Friction and anchorage loading revisited

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Contemporary concepts of sliding mechanics explain that friction is inevitable. To overcome this frictional resistance, excess force is required to retract the tooth along the archwire (i.e., individual retraction of canines, en masse retraction of anterior teeth), in addition to the amount of force required for tooth movement. The anterior tooth retraction force, in addition to excess force (to overcome friction), produces reciprocal protraction force on molars, thereby leading to increased anchorage loading. However, this traditional concept was challenged in recent literature, which was based on the finite element model, but did not bear correlation to the clinical scenario. This article will reinforce the fact that clinically, friction increases anchorage loading in all three planes of space, considering the fact that tooth movement is a quasistatic process rather than a purely continuous or static one, and that conventional ways of determining the effects of static or dynamic friction on anchorage load cannot be applied to clinical situations (which consist of anatomical resistance units and a complex muscular force system). The article does not aim to quantify friction and its effect on the amount of anchorage load. Rather, a new perspective regarding the role of various additional factors (which is not explained by contemporary concept) that may influence friction and anchorage loading is provided. ORTHODONTICS (CHIC) 2012;13:200–209.

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Due to its simplicity and predictable outcome, sliding mechanics is an easier method of space closure than loop mechanics. However, with sliding mechanics, friction is inevitable. There are two types of space closure using sliding mechanics: (1) only the canine bracket slides over the archwire (in cases of individual canine retraction) (Fig 1), and (2) where an archwire slides through the premolar/molar bracket slot (in cases of en masse retraction of anterior teeth) (Fig 2). In the first instance, the archwire remains stationary in relation to all the teeth, and only the canine bracket slides over the stationary archwire into the premolar extraction site, thus opening space between the lateral incisor and canine. Following this, the space is closed by incisal retraction. In the second instance, all six anterior teeth and the archwire are retracted such that archwire slides through the premolar and molar brackets, thereby closing the premolar extraction site. Therefore, regardless of how the premolar extraction space is closed, friction will be present.

Let us assume that the anchor unit is the molar and the tooth to be moved is the canine (individual canine retraction in the premolar extraction space). Figure 3 explains that for tooth movement to occur, if grams of force required to be applied from the anchor unit, then in sliding mechanics, grams of force will be required (contemporary model/concept). The additional grams
of force will be required to overcome frictional resistance between the archwire and bracket on the tooth to be moved. In the absence of frictional resistance, only x grams are necessary from the anchor unit to move the tooth. Therefore, in the presence of friction, there is increased loading by grams on anchor units to achieve the tooth movement by sliding or friction mechanics.

However, Southard et al. challenged the belief that the friction that resists the distal movement of the tooth will also exist in relation to anchor units and thereby prevent mesial movement. The frictional resistance in the canine and molar region will therefore counteract each other and not lead to any additional anchorage loading (Fig 4). Friction, therefore, would not increase anchorage loading (Southard concept/model).

The following points have not been considered in either of these models:

