Intra-arch Retraction Mechanics -
A contemporary review.

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Abstract

Extraction space closure involves carefully designed treatment strategy as to lose or not to lose the anchorage. Whether anterior retraction or posterior protraction, or a combination of both is used, the same basic principles of retraction mechanics apply. Retraction mechanics can be divided into two categories, friction and frictionless. Once a decision to extract teeth has been made, the clinician must plan to implement the mechanics based on the demands of the case. Both the mechanics have their own merits and demerits. This article consolidates the basic information regarding the loop and sliding mechanics and their application in contemporary practice.

Keywords

Loop mechanics, sliding mechanics, friction mechanics, frictionless mechanics, retraction mechanics.

Introduction

Anteroposterior therapy procedures to close spaces, correct procumbency, reduce overjet, and eliminate extraction sites often may be generally categorized as "retraction mechanics". Such therapy procedures may involve interarch action and response, extraoral appliance delivery or treatment within the single arch. Either a continuous - or segmented - arch approach might be undertaken. The usual common characteristics of the various procedures include posteriorly directed driving forces as the primary actions, posterior segment anchorage, and, often bilateral action in the presence of mid-sagittal symmetry. This article highlights the retraction mechanics within the single arch. The displacements include the retraction of a canine into a space created by the extraction of a first premolar, and the retraction of an incisal segment or en masse retraction.

Retraction mechanics can be broadly divided into two categories, friction (sliding mechanics) and frictionless (loop mechanics) mechanics. In sliding mechanics, the wire and position of the bracket control the tooth movement, whereas in a loop-spring system, control is built into the spring.

Sliding mechanics vs. Closing loop mechanics

The friction system is distinguished by the fact that a certain degree of friction exists between the wire and the bracket. The level of friction depends on multiple factors, including the type of orthodontic brackets and wires used. Stainless steel brackets slide with relative ease on steel wires. In contrast, wires that contain a certain percentage of titanium (B-Ti or NiTi wires) present a rougher surface compared to steel wires and therefore produce more friction in retraction. Ceramic brackets present an even rougher surface and therefore, more friction when compared to metal brackets. From a biomechanical point of view, all of these factors cause a high degree of unpredictability in sliding mechanics. In order to move a tooth along an arc it is necessary to apply a force of such magnitude to overcome friction and thus start the movement of the tooth. The major difficulty is that of evaluating just how high this force
should be. If the force is too excessive, the posterior segment can inadvertently move anteriorly. The occurrence of bodily tooth movement with sliding mechanics can be explained as follows. The tooth experiences a moment of force in two planes of space. One moment rotates the tooth mesial-out, and the other causes distal tipping of the crown (Figure 1). The mesial out moment is an undesirable side effect, but the distal crown moment contributes to the retraction. Eventually, this distal tipping causes binding of the archwire, which produces a moment of a couple that results in distal root torque (Figure 2). As the tooth uprights, the moment decreases until no longer the wire binds. Then, the crown slides along the archwire until the distal crown tipping again causes binding. The process is repeated until the tooth is retracted or the elastic force is dissipated. A major advantage of friction mechanics is that complicated wire configurations are usually not needed, making initial wire placement less time consuming. Also, this can enhance patient comfort.\textsuperscript{3}

In frictionless mechanics, teeth are moved without the brackets sliding along the archwire. Retraction is accomplished with loops or springs, which offer more controlled tooth movement than sliding mechanics. Generally, closing loop mechanics are more complex due to the construction of the closing loop springs and their clinical management. When compared to sliding mechanics, closing loop mechanics have the following advantages: absence of friction between the bracket and the wire, the force levels are easier to evaluate clinically and the M/F ratio of the cuspid and the posterior segment is predictable and controllable during retraction. According to Burstone\textsuperscript{4}, a spring with closing loops for retracting cuspids can be described by three principal characteristics:

1. Moment to Force ratio (M/F) applied at the bracket whose value determines the position of the center of rotation during the orthodontic movement;
2. Load/deflection rate (F/D) of the spring (the level of force caused by the spring per activation);
3. Maximum strength (F max) that the spring is able to release without permanent deformation.

