

The dynforce archwire

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Summary

This article is a presentation of a clinical methodology aimed at minimizing binding in fixed orthodontic appliances. The dynforce archwire is explained. The dynforce archwire has a full size anterior segment (e.g. .021x.025) and undersized posterior segments with rectangular cross-section (e.g. .018x.025 or .018x.022), and is used in the orthodontic phase of space closure with or without TAD miniscrews. Two clinical cases are presented.

Key words: archwire, binding, friction, incisor, torque, sliding, retraction, miniscrew, TAD, skeletal anchorage, ceramic brackets.

Introduction

It is the Authors' view that low forces in orthodontics can minimize archwire to bracket binding and resistance to sliding in fixed appliances. Orthodontic archwires, when deflected (Fig. 1), give a force of response. The force of response produces binding of the archwires at the edges of the bracket slots. Wires with lower force of response can minimize binding during the orthodontic treatment. This model will be explained in the article.

Materials and methods and discussion

Orthodontic archwires can be seen like beams supported on one or two ends (1).

It is of fundamental importance to know the behavior of orthodontic archwires in order to understand binding.

Orthodontic archwires are made of different alloys, like stainless steel, nichel-titanium, beta-titanium, and others. The physical features of orthodontic archwires are expressed in the stress-strain or load-deflection diagram (1, 2) as shown in Figure 2.

Orthodontic archwires have an elastic behavior. When the wire is deflected, it gives back a force of response (Figs. 1, 2). Linear deflection is expressed by "d" in Figure 1. The force of response depends on the rigidity of the archwire, represented by the slope of the curve represented in Figure 2. Archwires with higher rigidity have a more vertical slope. Archwires with lower rigidity (higher flexibility) have a more horizontal slope.

The diagram (Fig. 2) is also useful to understand the resilience of the archwires. The resilience is defined as the area under the load-deflection curve out to the proportional limit. It represents the energy storage capacity of the wire (1). In other words it is the energy that a wire

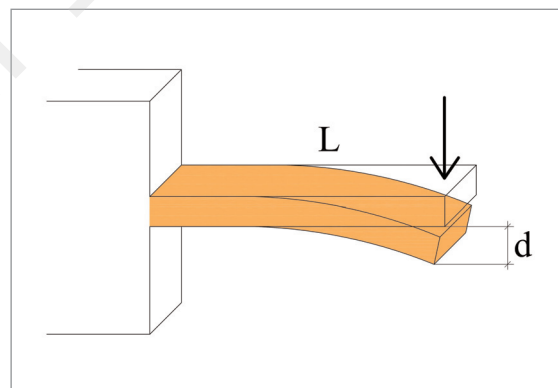


Figure 1. Deflection (d) of a beam of orthodontic wire of length L, redrawn from Proffit and Fields (1).

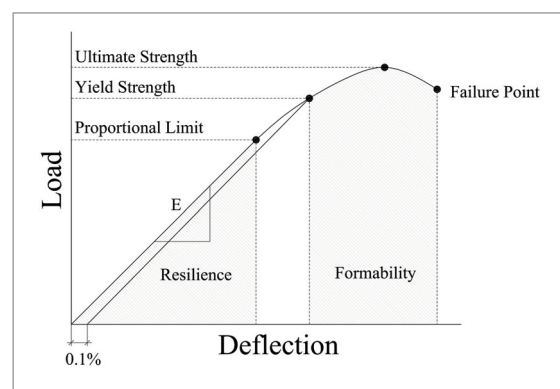


Figure 2. Load-deflection diagram.

is able to absorb in the elastic range and is able to give back during the alignment of teeth.

Wires with higher proportional limit have higher resilience. They can be bent at greater angles before they undergo plastic deformation. Infact the proportional limit is the point at which plastic (permanent) deformation starts to occur (1, 2). It is desirable that orthodontic archwires have high resilience so that they can give back the energy they absorb during the deflection phase and efficiently align teeth. Other important parameters to know are the yield strength, represented by the point at which 0,1% of permanent deformation is measured, and the ultimate strength at which the wire breaks (1), as shown in Figure 2.

The flexural rigidity of an archwire is defined as "E" multiplied by "I" (3). "E" is the Modulus of Elasticity of the wire, and it depends on the alloy of the wire (stainless steel, nichel-titanium, beta-titanium or others).

"I" is the second moment of inertia. The second moment of inertia is used in structural engineering and it expresses the resistance to deflection of a beam.

