Jost-Brinkman and Miethke13 reported that “additional tooth movement by occlusal load resulted in significant reduction of friction magnitude.” This effect can be attributed to the same temporary release of binding or notching observed in laboratory studies.

Fig 5. Coefficient of binding for the same brackets and wire sizes. Binding, in contrast to friction, is remarkably similar for conventional and all types of self-ligating brackets (data from Thorstenson and Kusy9).
In 2003, Iwasaki et al.\textsuperscript{14} studied the effects of bracket ligation forces and forces of mastication on friction when sliding a bracket down an archwire, using a design with parallel laboratory and intraoral experiments. In the intraoral experiments, the bracket being moved down the wire was not actually attached to a tooth (neither was the wire), and the bracket/moment spring assembly did not allow normal binding. With this setup, having the subjects chew gum did not decrease friction; ie, the results were not compatible with binding and release as the major component of resistance to sliding. This result disagrees with other studies of the effect of oral function, probably because it evaluated bracket movement, not tooth movement, in both the laboratory and intraoral experiments.\textsuperscript{10-13,15-19}

The clinical advantage of reduced resistance to sliding should be a reduction in the amount of time to align the teeth and close the spaces. Several clinical studies have investigated this. In a prospective clinical trial with 54 subjects who had nonextraction treatment, Pandis et al.\textsuperscript{20} investigated the time needed to correct mandibular crowding with conventional vs Damon2 self-ligating brackets. They concluded that “there was no difference in the time required to correct mandibular crowding between self-ligating Damon2 and conventional edgewise brackets.” In a similar study, Miles et al.\textsuperscript{21} concluded that the Damon2 bracket “was no more effective at reducing irregularity than the conventional twin bracket with elastometric ligation.” Miles\textsuperscript{22} also did a limited clinical trial comparing SmartClip to conventional brackets, with the same conclusion.

In their 2007 review of studies of self-ligating brackets, Rinchuse and Miles\textsuperscript{23} discussed treatment time with self-ligating vs twin brackets. Past studies showed no difference in treatment time.\textsuperscript{20-22} Subsequently, Miles\textsuperscript{24} compared the rate of en-masse space closure with conventional brackets tied with steel ligatures vs self-ligating brackets and found no difference.

The bottom line is that clinical studies (1) support the laboratory findings that resistance to sliding is largely due to binding and notching that is temporarily released by oral function, and (2) provide no evidence to support the claim of reduced treatment time with self-ligating brackets.

**CONCLUSIONS**

All manufacturers of self-ligating brackets offer reduced frictional resistance and reduced treatment time as reasons for using them, and, to some degree, all have “cherry-picked” the research data to support their contentions. Despite the emphasis it receives in the marketing of self-ligating brackets, friction is not the major component of resistance to sliding in clinical treatment, and ignoring the other components distorts clinical reality. Swartz\textsuperscript{25} summed it up nicely when he stated that the “simplification of complex biomechanical interactions that inevitably occur in steady state laboratory testing may have resulted in an over-estimation of the clinical significance of friction.” Clinical studies support the view that resistance to sliding has little to do with friction and, instead, is largely a binding-and-release phenomenon that is about the same with conventional and self-ligating brackets. The limited clinical trial data now available do not support the contention that treatment time is reduced (presumably because of lower friction) with self-ligating brackets.

Studies in Robert Kusy’s laboratory at University of North Carolina are particularly helpful in understanding resistance to sliding in orthodontics, and his contributions are gratefully acknowledged. I thank William Proffit for his editorial assistance.

**REFERENCES**