- The anchor unit and the tooth to be moved differ in their anatomical structure, mass, and surrounding bone quality.
- Molars are situated along the relatively straight portion of the arch form, whereas canines are along the curved portion of the arch and the retraction force element acts along a straight line. Therefore, the force system along transverse plane needs consideration. Similarly, force systems resulting due to friction need consideration, even along the vertical plane.
- Masticatory forces and forces of surrounding musculature (such as the tongue and lips) are more prominent along the sagittal plane. The sagittal plane (ie, mesiodistal plane) of the molar and canine are noncollinear and nonparallel to each other and to that of the direction of natural forces of mastication and the surrounding musculature. Therefore, the influence of these forces in conjunction with friction would differ based on the location of the tooth.
- The amount of friction in the canine and molar region with the same materials would differ (in contrast to the Southard et al. model) because molar tubes are longer than the width of the canine bracket. The bracket-archwire angulations in active state would differ in the canine and molar region, as would the amount of binding friction. Also, friction in the second premolar region may exist or develop later during space closure and may affect the entire force system, especially in relation to anchor units.
- The Southard et al. model would hold true only in the presence of a two-body system along a straight line with the anchor unit and tooth (to be moved) of the same mass, structure, and surrounding constraints (such as bone density) in the absence of any additional forces (other than retraction forces).
- Neither of these models consider that tooth movement is a quasistatic process. In a quasistatic process of tooth movement, there will be a series of closely associated alternating processes of passive and active bracket-archwire configurations. Therefore, when the bracket and archwire are in a passive configuration, as per the contemporary model, the tooth (canine) will receive x + y grams of force, while in active configuration, it will receive only x grams of force. Similarly, the anchor unit will experience different force levels depending on whether the molar tube–archwire configuration is active or passive.
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When the bracket-archwire configuration is passive, the contemporary model seems apt. In the active state, the model put forward by Southard et al. looks appropriate. This is in accordance with Burrow. These situations are not clinically distinguishable, and various factors mentioned above need to be considered so as to substantiate whether friction may have any implications on anchorage loading.

It therefore seems that our understanding of the effect of friction on anchorage loading is controversial and probably lacks a satisfactory explanation as to how friction affects anchorage loading. The aim of this article is to emphasize the plausible role of additional factors (not previously explained) that reinforce the fact that friction would increase anchorage loading, even in individual canine retraction cases. For en masse retraction using sliding mechanics, it will be then easily recognizable that friction increases anchorage loading. The explanation is not aimed to quantify the amount of anchorage loss, but rather make an attempt to introduce the concept that these additional factors and their effects on friction, if any, will lead to anchorage loss.

ANCHORAGE

In orthodontics, anchorage is defined as the nature and degree of resistance to displacement offered by an anatomical unit for the purpose of tooth movement. Anchorage, in simple terms, means resistance to any unwanted tooth movement. In case of molars as an anchor unit, anchorage loss can be direct (due to unwanted tooth movement—mesial movement, extrusion, mesiolingual rotation—of anchor teeth) or indirect (due to unwanted movement—extrusion or proclination—of anterior teeth).

Friction

Three aspects of friction need to be considered: classical friction, binding, and notching.

Classical friction. Classical friction occurs when clearance exists between the bracket slot and archwire during sliding (ie, passive bracket-archwire configuration). This would occur when there is enough play between the bracket and archwire along the vertical plane, and friction occurs as a result of pressing the archwire against the base of the bracket slot due to ligation forces. It is independent of the surface area of interacting material.

Binding. When the archwire-bracket clearance is gone, sliding is progressively hampered and binding dominates. This occurs when point contacts are formed between brackets, archwires, and/or ligatures, producing a force couple that resists sliding (active bracket-archwire configuration). Binding exists in the presence of high angulations and torque. This force may prevent tooth movement and damage the surface of the orthodontic appliance, resulting in notching.

Notching. When all motion ceases due to binding, notching occurs. This occurs as a result of gouging and cutting the archwire surface. These notches can range from a few large to many small notches and from edges to flats. These are common with damaged or soft wires and hard brackets (such as ceramic brackets).