For orthodontic archwires with rectangular cross-section "I" is equal to $h^3w/12$ (where "h" is the height and "w" is the width of the rectangular cross-section).

For orthodontic archwires with round cross-section "I" is equal to $\pi r^4/64$ (where "r" is the radius of the cross-section).

Under a practical stand-point we can think the second moment of inertia like the cross-section area of the wires. Wires with larger cross-section area have a higher second moment of inertia and therefore are more rigid.

If we want to have a more flexible wire (less rigid) we can choose a wire with a lower modulus of elasticity (for example choosing nichel-titanium instead of stainless steel) or a wire with a smaller cross-section area.

Following is a discussion on the factors that affect resistance to sliding (RS) in orthodontic fixed appliances. For the sake of simplicity the discussion will be divided in four points.

Point 1 - the Force of Response of the deflected wires (1, 3)

The Force of Response of the deflected archwire is equal to $3 \times E \times I \times d \div L^3$ where :

E = Modulus of Elasticity of the wire,

I = Second Moment of Inertia of the wire

d = linear deflection of the wire (as shown in Fig. 1),

L= length of the beam of wire (as shown in Fig. 1),

Higher force of response increases the resistance to sliding (7-10, 12). This concept will be further explained in point 2.

Point 2 - Resistance to sliding is the sum of classical friction, binding, permanent deformation (4).

Classical friction is generated by the systems that secure the archwires into the bracket slots: elastomeric ties, steel ligatures, clips or slides of self-ligating brack-

ets. These systems generate a force that is perpendicular to the direction of movement of the archwire through the bracket slot.

Classical Friction depends on the law traditionally described in friction: classical friction= $\mu \times F_n$ where:

μ = coefficient of friction,

F_n = force perpendicular to the opposing surfaces sliding on each other.

The coefficient of friction (μ) is an intrinsic property of the wire-bracket couple and it depends on the surface features of the material.

Classical friction has been reported (5, 13) to be:

- > almost zero for self-ligating brackets,
- > 10 to 29 grams for steel-ligatures,
- > 106 to 138 grams for elastomeric ligatures.

Under a clinical standpoint tighter steel ligatures generate higher levels of classical friction because the steel ligature produces a force that is perpendicular (F_n in the above formula) to the direction of sliding of the wire through the bracket slot. On the other hand, loose steel ligatures can be made if low levels of classical friction are clinically desirable.

Elastomeric ligatures show higher levels of classical friction than steel ligatures. However, the polymers of the elastomeric ligatures undergo degradation and plastic deformation (19) and lose 70% of their force 48 hours after placement in the oral environment (6). Hence it can be expected that 2 days after placement in the mouth elastomeric ligatures generate 40-50 grams of force (20).

When the archwire is parallel to the bracket slot only classical friction contributes to resistance to sliding. This situation in which the wire does not contact the edges of the bracket slot is called "passive configuration" (4) and it is rarely encountered in clinical settings. With angulation between the wire and the bracket slot, the wire starts to contact the edges of the bracket slot ("critical contact angle for binding") and binding phenomena start to occur (5), as shown in Figure 3. This is called the "active configuration". In binding the archwire is elastically deformed, and due to its elastic properties it tends to return to its original shape, generating binding of the wire at the opposing corners of the bracket slot, as shown in Figure 3 (15, 16). Resistance to sliding due to binding has been reported to reach levels as high as 826 grams (10).

At greater angulations the archwire can no longer withstand the forces of the slot walls and it begins to permanently deform (notching) (5), as shown in Figure 3. Wires with higher force of response generate higher levels of binding.

We saw in point 1 that the force of response of the deflected wire is equal to $3 \times E \times I \times d \div L^3$.

This formula can explain most of the factors that affect binding, as summarized in the following discussion.

- a. A small inter-bracket distance increases the resistance to sliding (7). In fact a longer beam of wire ("L" in the above formula) reduces the force of response of the wire by the third power of the length.
- b. A greater angulation between archwire and bracket slot increases the resistance to sliding (8, 10). In