Friction Mechanics

In sliding mechanics, there is no need to apply a balancing moment for bodily movement. The appropriate moment is applied to the teeth via a continuous archwire that passes through the brackets. The moments are delivered via couples, equal and opposite noncollinear vertical forces, at the mesial and distal bracket extremities. The crown of the canine will tip distally until the diagonally opposite edges of the bracket slot contact and bind with the archwire. The wire then produces a couple to upright the root (Figure 3). The magnitude of the moment is determined by the width of the bracket as well as characteristics of the wire such as alloy, size, and shape. The M/F changes as the tooth moves, and the tooth responds, typically progressing from controlled tipping to translation to root movement. Wire bracket friction is a variable factor as the moving teeth displace along the archwire with this approach, making it difficult to accurately predict M/F.\textsuperscript{2}

![Figure 1: Moments of force placed at bracket level and not at center of resistance. A. Crown rotation. B. Crown tipping.](image1)

![Figure 2: This couple produced by archwire binding results in distal root torque.](image2)
V – Bend Sliding Mechanics

Originally developed by Thomas F Mulligan, this approach is particularly efficacious for closing space by moving individual teeth (i.e., canine retraction or molar protraction). Mulligan introduced the concept of “Differential torque” as a means of effective Intraoral Anchorage. Differential anchorage is obtained by the application of unequal alpha and beta moments. The higher moment is applied to the anchorage teeth. The differential moments are obtained by applying the concept of the off-center V-bend. An off-center V-bend in a wire results in unequal moments. The closer the V-bend to a tooth or set of teeth, the higher the applied moment. A simplistic model for envisioning this force system is to consider the length of wire from the position of the V-bend apex to the brackets (Figure 4). The closer the V-bend apex is to a bracket, the shorter the wire; the further the distance of the V-apex to the bracket, the longer the wire. A shorter wire has a higher bending moment than a longer wire. Therefore, a higher moment acts on the bracket closer to the V-bend than the more distant bracket. Depending on the angle at which the wire with an off-center bend crosses the bracket, and the length of the longer segment, the smaller moment can be clockwise, counterclockwise or non-existent.

Canine Retraction via V-bend Mechanics

If anchorage is required, then the V-bend is placed off center. The tooth located closest to the bend indicates the anchor side. The opposite is the non-anchor side. The anchor side requires a bodily type movement for displacement, whereas non anchor side tips somewhat due to the lesser moment (Figure 5). As the cusps continue to move distally, the bend automatically “approaches” the center of the wire, until finally when the extraction sites are closed, the bend is centered. So, as the off center bend moves toward the center during space closure, the differential torque begins to gradually disappear, and becomes equal and opposite torque when the bend is finally centered. Root Parallelism begins to effect as the bend approaches center.
Friction Issue in Sliding Mechanics

When two surfaces are pressed together with a perpendicular force, another force acting parallel with these surfaces is required to cause one of the surfaces to move against the resistance of the other. This is caused by the phenomenon of friction. Frictional force is that force required to move a body against the resistance caused by friction. The amount of frictional force required depends on the smoothness of the two surfaces and on the force that presses them together. Friction can occur because the archwire - bracket - ligature combination in some way produces a resistance to sliding from classical friction, elastic binding and notching.7

For each archwire - bracket combination, a critical contact angle of 2nd order angulation (θ1) exists, at which classical sliding friction gives way to binding. 'θ' is 2nd order angulation of an arch wire relative to a bracket. θ is critical contact angle or the second order angulation after which elastic binding (BI) occurs. Resistance to sliding is partitioned into classical friction (FR), elastic binding (BI) and physical notching (NO). Both FR and BI are defined in terms of normal forces, N and kinetic coefficients mk. θ is second order angulation at which elastic binding ends and physical notching (NO) begins. Classical friction occurs because of the ligation or normal force (N) that either presses the wire into the slot base or slot wall. In the passive configuration, FR is smaller in magnitude but controls sliding because binding and notching do not exist at this juncture. In the active configuration FR is the least in magnitude because binding, notching or both dominate (Figure 6). In the active configuration, BI can be negligible when the angulation θ approximately equals θ (θ = θ). Comparable in magnitude to FR, or it can dominate when θ >> θ. When elastic binding occurs, it can assume two forms: elastic deformation, wherein the wire and bracket spring back to their original shapes upon removal of force, or plastic deformation, wherein the wire, bracket or both permanently change shape. This second type of binding is called physical notching.8 In the active configuration, physical notching is the ultimate manifestation of binding in which plastic deformation has occurred at the diagonal tie-wings but more likely at the opposing wire contacts,9 when the normal force of binding becomes sufficient to cause this notching (θ > θ), sliding mechanics all but cease until the tipping forces or the forces of mastication at least temporarily remedy the situation.