Tooth movement

Tooth movement in sliding mechanics is not pure translational movement, but rather a combination of many small tipping and uprighting movements. Consider an example of retraction of a canine along a 0.019 × 0.025-inch stainless steel archwire in a 0.022-inch bracket slot. On application of retraction forces (away from $C_{req}$), the canine will tip distally until the play between the corners...
of the bracket and the archwire is eliminated. Next, the friction between the bracket corners and archwire creates the moments necessary to bring about bodily tooth movement. At times, this binding type of friction is generated between the archwire and bracket/molar tube, which, at that moment, resists any further tooth retraction despite the presence of retraction forces. At this particular moment, the retraction forces may dissipate by causing the archwire to flex. However, considering the rigidity of 0.019 × 0.025-inch stainless steel archwires, the routinely employed retraction forces are not high enough to flex the archwire in an obvious manner. But if it is assumed to happen (as per Southard et al²), this flexion might exist in the magnitude of a few microns. The flexed archwire thereby leads to distal tipping of the canine along with extrusion of anterior teeth (bite deepening). Once the binding of archwire and bracket is released (due to masticatory forces or other factors), the tooth gets retracted and the flexed archwire straightens and generates uprighting moments. This entire cycle occurs several times during the space closure phase, which is a combination of tipping and bodily tooth movements. At times, tooth retraction is virtually halted, which leads to archwire flexion. It should be remembered that archwire flexion with rectangular wires would occur more easily along the vertical plane compared with the horizontal plane (as vertical dimensions are smaller than buccolingual dimensions of archwire), leading to bite deepening.
On application of retraction forces, at one particular stage of quasistatic process of tooth movement, flexion of the archwire will occur due to increased friction at the molar and canine region due to binding of the bracket or tube and archwire.\textsuperscript{2,9,10} In clinical situations, since the flexed wire (due to binding/increased friction in the molar and canine region) will have the tendency to straighten (to achieve equilibrium), three possibilities (situations) are there in subsequent stages of the quasistatic tooth movement process. These situations constitute very small stages of the entire tooth movement process. These situations follow each other and exist independently, but cannot be differentiated in clinical situation (similar to the quasistatic process in thermodynamics).

**Situation 1: Greater friction in canine region than the molar region.** In this case, the flexed archwire would slide through the molar tube, and the anterior teeth move as one unit since the canine bracket is not free to slide over the archwire due to friction. This simulates en masse retraction and increases the anchorage load at the quasistatic tooth movement stage. This phenomenon can be explained in Fig 1; individual canine retraction was initiated without consolidating the central and lateral incisors. After completion of canine retraction, even the incisors were retracted by some amount.

**Situation 2: Friction in the molar region (ie, if it is increased infinitely by molar stops\textsuperscript{4}) is greater than in the canine region.** If friction does exist in the canine region, it requires the use of relatively heavier forces to overcome classical friction. Once this excess force overcomes friction in the canine region, the canine bracket tips or slides distally until the bracket corners and archwire bind, after which the canine bracket is not free to slide distally (binding friction). However, if comparatively heavier retraction force (excess force to overcome the binding friction in the canine region) is used (in presence of molar stops), it may lead to flexion of the archwire. This results in anchorage loss in the vertical plane by causing bite deepening (due to extrusion of anterior teeth) and probably even in the transverse by causing deformation in arch form (if the archwire is not rigid enough). Also, due to flexion of the archwire, the periodontal ligament (PDL) of the molar region is now compressed due to retraction forces, thereby initiating the bone remodeling process in the alveolar bone and favoring movement of the anchor teeth.

At this stage, the flexed archwire (along with compression of the PDL in the molar and canine region) has a tendency to straighten. It will do so by sliding past the canine bracket, while causing proclination of anterior teeth (explained below) and leading to indirect anchorage loss. It should be noted that, in situation 2, retraction forces of high magnitude (to overcome binding friction) are seldom used clinically. In vivo, such binding does occur, and the vibratory force of mastication helps overcome without the need to use detrimental high forces of retraction.\textsuperscript{11}

If by any means this type of friction in the canine region is minimized (hypothetical situation), canine movement (using continuous retraction forces) should occur with minimum anchorage loss. But, in actuality, the limiting factor for the amount of tooth movement (in this case, the canine) is the biology of surrounding tissues (remodeling of bone and soft tissues), which in itself is not a continuous process. Therefore, even with zero friction in the canine bracket and infinite friction in the molar region (ie, molar stops), the canine retraction will get halted at various intervals until the new cycle of remodeling starts. During this time, the PDL of molars will get compressed due to a continuously acting retraction force. Due to the presence of molar stops and the rate-limiting biologic factor in the canine region, the retraction force will dissipate over the archwire segment between the incisors and molars, bypassing the canine, since the friction in canine region is assumed to be minimum or zero. This will lead to molar protraction, which will also lead to proclination of the incisors.
It should be noted that anterior teeth would not get retracted due to the presence of molar stops and the fact that retraction force is used between the molars and canines (whose tooth movement is biologically limited during this stage), not including the incisors.