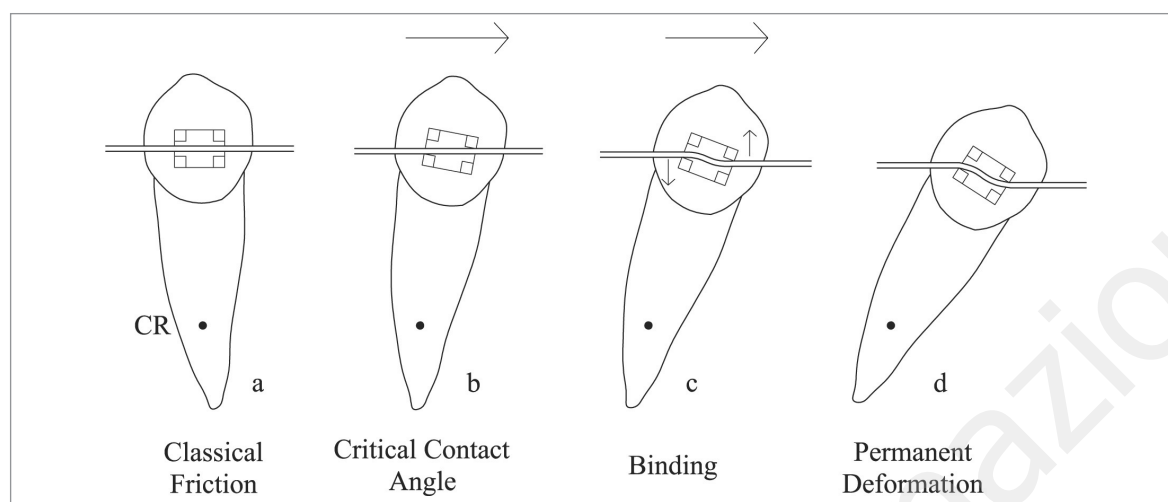


Figure 3. Resistance to sliding in orthodontic fixed appliances is the sum of Classical Friction, Binding, Permanent Deformation (notching).

- fact greater deflection ("d" in the above formula) increases the force of response of the wire.
- Stainless Steel wires have coefficients of binding much higher than nichel-titanium or beta-titanium wires (7, 9, 12). In fact greater Modulus of Elasticity ("E" in the above formula) increases the force of response of the deflected wire.
 - A larger cross-section area of the archwire increases the resistance to sliding (8, 10). In fact greater second moment of inertia ("I" in the above formula) increases the force of response of the deflected wire. Particularly, Moore et al. (8) found that a .021x.025 stainless steel wire has a coefficient of binding three times larger than the coefficient of binding of a .019x.025 stainless steel wire.

Smaller inter-bracket distances, greater angulations between wire and slot, higher modulus of elasticity and larger cross-section areas of wire increase the force of response of the deflected wire and increase binding of the wire against the bracket slot, slowing down tooth movement.

It is important also to review the meaning of the Coefficient of Binding.

Resistance to sliding due to binding is equal to Coefficient of Binding multiplied by wire-bracket angulation beyond critical contact angle (4).

Studies (7, 8, 10, 11, 13) have been done where the wire slides through the bracket slot when the bracket has different angulations in relation to the archwire. A diagram is produced where the horizontal axis represents the wire-bracket relative angulation and the vertical axis represents the resistance to sliding. The slope of the curve represents the coefficient of binding.

The coefficient of binding for the .019x.025 stainless steel wire has been reported to be 66 grams/degree of wire-bracket angulation (13) and coefficient of binding for the .016x.022 nichel-titanium wire 12 grams/degree of wire-bracket angulation (13). For example at 5 degrees of wire-bracket angulation resistance to sliding for the .019x.025 stainless steel wire is 330 grams (66x5), while the resistance to sliding of the .016x.022

nichel-titanium wire is 60 grams (12x5). In other words, at 5 degrees of wire-bracket angulation the resistance to sliding of the .019x.025 stainless steel wire (more rigid, hence with higher force of response) is 270 grams higher than the resistance to sliding of the .016x.022 nichel-titanium wire.

Some strategies can be adopted in order to minimize the force of response of the deflected wires and binding in clinical orthodontics:

- Use of larger inter-bracket distances, for example using single wing brackets (14),
- Reduction of the angulation between archwire and bracket slots during space closure in sliding mechanics, for example by means of power arms or by completely leveling the curve of spee before the phase of space closure,
- Use of archwires with lower modulus of elasticity,
- Use of archwires with smaller cross-section area.

All above mentioned methods reduce the force of response of the deflected wires and reduce resistance to sliding in orthodontic treatments.

Finally, resistance to sliding is also affected by notching. Notching (plastic or permanent deformation) happens when the wire is deflected beyond the elastic (proportional) limit (1), as shown in Figure 2 and Figure 3. When the wire is permanently deformed, it does not return to its original shape. Notching causes all motion of the archwire through the bracket to cease (5). Clinically this is particularly important in extraction space closure. The long span of wire running along the extraction area can be distorted by the food during mastication. Wires with permanent deformation stop any sliding of the wire through the brackets of posterior teeth if space closure is performed with sliding mechanics.