Sliding mechanics should occur only at values of angulation (θ) that are in close proximity to the critical contact angle of second order angulation (θc) (θ = θc). Material innovations can decrease FR at θ < θ, by reducing the coefficient of friction (mk-FR), the normal force of ligation (N), or both, among which various surface treatments and stress-relaxed ligatures are two means. Composite materials can stabilize θ at θ = θc by maintaining the same arch wire - bracket clearance while permitting the force - deflection characteristic to vary. Decreasing the wire stiffness or increasing interbracket distance can reduce RS at θ = θc, independent of the material used.

Frictionless Mechanics

This mechanics involves bending archwire loops of various configurations, sectionally (to deliver the desired M/F to an individual tooth) or segmentally or in a continuous archwire (to deliver the desired M/F to several teeth). This approach is friction free, when activated, the arch wire loops distort from their original configuration; as the tooth (or teeth) moves, the loop gradually returns to its undistorted (preactivated) position, delivering the energy stored at the time of activation. Brackets are not sliding along the arch wire during the process. An essential characteristic of closing loops for orthodontic space closure is that they are free of friction as they act. Groups of teeth can therefore be moved with more accurately defined force systems for more precise anchorage control to achieve treatment
goals more readily than methods in which friction plays a role.  

**Engineering Principles in Loop design**

The performance of a closing loop is determined by 3 major characteristics:

1. Spring properties - the amount of force it delivers and the way the force changes as the teeth move.
2. The moment it generates - Control of root position (location of loop - V-bend principle).
3. Additional design principles.

**Spring properties**

These are determined almost totally by the wire material (stainless steel or TMA), the size of the wire and the distance between the points of attachment. Wires of greater inherent springiness or smaller cross sectional area allow the use of simpler loop designs.  

**Root paralleling moments**

A closing loop must generate not only a closing force but also appropriate moments to bring the root apices together at the extraction sites. When a closing loop is activated, its horizontal legs attempt to rise at an angle to the plane of the arch wire (Figure 7). The horizontal legs are constrained by brackets and therefore deliver a moment to those brackets. The moment produced by a closing loop during activation is termed activation or Inherent Moment. The activation moment is dependent on the change in angle that the horizontal arms of the loop make with the bracket when a loop is pulled apart. The ratio of these moments to the activation force is termed inherent M/F, a constant for any given loop geometry. Inherent M/F increases as loop height increases. Because of intraoral anatomic limitations, loops cannot be made with enough height to achieve inherent M/F to translate individual teeth or groups of teeth. To achieve a higher M/F ratio, an angulation or a gable type bend must be put in the loop. The additional moment produced by gabling in a loop is termed residual moment. To achieve net translation, residual moments in the form of gable bends or anterior lingual root torque and posterior gable bend must be added. Adding these residual moments has several disadvantages:

1. The teeth must cycle through controlled tipping to translation to root movement to achieve net translation.
2. Whenever residual moments are added, the loop’s neutral position (zero activation position) becomes ill defined, making it difficult to achieve proper activations.
3. The resulting ever-changing periodontal stress distributions may not yield the most rapid, least traumatic method of space closure.

Two principles to remember in obtaining a constant M/F ratio are (1) use as high an activation moment and as low a residual moment as possible, and (2) lower the force - deflection and moment - deflection rates.  

If a closing loop design capable of achieving inherent, constant M/F of 8 to 9 mm without residual moments were available, en masse space closure with uniform periodontal stress distributions could be achieved.  

**The Gable bend and Neutral Position**

It has been shown that the M/F ratios resulting from activating various loop configurations are insufficient to prevent uncontrolled tipping unless Gable bends are included.  