If molar stops did not exist, then molars would have protracted only until the canine retraction would have resumed with initiation of next remodeling cycle of bone. This would not have caused any proclination of the anterior teeth. In the presence of molar stops, anterior teeth may augment the PDL surface area to better resist anchorage drain during the biologically limited period of canine retraction. However, the fact that incisors that are situated along the curved portion of the arch against the lips do not provide enough resistance to anchorage drain and that these incisors (with additional proclination) would have to be retracted later during treatment using the same molars as anchorage leads to round tripping and anchorage loss.

Situation 3: Friction in molar region is same as that in canine region. Assuming that at one momentary stage of the quasistatic tooth movement process, the friction in canine and molar regions is equal, probably due to binding of the archwire, the archwire flexes (though by few microns, due to dissipated retraction forces) rather than sliding past the canine bracket or molar tube. This flexed wire will deliver equal and opposite forces on canines (mesial force) and molars (distal force). If there is no space mesial to the canine (ie, just at the initiation of canine retraction), then the flexion of the archwire, if it exists, would cause tipping of the anterior teeth and/or molars into the extraction space. In that case, as the wire straightens, the mesial force will be transferred to the anterior teeth (labial segment), pushing them back to their initial position, and/or to the molars, pushing them distally to their original position. Hence, no net tooth movement has occurred. This situation
Controversy

would occur only in two-body systems of equal mass/weight (in free state) or similar anatomical constraints and in the absence of any other external forces. In clinical situations, it should be emphasized that the distalizing force on molars is resisted better by the anatomical limits of second molars compared with the mesial tipping of canines or proclination of incisors. In the presence of continuously acting retractive force, the wire still has a tendency to flex (since it is assumed to not slide through the canine bracket or molar tube).

Therefore, to achieve equilibrium, the wire will straighten while pushing the canine and molar to their original positions and will continue to do so, assuming that this process is small and occurring several times. This will happen until the binding friction at one point (either at the canine or molar) is relatively reduced by vibrations due to mastication to allow sliding of the wire either through the canine bracket or molar tube. Until this point, the second molar (if it was not initially included in the main archwire) will slowly start migrating into that minute space created due to momentary mesial tipping of the molar (due to flexion of archwire) in the presence of mesial/anterior components of force of mastication (this magnitude also depends on growth patterns). The tendency of flexed wire to straighten will then favor the shift of equilibrium (in a quasistatic process of tooth movement) toward anterior proclination. In turn, this leads to increased anchorage demands for correction of anterior proclination at later stages of treatment. However, clinically, in the presence of masticatory forces, the time period for this situation does not last long but surely accounts for one of many infinitesimally small cycles of tooth movement, and a new cycle of the stick-slip phenomenon begins. The subsequent stage then resembles either situation 1 or situation 2 (which in itself explains that friction increases anchorage loading). Since it is known that higher forces of better mastication resist the mesial migratory tendency of first molars, one may partly elucidate lesser anchorage loss in horizontal vs vertical growers. In the presence of friction mechanics, anchorage control becomes more challenging with vertical growth patterns.

Clinically, in individual canine retraction, it is the combination of closely associated situations 3 and 1 and a look-alike situation 2 (without using too high forces). The predominance of situation 1 or 2 would depend on the magnitude of friction in the canine and molar area. Situation 3 would exist only for a fraction of the entire process, predominantly in cases of notching of the archwire that may occur either at the canine or molar region.