A method to increase the proportional limit of stainless steel archwires is heat treatment (2). Wires are heated at low temperatures (370 to 480° C) for few minutes after archwires have been given the archform. Heat treatment relieves the internal stress generated during the shaping of the archform (cold working). After heat treatment wires exhibit a higher resilience, in other words

they can be bent at greater angles before they undergo plastic deformation. The measured increase in elastic strength may be as great as 50% (2). Heat treated wires also show a slightly higher (by 10%) modulus of elasticity (2). The advantage of these wires is that they maintain their shape during clinical use, improving sliding mechanics.

Point 3 - Archwires with low coefficient of binding are of critical importance to minimize resistance to sliding when ceramic brackets are used.

Bagby and Ngan (9) studied the coefficient of binding for the .019x.025 stainless steel wire and for the .019x.025 nichel-titanium wire inserted in different ceramic brackets.

They found that at 5,9° of wire bracket angulation the .019x.025 stainless steel wire has 180-400 grams of resistance to sliding, while the .019x.025 nichel-titanium wire has 5-20 grams of resistance to sliding.

Stainless steel wires have lower coefficient of friction than nichel-titanium wires (2), due to the smoother surface of stainless steel. However, nichel-titanium has a lower modulus of elasticity than stainless steel, hence when it is deflected it has a lower force of response thus minimizing binding.

According to the findings of this study, when ceramic brackets are used in orthodontic treatments, archwires with low coefficients of binding should be utilized in order to minimize resistance to sliding.

Point 4 - Binding is present in orthodontics in most clinical situations.

We will analyze the alignment phase and the space closure phase.

During alignment, most of the time teeth are crowded so that the wire exceeds the critical contact angle and binding phenomena are present. Small diameter nichel-titanium archwires, with low force of response and low coefficient of binding are recommended by the authors in this phase.

Space closure is performed after the alignment phase is finished. In sliding mechanics the Class I force needed to close the spaces is generated by elastic chains or coils attached to the brackets. Since brackets are far from the center of resistance of the tooth, the tooth tips until the wire contacts the edges of the bracket slot and binding phenomena start to occur (15, 16). The deflected wire then tends to return to the original (non-deflected) shape and generates a moment of a couple that uprights the root of the tooth (17), as shown in Figure 4. Tipping and uprighting repeat many times until the tooth reaches the final position desired by the orthodontist. Orthodontic tooth movement in sliding mechanics is not a continuous process; rather it is a multi-step "tipping and uprighting" or "binding and releasing" mechanism. Wires with higher flexibility are more efficient in the tipping phase due to their lower coefficient

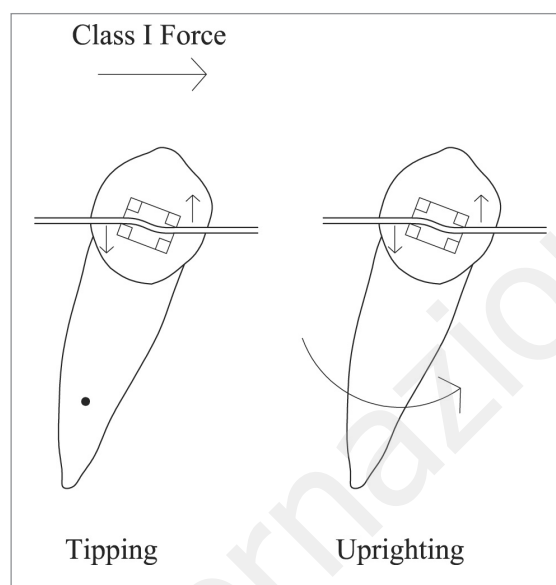


Figure 4. Tooth movement in sliding mechanics is a multi-step tipping-uprighting mechanism.

of binding. Wires with higher resilience are more effective in the uprighting phase. Orthodontic archwires have a dynamic behavior. The work and the resilience of the archwires are of critical importance in this process.

Heat treatment of stainless steel increases the proportional (elastic) limit of the wire, improving the uprighting phase of tooth movement. Heat treated wires are recommended by the authors during space closure with sliding mechanics.