When Gable bends are placed in the occlusal portion of a vertical loop configuration, an unintended mesiodistal force is introduced (Figure 8). This force will alter the desired mesiodistal force originally intended because of the cross over of the vertical legs. This cross over forces shortens the horizontal wire length between the brackets. Burstone et al. have
shown that the neutral position of the loop configuration has been altered by the introduction of Gable bends.\textsuperscript{14} The Neutral Position can be defined as the horizontal separation of the vertical legs of the spring before the introduction of a horizontal or mesiodistal force. It has been shown that appropriate magnitudes and occlusogingival locations of the Gable bends are vital to maintain the neutral position of the closing loop. Otherwise the clinician has no meaningful reference point from which to judge the spring’s activation to obtain the force aspect in the M/F ratio (Figure 9).\textsuperscript{15}

Location of the loop

Because of its gable bends, the closing loop functions as a V-bend in the arch wire. With greater eccentricity at one of the brackets, a larger M/F could be produced. Practically, this means that during canine retraction, with the vertical loop placed closer to the canine, a higher ratio would be present on the canine which could better control the apex. The undesirable effect is extrusion of the canine.\textsuperscript{14}

If only anterior retraction is necessary, the retraction loop should be placed closer to the canine than to the molar, and a gable bend should be added near the molar. A gable bend that is larger in the posterior dimension will produce a larger beta moment, thus, increasing the posterior anchorage. For both retraction of the anterior segment and protraction of the posterior segment, the loop should be placed mid way between the posterior and anterior segments. A gable bend of equal dimensions should be used, so that the alpha and beta moments are equal and reciprocal space closure occurs. When only posterior protraction is desired, the loop should be located closer to the posterior segment.\textsuperscript{15}

Regardless of the initial magnitudes of the alpha and beta moments, changes in magnitudes will occur during retraction. As the anterior teeth are retracted, the magnitude of the alpha moment decreases faster than that of the beta moment, enhancing posterior anchorage.\textsuperscript{14} The alpha/beta moment differential obtained by eccentric positioning underscores the importance of careful clinical placement of the position of loop placement.

Additional design considerations

1. The loop should be "fail safe" - This means that, although a reasonable range of action is desired from each activation, tooth movement should stop after a prescribed range of movement.
2. Design should be as simple as possible.
3. Open versus closed retraction loops.

A loop is more effective when closed (lower load / deflection rate) rather than opened during activation. On the other hand, a loop designed to be opened can be made so that when it closes completely, the vertical legs come into contact, effectively preventing further movement and producing a desired fail safe effect.

Ricketts’ maxillary canine retractor

It is a combination of a double closed helix and an extended crossed T. The retractor is fabricated using \textsuperscript{0.016”} blue elgiloy wire (Figure 10A). In critical anchorage cases, 45° gable bends and 30-50 g/mm activation is recommended.\textsuperscript{17} For lower canine retraction, double closed helix is used. This delivers 50g/mm of activation (Figure 10B).

PG Spring

If offers excellent control of forces and moments and is the most effective current design. This retractor is

\begin{figure}[h]
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\caption{Ricketts retractor.}
\end{figure}

A. Maxillary cuspid retractor. B. Mandibular cuspid retractor
fabricated using .016" .022" stainless steel wire (Figure 11). The design consists of double ovoid specialized spring with a small loop occlusally in order to lower the level of activation in the brackets in the short arm. About 30 Sweep was incorporated into the distal leg and mesial leg was angulated by 15°.

Drum spring

The spring consists of 4 parts namely a constant force spring, a drum, a spring box, and a central pin soldered to the molar band. It is activated by pulling the end of the spring. The force level is always 50g and doesn't vary with the amount of retraction. It provides a continuous and constant force resulting in faster space closure compared to conventional closed coil springs.  

Niti canine retraction spring

The spring is available in 016 x 022 NiTi wire with antitip and antirotation incorporated. Ability to deliver continuous forces and moments over a broad range of activation.

T-loop

Segmented T-loop

These specialized springs are engaged in the attachements only at their ends. These springs are first bend into their passive shape in relation to the attachements and then permanently deformed by incorporation suitable bends (preactivation bends) to apply the required force system to the tooth or teeth to be moved.