The above explanation was only in relation to the sagittal and vertical planes. In cases where friction is increased to very high levels due to notching of the archwire, especially if round wire is used for canine retraction, flexion of the archwire due to retractive forces can occur along the horizontal plane. The archwire (buccal to center of resistance of the tooth) has a tendency to straighten with the distal force on the molar and mesial force on the canine. The retractive force (applied buccally to center of the resistance of teeth) still occurs, with mesial force on the molar and distal force on the canine. If these force vectors are resolved (and considering the curved arch form in the canine/premolar region), the mesially and distally directed force vectors along the retractive element cancel each other, but the buccally/lingually directed force vectors (in relation to the center of resistance) resolved from mesially and distally directed forces (which are noncollinear and parallel along transverse plane) continue (Fig 5). These forces are not completely counteracted by less rigid archwires and may lead to deranged arch forms, similar to the transverse bowing effect observed with space closure in lingual orthodontics, wherein there is lingual movement of molars and buccal movement of premolars. To counteract this, rigid archwires (such as 0.019 × 0.025-inch stainless steel) are used. Regardless of the rigidity of the archwire, these buccally directed forces
press the archwire along the sides of bracket/molar tube walls, thereby increasing the friction. These processes highlight unwanted tooth movements along the vertical and transverse plane, which to a certain extent can be counteracted by the use of rigid rectangular wires, bite sweeps, and lingual or palatal arches. In the transverse plane, flexed archwire may cause buccal tipping of canines and probably molars (if not counteracted by the transpalatal arch), leading to a loss of buccal root torque, changes in arch form, and associated drawbacks, which in turn place increased demands on anchorage. This can be easily observed in routine clinical scenarios, when anterior tooth retraction is done in the presence of increased friction, which may result in overhanging palatal cusps with some amount of buccal tipping of molars and/or buccal tipping of canines (depending on the rigidity of the archwire and whether the magnitude of friction is higher in canines or molars).

**DISCUSSION**

This article considers the effects of friction not only along the sagittal plane but also along the vertical and transverse planes. It also considers other variables such as curved arch form, differences in archwire-bracket configuration in the canine and molar regions, anatomical structure and investing tissues, physiologic forces, and the quasistatic nature of tooth movement, as well as how these variables modulate the effect of friction on anchorage loading. Friction increases anchorage loading, but the reasoning offered is too simplistic for a complicated quasistatic tooth movement process. If a contemporary concept model of friction causing increased anchorage loading is considered the way it is, then Southard’s concept can be logically applied to rationalize that friction does not increase anchorage loading, which is not the case in reality. This in turn implies that the contemporary concept, although correct in making a final conclusion that friction increases anchorage loading, is not necessarily justifiable. There is a need to identify important factors to validate the fact that friction increases anchorage loading.

With increased friction, more force will be required, which in turn will increase anchorage load, either directly, in the form of molar protraction, or indirectly, in the form of proclination of anterior teeth, buccal tipping of posterior
teeth, bite deepening, etc. The magnitude of anchorage loss due to increased friction cannot be precisely quantified on only the basis of magnitude of friction or retractive forces, owing to the variations of external forces (tongue and mastication), bone density, root surface area, and so on for each tooth. But the fact that these variables are present in each and every person makes it obvious that increased friction would increase anchorage loading in vivo.

Therefore, the best approach to decrease anchorage loading is to decrease the force by reducing the amount of friction in the area of the tooth to be moved and possibly even in the area of the anchor unit (even in cases of individual canine retraction), as discussed in situation 2.

There may be an argument that the anterior component of force of occlusion, tongue forces, etc, are present even in nonorthodontic individuals and that there has to be mesial migration of the dentition. It is present, but in much smaller quantities if considered in a time frame of 1 to 2 years (comparable to the time frame of orthodontic treatment) for the following reasons. Firstly, there is no edentulous space; if there is, then the tipping of adjacent teeth in that space is seen. Secondly, in untreated individuals, teeth resist forces of occlusion better, owing to the natural bone trajectories and orientation of bony trabaculalae. The PDL is not stressed, nor is its cellular activity as high as that which occurs during log phase of orthodontic tooth movement.