The four points explained above are the basis of a protocol aimed at minimize binding in clinical orthodontics. The protocol is characterized by the use of small diameter nichel-titanium wires (size .010 or .012) during the orthodontic alignment phase and by the use of the dynforce archwire (18) during the phase of space closure. Some clinical examples are presented.

During the orthodontic alignment phase the use of small diameter nichel-titanium archwires has several advantages. Thinner wires generate lower force when deflected, so it is easier to ligate teeth that are severely crowded. Lower forces also minimize the patient discomfort during the first days of orthodontic treatment. Thinner wires with lower force of response also have lower coefficient of binding (13). This is particularly important during the alignment of highly positioned canines (Fig. 5).

Infact, in the presence of high resistance to sliding, the wire cannot slide through the brackets of canine, premolars, molars. As a consequence spaces may open between canine and lateral incisor or between canine and first premolar, like shown in Figure 6. Wire to bracket binding would create spacing during the alignment phase and buccal flaring of incisors.

The use of thin nichel-titanium wires with low force of response and low coefficient of binding allows the wire to slide through the brackets of canine, premolars and

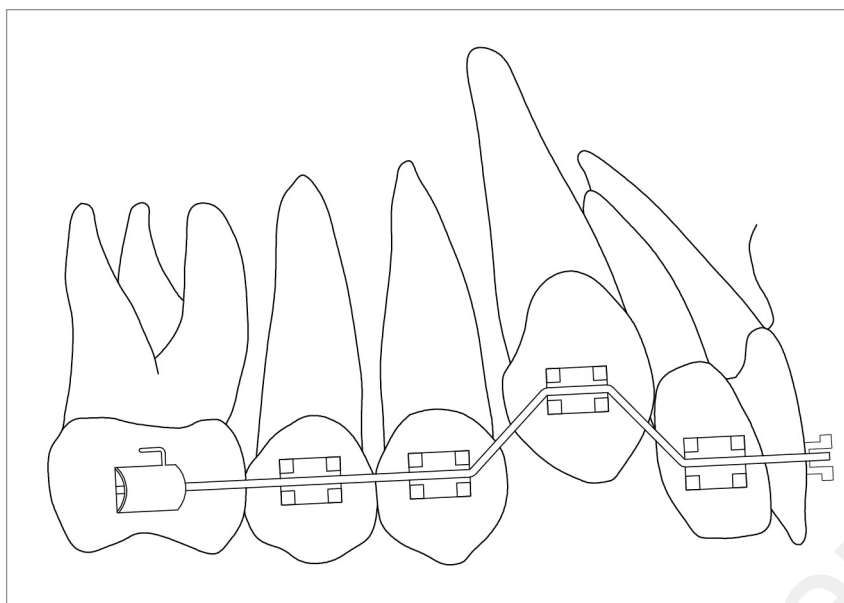


Figure 5. Start of alignment of a highly positioned canine.

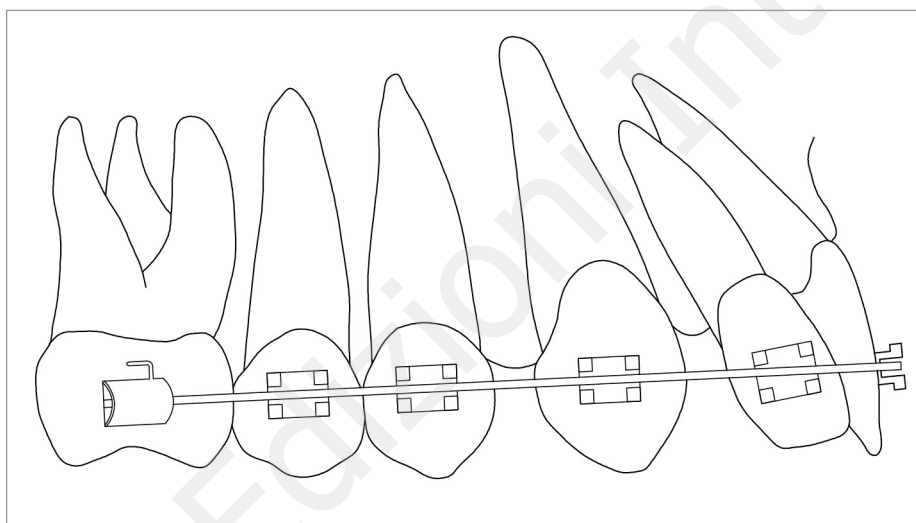


Figure 6. In the presence of high resistance to sliding, opening of spaces and buccal flaring of incisors may occur during the alignment phase.

molars, without opening of spaces and without buccal flaring of incisors as shown in Figure 7. It is typical to observe the wire coming out distally to the bracket of the molar during the alignment phase (Fig 7).