Burstone 017 x 025 TMA T-loop

This new shape is called preactivation or deactivation shape. When the preactivated spring is engaged into the attachment it converts into the activation shape. Differential anchorage is obtained by the application of unequal alfa and beta moments. The higher moment is applied to the anchorage teeth. Previously, the approach described for achieving differential a/b moments with segmented T-loops used asymmetric angulation of the preactivation bends. The present trend is that the off center positioning with a symmetric shape is used to achieve a moment differential, and not spring shape.

The T-loop (017 x 025 TMA) is designed for an activation of up to 6 mm. At a full 6 mm activation, tooth movement occurs in 3 phases - tipping, translation and root movement. The spring is positioned closer to the anchorage teeth. Clinically, the spring usually needs to be 1 to 2 mm closer to one side than to the other to obtain a moment differential. Other methods to produce the differential moments with segmented T-loops, include composite T-loop and use of gable bends.

Composite retraction spring

T-loop

This spring consists of 018" TMA loop welded to 17 x 25 TMA. This spring can be used for either en masse retraction of incisors or canine retraction.

Titanium T-loop Retraction Spring (TTLRS)

TTLRS is placed in a-position for maximum retraction of anterior segment and a 45° bend is placed in the posterior or b-position.

Continuous arch T-loop

The T-loops, one on each side, are made distal to the cuspids. Desired alfa and beta moments are placed anterior and posterior to the T-loop vertical legs. Recommended b-activation for A, B, C anchorages are 40, 30 and 20 respectively.

Opus loop

This new design delivers a nonvarying target M/F within the range of 8.0 - 9.1 mm inherently, without adding
residual moments by twist or bends anywhere in the arch wire or loop before insertion (Figure 12). The loop can be fabricated from 16 x 22 or 18 x 25 or 17 x 25 TMA wire. The design of the loop calls for an off center positioning with the loop 1.5 mm from the mesial (canine) bracket. It is activated by tightening it distally behind the molar tube and can be adjusted to produce maximum, moderate, or minimum incisor retraction.12,13

**Kalra Simultaneous Intrusion Retraction Spring (K-SIR)**

K-SIR is a continuous 0.19 x 0.25 TMA arch wire with closed 7 mm x 2 mm U-loops at the extraction sites for en masse retraction. (Figure 13). A 90° bend placed in the arch wire at the level of U-loops creates equal and opposite moments, when centered in the extraction space. A 60° V-bend located posterior to the center of the inter bracket distance produces an increased clockwise moment on the first molar.14

**A statically Determinate Retraction System [SDRS]**

This novel system consists of a single-force cantilever arm made of 0.17 x 0.25 TMA for active retraction and a passive rigid stabilizing unit. Since the active component for space closure is a cantilever, it is simple to measure the force system of the spring with a force gauge. A turn of helix is placed in front of the auxiliary tube for the molar and ended with a hook at its anterior end. A 90° bend is placed in the middle of the spring. The spring is activated 90° at the helix as well.24

**The Wave Spring**

This spring takes the shape of a wave when extended. A superelastic nickel titanium alloy delivers a relatively large amount of activation—about 90g of force—from an extremely compact spring—only 6mm long in its resting state. The wave spring can be used in any situation where a closed-coil spring would be appropriate for retraction.25

**Conclusion**

Frictional binding and the swing effect are the main problems associated with sliding mechanics. Theoretically, these can be overcome by the use of a frictionless system, which includes a loop as the source of the applied force. However, the frictionless system fails to produce better results in practice because of the complexity of loop forming and the presence of unknown factors. In addition, minor errors can result in major differences in tooth movement, and some patients find the loop uncomfortable.

Predictable force system is a big advantage of retraction with closing loop mechanics. M/F applied at the bracket is the most important factor that controls the type of tooth movement induced by a retraction spring. And, load deflection rate is considered as a principle characteristic to describe a spring for closing loop mechanics. A recent study on comparing the effects of friction and frictionless mechanics reported a superiority of friction mechanics over frictionless system in terms of rotational control and dimensional maintenance of the arch. Frictionless mechanics were shown to be more effective at reducing tipping and extrusion. No difference were found in anchorage control and concluded that both mechanics perform similarly.26 Therefore, a working knowledge of both friction and frictionless mechanics is mandatory for a clinician.

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Communications

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