One may argue that constant presence of mesial migratory tendency of molars and surrounding musculature should cause anchorage drain even in loop mechanics. The explanation is that teeth are under a constant state of eruption, and arch length only decreases with age in the absence of any opposing external orthodontic forces, the magnitude of which can be considered negligible (if no edentulous space is present) in a time frame of approximately 1.5 years (time required for orthodontic treatment involving extraction of first premolars). Assuming the same type of tooth movement (bodily retraction of anterior teeth or individual canines), in both loop and sliding mechanics, the force required in sliding mechanics to achieve the same type of tooth movement will be higher (to overcome friction). If one has a unyielding opinion that when an additional force is used to overcome friction the same frictional force would even resist mesial movement of molars (in a most conservative form), and the roots of the teeth will not experience any additional load to cause any anchorage loss, then it can presumably happen only along the sagittal plane and only when the bracket-archwire configuration is in an active state, not in a passive configuration. Also, along the transverse and vertical planes, this excess force does not get counteracted by friction in the canine and molar regions, which will lead to unwanted tooth movements and anchorage loss. Therefore, if we keep all the factors constant, the only variable denominator remaining is the magnitude of force employed, which is determined by presence or absence of friction.

Another point of argument that may be possible is that regardless of the magnitude of friction, the amount of anchorage drain is dependent on stress developed at the PDL of the anchor teeth. So in the presence of increased friction, the excess force is used only to overcome this additional friction. The remaining amount of force shall be near normal to put any additional stress on the PDL of anchor teeth to cause anchorage drain. But knowing the fact that tooth movement is a quasistatic process and that the retraction force system employed is rather a continuous one, the stress developed in the PDL of anchor teeth may not be the same throughout the space-closure phase. Therefore, the stress developed in the PDL would be higher during the passive state of bracket-archwire configuration as compared with that during the active (binding) bracket-archwire configuration. Thus, we see that with higher friction, higher force is required, which in turn leads to increased anchorage drain.
It is also very important to discuss the anchorage demands in terms of sagittal, vertical, or transverse planes. In sliding mechanics, friction helps generate necessary counter moments to achieve bodily tooth movement. In loop mechanics, the same is achieved by incorporating counter moments in loop assembly. In loop mechanics, we overcome the problem of friction and its effects on anchorage loading but we create sufficient counter moments to compromise anchorage along the vertical and/or transverse plane. It is beyond the scope of this article to discuss or compare the amount of anchorage loading in sliding mechanics or loop mechanics. However, if friction and its effects on anchorage loading are concerned, we have seen that there is a definite positive correlation between the two.

CONCLUSION

For years, literature has shown that friction increases anchorage loading, and the same has been explained in contemporary textbooks. This concept provides too simplistic an explanation for the complex quasistatic tooth movement process in the presence of a continuous retractive force and only along the sagittal plane. However, the teeth subjected to external forces of retraction (molar and anterior teeth) differ in their morphology, anatomical boundaries, bracket/molar tube attachments, surrounding bone structure, forces from surrounding musculature, and so on. Most important, they are not free body systems. This makes it apparent that the simplistic explanation is not entirely the reality. Although in favor of the contemporary concepts that friction increases anchorage loading, this article differs significantly in its rationalization. The aim of this article was not to quantify friction and its effect on the amount of anchorage load, but rather provide a new perspective regarding the role of various additional factors that may influence friction and anchorage loading. This may provide a new path for further ex vivo experimental simulation of quasistatic tooth movement (considering these additional factors) mediated by the edgewise appliance and thereby evaluate the extent to which various factors influence friction and anchorage load. This may aid better application of our knowledge, which is currently based only on theoretic models, about friction in clinical situations because the process is as important as the result.

REFERENCES