In Figures 8 and 9 we can see the bonding of a patient with highly positioned canine. A .012 nichel-titanium wire is inserted the day of the bonding.

Figures 10 and 11 show the patient after 40 days. The canine has been aligned without opening of spaces and without buccal flaring of incisors.

The .012 nichel-titanium wire has a low force of response and low coefficient of binding, allowing the wire to slide through the ceramic brackets with minimum friction and to come out distally to the bracket of the molar.

After the .012 Ni-Ti, the authors recommend the use of

.016x022 nichel-titanium and .019x025 beta-titanium wires to finish the leveling/alignment phase.

During space closure the dynforce archwire (18) is used. The dynforce (Fig. 12) is made of heat-treated stainless steel and has an anterior segment with size .021x.025 occupying the incisor brackets, and posterior segments with size .018x.025 occupying the brackets of canines, premolars, molars.

The dynforce low friction (L. F.) has anterior segment with size .021x.025 and posterior segments with size .018x.022. The material is heat-treated stainless steel in order to reduce indentations (notching) during the clinical use and improve sliding mechanics. Posterior segments (either .018x.025 or .018x.022 in size) are more flexible and hence have lower coefficient of binding than the conventional .019x.025 stainless steel

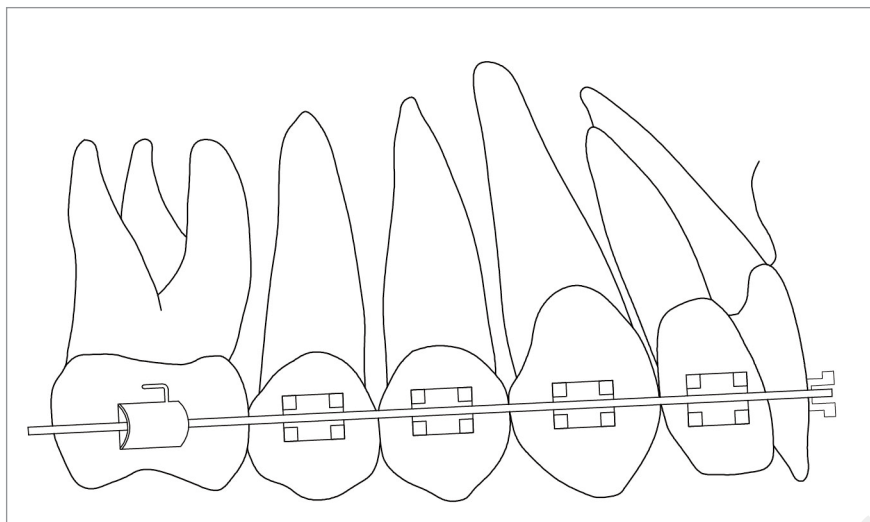
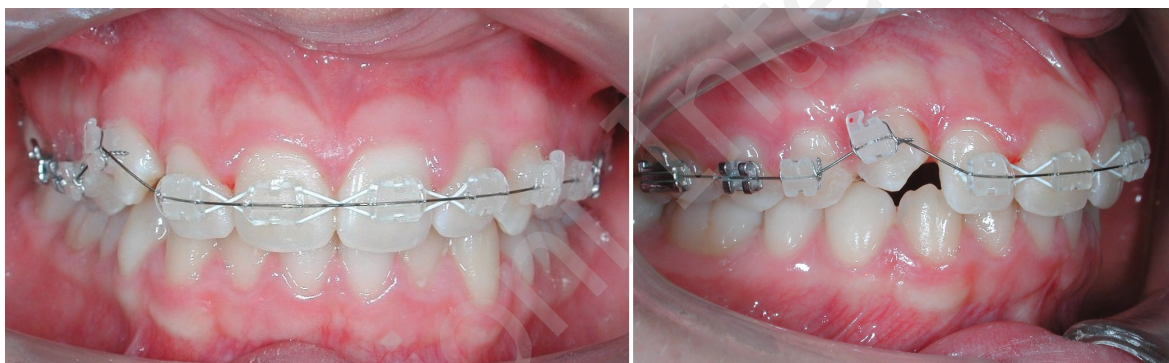
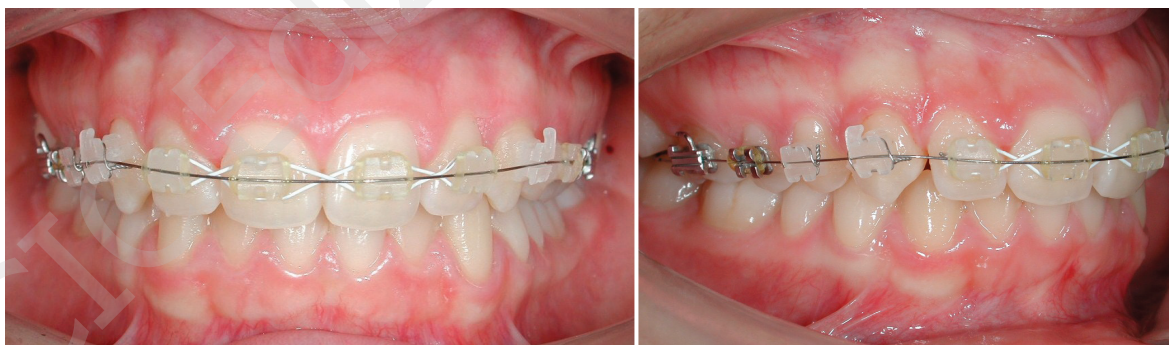


Figure 7. In the presence of low resistance to sliding, alignment is performed without opening of spaces and without buccal flaring of incisors. The archwire comes out distally to the molar bracket.



Figures 8 and 9. Frontal and lateral view of start of alignment of a patient with highly positioned canine. Use of .012 nichel-titanium archwire.



Figures 10 and 11. Frontal and lateral view of the patient after 40 days. Alignment of teeth occurred without opening of spaces and without buccal flaring of incisors. Low forces generate low binding. Also, low forces are more easily contrasted by the pressure of the lips (lip bumper effect).

archwires traditionally used for the retraction of anterior teeth. The aim is to minimize binding and notching during the phase of space closure. Further, posterior segments (either .018x.025 or .018x.022) have rectangular cross-section and not round cross-section, because the rectangular shape offers a better control of the arch-form during space closure mechanics.

The anterior segment (size .021x.025) has higher rigidity, in order to maximize the control of incisor tip and torque. Higher rigidity also helps to prevent canting of the incisal plane when asymmetrical forces are used, for example during midline shift correction. Hooks 6,5 mm long are used when the Dynforce arch-wire is utilized with TAD miniscrews.

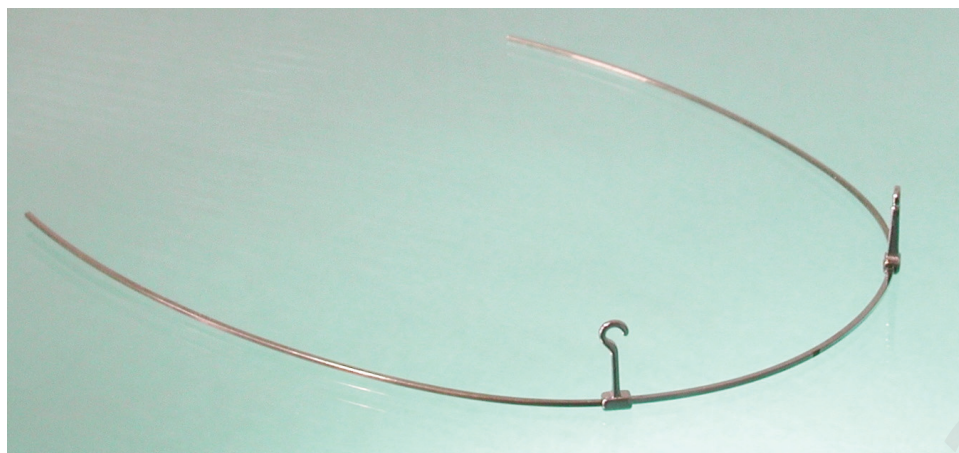


Figure 12. Dynforce Archwire

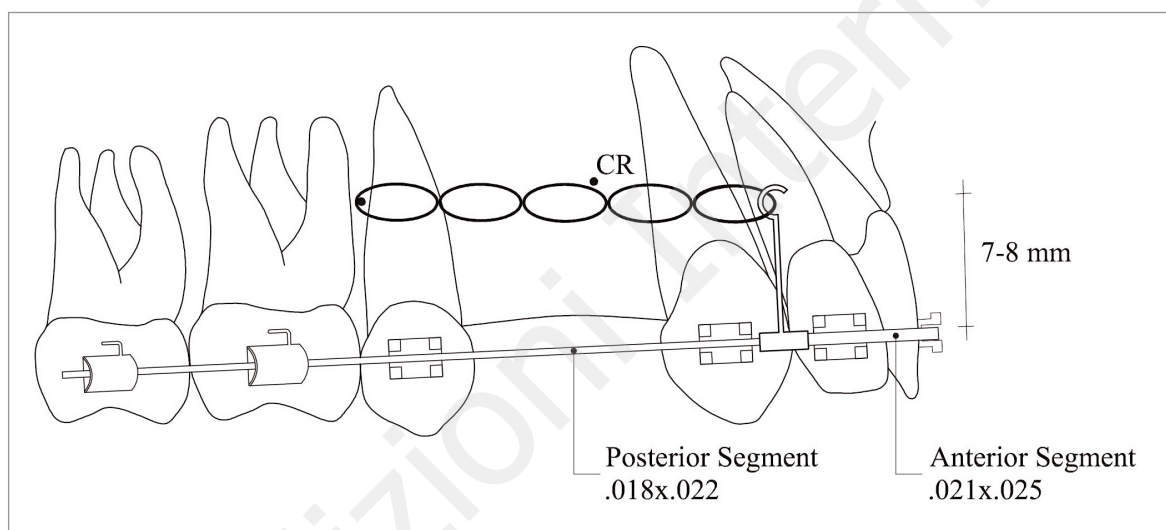


Figure 13. Dynforce Archwire with miniscrews placed 7-8 mm above the archwire.

As shown in Figure 13 the dynforce can be used in association with miniscrews positioned between second premolar and first molar 7-8 mm above the archwire. The retracting force is generated by elastic chain running from the miniscrews to the hooks of the archwire. The retracting force passes close to the center of resistance of the dental arch in order to produce a bodily movement of front teeth.

In this configuration binding is minimized for two reasons:

- Posterior segments of the Dynforce are undersized, hence with lower coefficient of binding,
- Hooks 6,5 mm long work like power arms: the point of application of the retracting force is close to the center of resistance of the dental arch, hence the angulation of the wire relative to the brackets and the deflection of the wire are minimized during the retraction phase.

A clinical case is presented. Figure 14 shows the start of en-masse retraction of anterior teeth with the dynforce

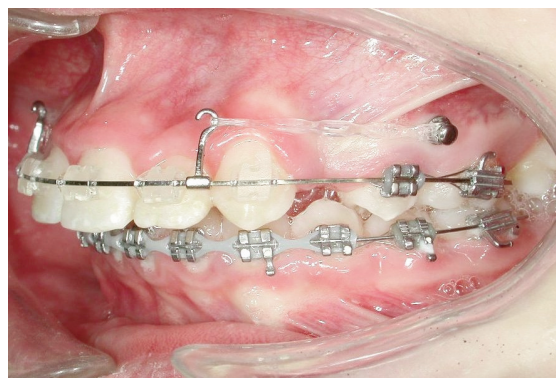


Figure 14. Start of en-masse retraction performed with the Dynforce archwire and miniscrews.

archwire low friction (L.F.), with anterior segment with size .021x.025 and posterior segments with size .018x.022.

After three months of retraction (Fig. 15) incisors and



Figure 15. After Canine Class I is achieved, retraction is continued with the Dynforce archwire with reciprocal anchorage.



Figure 16. Extraction space completely closed.

canines moved backwards. Canine class I relationship is achieved and miniscrews are removed. The hooks of the dynforce wire are bent with a three prong plier and converted into short hooks. Space closure is then finished with reciprocal anchorage with elastic chain running from the hook of the archwire to the hook of the molar bracket. Figure 16 shows spaces closed four months after the start of retraction. The settling phase is then performed with conventional methods.

Efficient sliding mechanics was performed thanks to low wire-bracket binding and proper point of application of the retracting force.

Conclusions

Archwire to bracket binding plays a significant role in sliding mechanics in clinical orthodontics. Binding can be minimized by appropriate strategies. Particularly, the use of low force nichel-titanium archwires (size .010 or .012) during the alignment phase, and the use of the dynforce archwire during the phase of closure of spaces are advocated by the authors.

The advantages of using archwires and mechanics that minimize binding are the possibility to use lower Class I

retracting forces. Also, ceramic brackets can be routinely used without compromising treatment time.

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